Visualizing Climate Change through LIFE-AMDRYC4: A VR mobile-based Video Game to educate adult audiences on sustainable agricultural practices.

Dr Manuel Hernández-Pérez

School of the Arts, Media, and Creative Technologies, University of Salford, Manchester, UK (ORCID: 0000-0001-9974-7056)

Prof Carmen Pérez-Sirvent (melita@um.es)

Department of Agricultural Chemistry, Geology, and Pedology, Faculty of Chemistry, University of Murcia, Spain (ORCID: 0000-0002-7631-7413)

Prof María-José Martínez Sánchez (mjose@um.es)

Department of Agricultural Chemistry, Geology and Pedology, Faculty of Chemistry, University of Murcia, Spain (ORCID: 0000-0002-2924-1954)

Esteban Jordán González

CEO Ingeniería del Entorno Natural (IDEN) esteban@entornonatural.org

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LIFE-AMDRYC4 (2021) is a VR app designed for mobile phones combining informational design and gamification to stimulate critical reflection and awareness about agricultural practices and their effects on the environment. Agile production frameworks and researchers input in the design are discussed. A Likert-based questionnaire was employed to measure attitudes from academics (environmental sciences) and professionals (farmers). Qualitative data showed that academics were more concerned about the representational aspects of the game while professionals were more concerned about its designing performance. Positive significative correlation among items, including the dimensions of 'enjoyment' and 'realism' were also part of the findings.

Keywords: serious games; climate change; adult education; VR; mobile

Introduction

Digital technologies, including those employing different forms of video games, are seen as a tool of great potential for environmental education and, particularly, for raising awareness of climate change and its consequences (Martínez-Rodríguez & Fernández-Herrería, 2021; Whitehouse, 2008; Wok, 2019; Wu & Lee, 2015). Research on educational video games has also emphasized their immersive nature through interfaces such as virtual reality (VR), augmented reality (AR), or any form of extended reality (XR). Combining the real world with multimedia allows the user to access more information about educational content while maintaining a sense of presence and greater user engagement (Lee & Hu-Au, 2021; Raybourn et al., 2019; Stanney et al., 2021).

In recent years, the fight against climate change has taken center stage in many environmental research initiatives. Most somber predictions about climate change include

the disappearance of Mediterranean rainfed agriculture, with serious consequences of loss of arable land, desertification, migration, and famine. The role of environmental education in tackling the problem of climate change has been clearly outlined, without forgetting the ethical dimensions and the impact on international cooperation and the development of less favored nations (UNESCO, 2009, 2017).

The LIFE AMDRYC4 project (LIFE16 CCA / ES / 000123) main aim is to study the adaptation to climate change of rainfed agricultural systems in the Mediterranean area. The pilot project is being carried out in Murcia province, South-Eastern Spain (Figure 1) which is one of the European areas with the higher risk of desertification. This is an international project – involving stakeholders from Italy, Spain, and Portugal –, informed by a perspective of Ecosystem-based Adaptation (EbA), whose final objective is to carry out organic agriculture in rainfed crops, involving conservative agricultural practices, traditional approaches to biodiversity conservation, and ecosystems for sustainable socio-economic development.

The design of the app is inspired by common methods on digital design: agile methodologies (McInerney & Maurer, 2005) and Participatory Design (Khaled & Vasalou, 2014; Vieira et al., 2022). In contrast with other types of production frameworks, such as User Center Design (UCD), the Agile frameworks defines the creative product as the result of dialogue between the stakeholders – researchers in this case – and the designers. Evaluation is also part of the process but, unlike UCD methodologies, does not take place before the design process and does not condition it (McInerney & Maurer, 2005). Instead, Agile methodologies are organized around iterations or 'scrums', which are short meetings with stakeholders.

