Stimulating awareness of precision farming through gamification: the farming simulator case

Pavlenko, T., Argyropoulos, D., Arnoult, M., Engle, T., Gadanakis, Y. ORCID: https://orcid.org/0000-0001-7441-970X, Griepentrog, H. W., Kambuta, J., Latherow, T., Murdoch, A. J., Tranter, R. ORCID: https://orcid.org/0000-0003-0702-6505 and Paraforos, D. S. (2024) Stimulating awareness of precision farming through gamification: the farming simulator case. Smart Agricultural Technology, 9. 100529. ISSN 2772-3755 doi: 10.1016/j.atech.2024.100529 Available at https://centaur.reading.ac.uk/117835/

Smart Agricultural Technology 9 (2024) 100529

Contents lists available at ScienceDirect

Smart Agricultural Technology

journal homepage: www.journals.elsevier.com/smart-agricultural-technology

Stimulating awareness of Precision Farming through gamification: The Farming Simulator case

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ARTICLE INFO

Keywords:
Adoption
Gamification
Variable rate
Site-specific

ABSTRACT

Precision Farming (PF) provides different solutions to assist the decision-making process on farms. Current PF technologies such as variable rate site-specific applications can bring financial benefits to farmers as well as environmental advantages. Increasing scientific research and an expanding number of PF products are supporting a growing interest in PF applications. However, the actual implementation of these technologies on farms in many cases remains low. Therefore, there is a need to disseminate and transfer knowledge about the positive aspects of PF. One of the ways to facilitate the adoption process of PF technologies is education and training among farmers and other interested stakeholders. This paper presents a case study using the computer game Farming Simulator as an educational tool for raising awareness about the topic in an engaging and enjoyable way. Two distinct downloadable content (DLC) versions were developed and implemented in the versions 2019 and 2022 of the game, respectively, each with a range of PF functionalities (automatic steering, variable rate applications, yield mapping among others). The PF DLCs have received positive feedback from students and scientists but also the general public. The growing number of downloads (3,661,069 in total for both DLC versions as of 15th November 2023) demonstrates the effectiveness of computer games as an educational tool to educate and inform stakeholders (farmers, scientists, students, and the general public) about agricultural challenges and the potential of PF as a solution.

1. Introduction

The use of Precision Farming (PF) technologies provides access to a large amount of data that can be used to make informed decisions on farms [1]. These technologies have the potential to reduce costs, increase yields and profits, and improve soil, water, and air quality [2]. There have been different rates of adoption of PF technologies at the farm level. Some of them are considered to be slow. Lowenberg-DeBoer and Erickson [3] provide an example, at the national level such as in Denmark, Australia, and the United Kingdom (except for cereal farms), adoption of variable rate technology for any purpose rarely exceeds 20.0%. In addition, Maloku [4], in a literature review on the factors influencing the adoption of various PF technologies highlighted that the level of adoption varied for different European countries. For example, Danish, Swedish, and German farmers adopted yield monitoring earlier than their peers in France, Belgium, and Holland.

There are financial, sociological, environmental, and business aspects that influence the adoption of PF technologies [5]. Among the sociological characteristics, formal education and age are considered to be significant adoption factors [5,6]. The European Commission highlights that an aging population is a major problem in agriculture and farmers under the age of 40 only manage 11.0% of all farm holdings in

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https://doi.org/10.1016/j.atech.2024.100529
Received 31 December 2023; Received in revised form 20 July 2024; Accepted 5 August 2024
Available online 6 August 2024

the European Union [7]. On the other side younger farmers, whom Barnes et al. [8] state, are more likely to adopt PF technologies, may be the key to such aging concerns. One of the ways to increase interest in agriculture in general and to facilitate the adoption process is through education and training of different groups of stakeholders. However, with the development of technologies, the education sector is also experiencing changes in the attitudes and motivation of learners towards the learning process [9]. For example, Prensky [10] addressed the "engage me or enrage me" group of learners who believed that education was a waste of time. As such, modern educators are constantly striving to be as engaging as possible to retain a higher level of interest in coursework [11].

A novel approach to engage students in the learning process effectively and to increase their interest is through game-based learning. In this process, the learner participates in goal-oriented play and experiments with different solutions to the challenge or problem in a virtual environment. Several other terms are applied to describe the use of computer games for learning purposes: edutainment, training simulators, and serious games. Edutainment represents the promotion of learning in a fun and engaging way. Training simulators are used for developing skills to solve challenges, which are accurately simulating real-world scenarios. Based on the taxonomy provided by Tang et al. [9], serious games are generally categorised as edutainment but do not necessarily have game-play elements. A serious game includes pedagogy, e.g. educational