Participatory Design (PD) employs audiences' input into the design employing different techniques such as storyboards and brainstorming (Khaled & Vasalou, 2014). PD has been traditionally discouraged in relation to serious games in younger audiences because the lack of knowledge on areas related to game content (i.e., environmental sciences) and game design are common challenges in the process (Khaled & Vasalou, 2014, p. 93). On this occasion, the PD only included researchers involved in the LIFE AMDRYC4 project. As a complementary step, user evaluation was performed with the aim of adequately assessing the reception of the last version of the prototype, as well as informing future iterations of the app.

Design and Development of the LIFE-AMDRYC4 application

Narrative Design and Gameplay

After some preliminary meetings with the researchers, a concept proposal for the product was pitched (March 2020). Our virtual experience, or video game, would present the user with a landscape that would change as a result of players' decisions. Digital storytelling would be developed using a sequence of playable scenes and ellipsis. Parallel to this, the gameplay would simulate five years over four turns, a total of twenty years of transformations of the landscape. In this experience, the user can choose up to a maximum of four actions before skipping the turn. After each turn and at the end of the game, the player adopts the role of the manager of a farm and is informed of the consequences that his decisions have had on the environment, as well as the social and economic outcomes.

Level Design

The game's design consisted of a single level that combines realistic 3D graphics and stylistic conventions from video games. Digital Elevation Models (DEM) of the terrain –a common tool in simulation tools (Henry, 2018; Kolb et al., 2018) – were used to reproduce faithfully the topography and vegetation of the chosen landscape. The level recreates one of the plots from the LIFE AMDRYC4 pilot project. In this plot, the following spaces are distributed to dynamically reflect the economic, environmental, and social transformations consequent to the user's decisions:

- Crop fields. This section is populated with trees and lateral vegetation.
- Residence. A house designed in blocks reflects the economic development of the inhabitants of the farm.
- Livestock corral. This area allowed the display of different species of livestock, and, depending on the decisions taken, also tourists visiting rural areas.
- Other facilities: waste containers, pruning, and common areas.

During the design process, the advice of the researchers was frequent and informed each scrum. They decisively influenced, for example, the asset design (e.g., animal manure containers) and the selection of photo-realistic textures (e.g., moist ground or rich in iron, plots after a desertification process, etc.).

To create a sense of presence in the user, the field of view (FOV) of the game camera was adopted to 110 degrees, emulating first-person shooters and other first-person simulator games. Here, however, immersion is limited to three degrees of freedom (3DoF), an experience similar to that provided by 360 videos. To deal with this limitation,

the areas where the game objects spawn had to be allocated closer to the camera and the user. Conversely, the environmental design had to achieve a compromise between accuracy and iconicity in the representation of these spaces (Figure 2). Their distribution obeys both story-world and gameplay.

Interfaces and UI Design

The prototype can be played in two different ways. The tactile mode, interacting with device screens (mobile or tablet), and the Virtual Reality (VR) mode, in which the user employs an animated grid to interact with each menu, by holding his gaze for a few seconds. The application is designed to be used with inexpensive and easily accessible VR systems such as Google Cardboard.

The user interface (UI) was designed according to the project identity guidelines as well as the derivative educational and promotional materials (LIFE AMDRYC4, 2020). Some elements were extra-diegetic or presented as a complement to the level design. As examples, the year is indicative of the turn the user is playing while a thermometer on the screen displays the level of carbon sequestration as direct cause for climate change.

Educational Content

Research on educational strategies on Climate Change has identified 'facts' and 'actions' as a way to differentiate 'science educators' from 'environmental educators' as well as the different attitudes they may elicit in their audiences (Monroe et al., 2019, p. 792). In this sense, our research tries to work as a bridge between these two paradigms, using facts, resulting from previous research conducted on soil contamination and actions

examined through the pilot studies under the LIFE AmdryC4 project, in order to address a bigger picture of the consequences of climate change. The educational component is conveyed through the development individuals' responsibility through the game, but also the visual and narrative representations of actual research data.

The choices available to the user (Figure 3) are based on dryland agriculture strategies ('actions') previously evaluated by the LIFE AMDRYC4 research project:

- Livestock waste: use of composted animal excrement.
- Sludge from treatment plant: use of composted solid waste from domestic water treatment plants.
- Pruning: Incorporation of crushed plant remains from pruning.
- Fallow: vegetative cycle without cultivating.
- Vegetation in lateral strips: planting of steppe herbaceous vegetation such as esparto grass.
- Platforms: Modification of the elevated slopes through stratified terraces.
- Green fertilizer: use of fast seasonal growing plants and cultivation between rows of trees.
- When there are different modalities between the user options, as in the case of plow depth (deep/superficial), plow direction (perpendicular/sloping) and grazing (soft/intensive), these options are mutually exclusive.

Users are introduced to these options and their consequences through a visual dictionary shown in the main menu (Figure 4). This submenu also includes a description of the project goals that are intended to inspire the player's journey:

- 4/1000 Initiative: represents the organic carbon content in the soil (4p1000, 2018).
- Ecosystem Services: refers to the benefits that nature brings to society.
- Circular economy: reducing the use of raw materials and the generation of waste.
- Mitigation of Climate Change: actions that reduce and limit greenhouse gas emissions.
- Adaptation to Climate Change: implement measures that reduce the vulnerability of an ecosystem to the adverse effects of climate change.

Variability and Randomness

Simulation games are considered instances of a conceptual model that embeds a sociological system (Barreteau et al., 2007) in the sense that they emulate stories or experiences of social nature (i.e. A football match, the management of resources in a military campaign, etc.). However, in this case, more than simulating social constructs or experience the application focus on disseminating a scientific model that explains the effects of agricultural practices on the environment and, eventually on the whole society. This information was delivered by employing visual metaphors, landscapes inspired by real geographical settings and the same variables employed in the real scientific pilot research. Conversely, simulation games have addressed environmental games employing natural resource management (NRM) as part of their game mechanics (Barreteau et al., 2007). Our experience employed variables which are hidden to the users so the consequences of their decisions through the game are communicated in terms of consequences (positive and negative) to the environment rather than presenting a complex table of results. The use of these variables will be also reflected in emergent digital storytelling, adopting the following forms:

- Short-term effect variables. These are visible and direct consequences of user actions in one turn. For example, when a user chooses the direction of ploughing, it changes on stage as the turn passes.
- Long-term variables. Several effects can take place in one or more turns. Their magnitude is determined by the interaction with other actions and their corresponding effects. For example, the use of sewage sludge and livestock waste, both contribute to an increase in organic matter

In both cases, the effect of these variables was designed in collaboration with the researchers and inspired by the hypotheses of the pilot project in three areas:

- Environmental: increase in organic matter, increase in soil moisture, carbon sequestration, and level of biodiversity.
- Social: increase in population and appearance of ecotourism.
- Economics: agricultural production and quality of work

Finally, to create an illusion of complexity and plausibility in the narrative world, random variables were incorporated. Those included among many others, the time of day, torrential rain, and the landing position of flocks of birds on the game level.

Evaluation of the prototype and distribution

Following the Agile methodology, results led to modifications on each iteration of the prototype. For example, the dictionary was improved through illustrations that follow the guidelines of the corporate identity of the project. Extra feedback messages at the end of each turn were added. These were all suggestions offered by researchers in different

scrum meetings, creating, in each case, a new milestone for the development of the project.

While the experience was originally designed for mobiles with the Android operating system, in a later phase of the project, it was decided to deploy it to IOS devices as well. In addition, the application was exported to WebGL, enabling the user to access the experience directly from the official website of the project. In June 2021, after a few months in the mobile application markets (Universidad de Murcia, 2021a, 2021b), the mobile application was evaluated using a questionnaire.

Methodology: User Evaluation

Study Design

The user evaluation was aimed to collect information about attitudes towards the product and its potential effectiveness, employing a Likert-type questionnaire, a common tool to evaluate serious games (Knol & De Vries, 2011; Patchen et al., 2020; Schneider & Schaal, 2018). Items were designed to reflect the immersive nature of the tool, its enjoyability, its playability and ease of access. This questionnaire (**Error! Reference source not found.Error! Reference source not found.**) also included qualitative items to collect the users' insights concerning these dimensions.

The sample consisted of 84 volunteers, who were distributed according to their professional status into two groups ("academics" and "professional"). The group of scholars included students and researchers, volunteers, from the Environmental Science Department (n = 64). The group of professionals (n=20) consisted of professionals working in primary industries. These were contacted through research stakeholders such as

agricultural associations. For both groups, only individuals with low experience with VR devices (i.e., VR headsets) were considered while the rest were discarded. Following previous research (Patchen et al., 2020; Schneider et al., 2020) Cronbach's alpha reliability test was used to judge the consistency of each item. The Cronbach alpha value was 0.823 for the 8 items, indicating a high level of reliability for our survey. This questionnaire (**Error! Reference source not found.Error! Reference source not found.**) also included qualitative items that sought to collect the insights of the users concerning these same dimensions.

Hypotheses and Data Analysis

The questionnaire was intended to test whether there were any significant differences between the two groups (academics and professionals), regarding the following variables: immersion (item 8), realism (item 7), plausibility or the quality of seeming reasonable regarding the world logic (item 4), learning (item 3), ease of use (item 1), enjoyment (item 2) and its ability to arouse interest in socioeconomic (item 6) and environmental (item 5) problems. Therefore, for each item it would be considered the following H0: 'Belonging to a group doesn't affect the variable'. Likert scales were encoded and analyzed in terms of frequency, mode and median. The Mann-Whitney method was employed to test these hypotheses.

Procedure for the prototype evaluation

Subjects could fill out the survey if they confirm that they had played the application for one entire game – 4 turns and, approximately 15 minutes. The results were then sent to the researchers by email for collection and subsequent analysis.

Results

General Results

The opinions concerning the game among the individuals of both groups were mostly positive. Quantitative and qualitative data indicated positive results in terms of enjoyment and appreciation of the tool's focus, especially in the dimensions of realism and plausibility of the simulations (Figure 5). The mode or most repeated value for most of the items of the scale was 4 (items 1-4 and 6-7), 5 (item 5), and 3 (item 8) equivalent to 'Agree', 'Totally agree' and 'Neutral'. The percentages of answers confirmed this (Figure 5).

Answers were later reencoded in terms of agreement/disagreement and neutrality, following common procedures for the re-encoding of Likert-based scales (Knol & De Vries, 2011). The opinions (Figure 5) were still mostly positive among groups although some items showed a higher level of disagreement (item 4) and neutrality (items 5, 7, and 8). However, the statistical test employed failed in pointing out differences between groups. Particularly, the Mann Whitney U test didn't show differences between groups (Table 1). On the other hand, there were significant correlations among the responses when both groups were considered (N=84). Highest values include a positive appreciation of the general enjoyment of the experience (item 1) with the representational realism or item 7 (r= .49; p=.00); consideration of economic consequences or item 6 (r= .47; p=.00), consideration of environmental consequences or item 5 (r= .43; p=.00) and self-assessed learning or item 3 (r= .47; p=.00). Interest on economic and environmental aspects - responses to items 5 and 6- also correlated positively (r= .75; p=.00). Finally, no correlation was found for the items 7 and 8 with the rest of the survey.

User Comments

Qualitative data was collected through user insights. After coding, a content analysis made from these comments (N=119) was performed assigning data to nine different categories. Most of the comments can be understood in a similar way to user's reviews and refer to problems the user has faced when using the tool. A significant percentage of the comments among groups (Figure 6) were related to the Performance of the System (11.87%), which may denote differences among users, depending on the platform (IOS, Android, WebGL) and the interface used (desktop, mobile, Cardboard). These qualitative results offer many useful insights for researchers and designers of this tool, not only in the form of explicit 'suggestions' (3.39%) but also through the different dimensions explored. For example, academics showed particular interest in discussing the plausibility of the tool (21.65%), commenting on processes such as carbon sequestration and, particularly, in the need for reflecting a wider diversity of positive and negative consequences to enrich future iterations of this environmental simulation. Qualitative insights obtained through the questionnaire on professionals showed increasing awareness about the social and economic implications of these agricultural practices ('*May sound silly, but before this, I have never thought about how much the final quality of the soil -and its contents- could depend on previous practices*').

Discussion

Professionals valued the tool very positively although most of their comments tend to focus on the general experience rather than particular aspects of the educational tool. They highlighted the 'novelty' of the game and its capacity to represent effectively

agricultural practices (**Error! Reference source not found.**). When considered as percentages, the responses among groups led to interesting insights for the researchers. Specifically, it can be seen a trend towards neutrality on professionals that avoid expressing disagreement. This is congruent with research that question the use of Likert scales, pointing out how they may amplify social desirability and reduce the respondent's willingness to differentiate among items responses. Some studies on attitudes employing Likert scales have found a positive bias in those scales which the 'agreement' is presented at the left or the beginning -in Western languages- also considered as a manifestation of the 'primacy' effect but also acquiescence (Chyung, Kennedy and Campbell, 2018; Keusch and Yang, 2018). This makes us to consider balancing the design of future scales for the prototype evaluations. The use of Likert scales could also be replaced by conducting the data collection through qualitative methods such as interviews or consumers panels (Bellotti et al., 2013). Relevant differences were found through the thematic analysis of users' comments among groups. Academics showed more interest in making comments related to the levels of plausibility of the app, while Professionals were more concerned about the UX design, their access, familiarity with the different interfaces and the general value of the experience provided by the tool.

In this sense, it may be worth further examining the relationship between realism on representation (item 7) and general enjoyment of the experience (item 1), as well as the self-assessment of learning and world's plausibility (item 4). While correlations between these and other items were strong, such explorations may also justify taking different methodological approaches for a deeper exploration. This may be using purpose-designed tests (Kolek, Šisler, Martinková, & Brom, 2021) or other qualitative approaches such as interviews or focus groups (Bernhaupt, 2010).

This tendency to neutrality through some of the items (i.e. item 8 on 'immersion') may also indicate a problem for the users in fully understanding the terminology used through the survey. For instance, the term 'immersion' originated in scholarship related to video games and virtual environments referring to 'the experience of being transported to an elaborately simulated place' (Murray, 1997, pp. 98-99). While the term has been popularized over the years, especially due to the rise and increasing access to the so-called 'immersive technologies' such as VR domestic devices, this does not necessarily imply that potential users of the tool will be familiar with it. The complexity of this kind of experience and the development of a larger corpus of studies on digital media have attracted some criticism of the term, and some authors suggest to replaced it by more specific descriptions of the user's experience in terms of engagement, presence, realism, plausibility, etc. (McMahan, 2013).

Conclusions

This article aims to report and critically reflect on the design, production, and evaluation of a mobile app VR experience as part of the LIFE AMDRYC4 Project research. The involvement of expert adult audiences (academics and professionals) in the design of this educational tool was examined using two complementary strategies. The first introduces the use of agile project management to inform game design using results from a previous research project. The second approach consisted of analyzing the results of the user evaluation questionnaires. The objective of these questionnaires was to measure acceptance by target audiences, explore their capacity to stimulate discussion about environmental problems, and collect qualitative information that could help future iterations of this prototype. The

potential social impact of these approaches seems especially relevant in the case of the wider research project due to the involvement of multiple social agents and audiences, and overall, the global significance of the problems associated with the economic, social, and environmental consequences of climate change.

Future studies should examine more deeply the differences among expert audiences in terms of ideology and attitudes to key environmental issues (i.e. 'climate change'). They can also consider previous knowledge about environmental issues to characterize in more detail the differences between professionals and academics. While this research narrates the process of designing an educational tool, the evaluation was conducted with informed audiences (professional and academic). The next steps should include testing the application in HE environments, such as universities and, particularly degree courses on environmental studies. This would help to improve future versions of the tool and stimulate further discussions on sustainable agricultural practices.

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Declaration of interest statement

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

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Figure 1

Left. Map of the area framed for the LIFE AMDRYC4 pilot project (LIFE16 CCA / ES / 000123). Right, areas selected for the intervention and sampling located in Region of Murcia (SE Spain)

Figure 2

Screenshot of the gameplay. The current game state displays a deteriorated residence as reflection of the poor level of the variables related to Socioeconomic development. Source: LIFE AMDRYC4 (Universidad de Murcia, 2021b).

Figure 3

Screenshot of the 'actions' menu. Icons are designed to ease the understanding of the agricultural strategies studied through the LIFE AmdryC4 Pilot Project. Source: LIFE AMDRYC4 (Universidad de Murcia, 2021b)

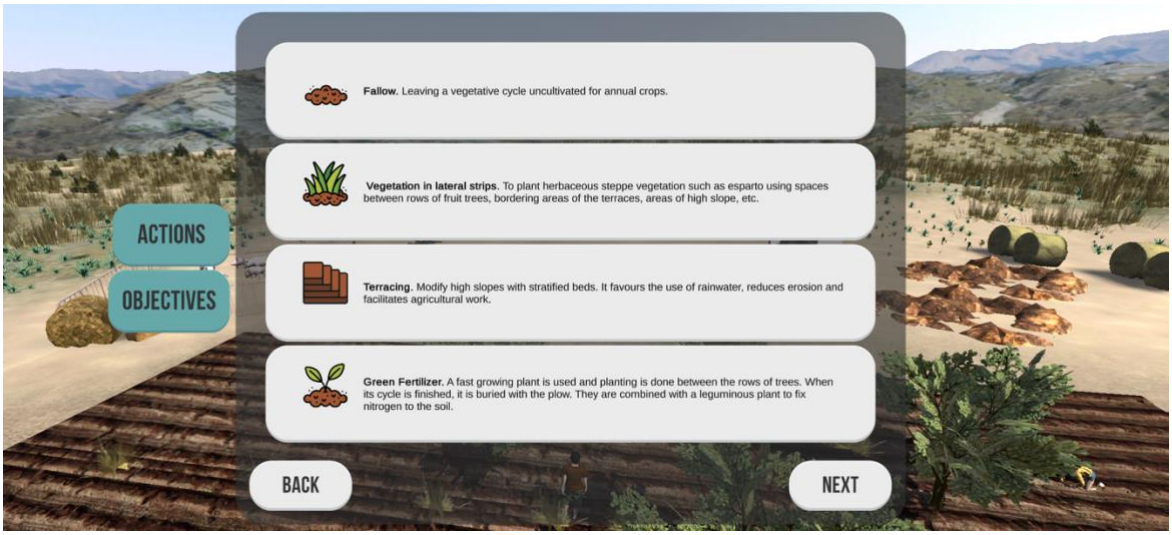

Figure 4

Screenshot of the 'visual dictionary' that gives information about the actions available for the user and introduces, briefly, the potential consequences on the gameplay. Source: LIFE AMDRYC4 (Universidad de Murcia, 2021b)

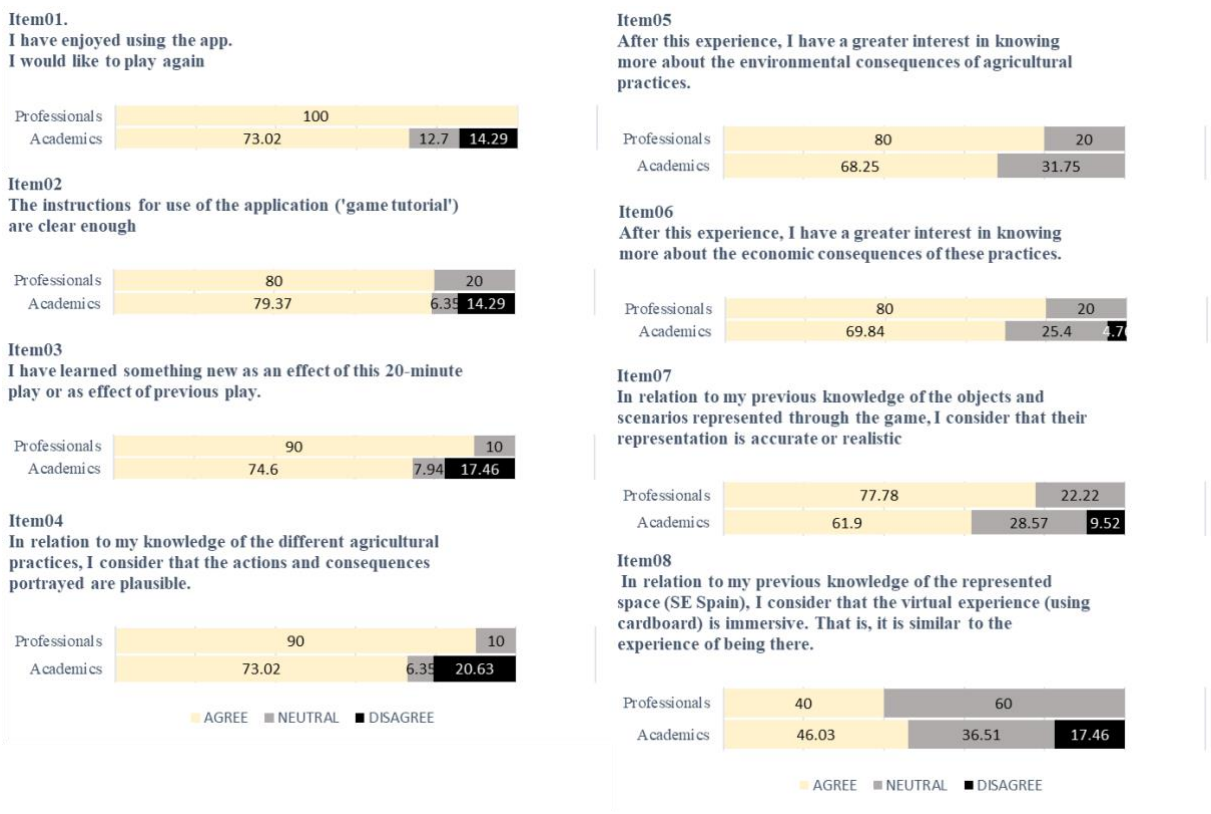

Figure 5

Percentages of responses re-encoded to show differences among groups.

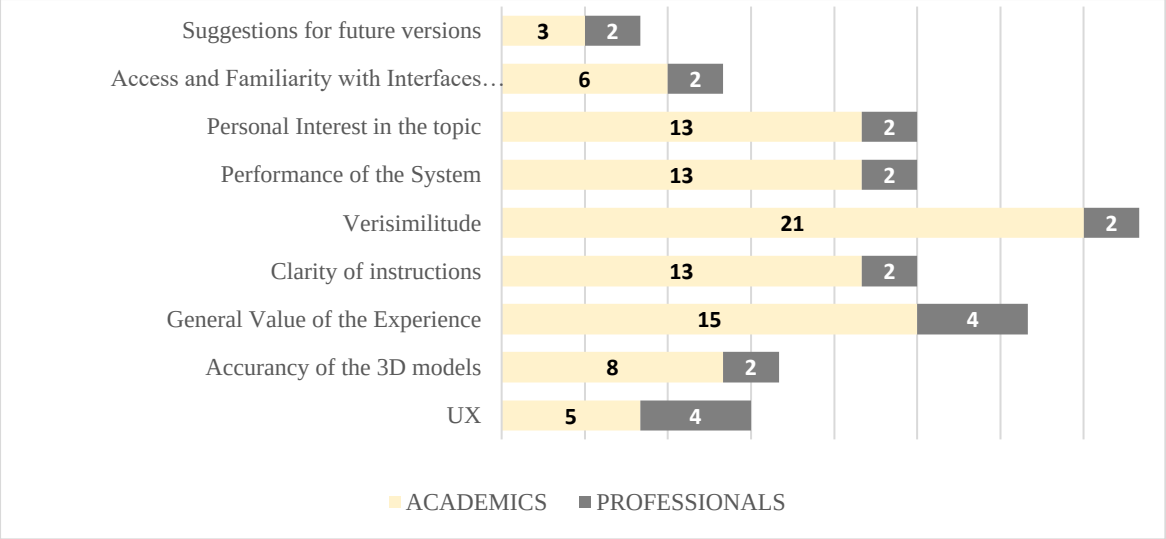

Figure 6

Number of comments found in the questionnaires (N=119) among professionals (n=22) and academics (n=97)

Items	Academics (N=64)					Professionals (N=20)					Stats		
	Totally Agree	Agree	Neutral	Disagree	Totally Disagree	Totally Agree	Agree	Neutral	Disagree	Totally Disagree	U	Z	p
01. I have enjoyed using the app. I would like to play again	12	35	8	9	0	4	16	0	0	0	295.000	-.451	.652
02. The instructions for use of the application (game tutorial) are clear enough	24	27	9	4	0	8	8	4	0	0	309.000	-.187	.852
03. I have learned something new as an effect of this 20-minute play or as effect of previous play.	16	31	12	5	0	6	12	2	0	0	266.000	-.925	.355
04. In relation to my knowledge of the different agricultural practices, I consider that the actions and consequences portrayed are plausible.	16	31	13	4	0	4	14	2	0	0	290.000	-.516	.606
05. After this experience, I have a greater interest in knowing more about the environmental consequences of agricultural practices.	22	21	21	0	0	12	4	4	0	0	238.000	-1.377	.168
06. After this experience, I have a greater interest in knowing more about the economic consequences of these practices.	18	26	17	3	0	8	8	4	0	0	265.000	-.922	.357
07. In relation to my previous knowledge of the objects and scenarios represented through the game, I consider that their representation is accurate or realistic	13	27	18	6	0	6	10	4	0	0	250.000	-1.174	.240
08. In relation to my previous knowledge of the represented space (SE of Spain), I consider that the virtual experience (using cardboard) is immersive. That is, it is similar to the experience of being there.	9	21	23	9	2	2	6	12	0	0	312.000	-.133	.894

Table 1. Frequencies of the 8 items Likert-style questionnaire used for the user evaluation of the mobile application (N= 84). The Mann-Whitney test revealed no significant (2-tailed) statistical differences among the groups.

TOPICS	Professio-nals%	Acade-mics%	Examples
User Experience (UX) Design and Interfaces	18.18	5.15	*"Sometimes, I have problems finding the way to close the menus"*
Accuracy of the 3D models	9.09	8.25	*"It feels quite real. However, in the game, I had problems in assessing this aspect when the gameplay was set up during the night".*
General Value of the Experience	18.18	15.46	*"I found it quite didactic and a good way to explore the impact of these consequences in the region"*
Clarity of instructions	9.09	13.40	*"(Instructions) should be clearer and elaborate"*
Plausibility	9.09	21.65	*"It feels as if there are no negative consequences of many of the actions"*
Performance of the System	9.09	13.40	*"My device (XXX, Android) isn't powerful enough to gain full access to the experience"*
Personal Interest in the topic	9.09	13.40	*"I'm more interested in the economic consequences of these practices"*
Access and Familiarity with Interfaces (Virtual Reality/Tactile)	9.09	6.19	*"The VR mode made me dizzy. Those options meant I had to make extreme movements with the head to select the right options"*
Suggestions for future versions	9.09	3.09	*"A story mode would be a great addition, adding dialogues and greater elaboration as regards the actions chosen"*
	100	100	
TOTAL	(N=22)	(N =97)	

Table 2

Distribution of comments found regarding the categories of analysis. An example from the coding is included to better describe these groups of insights.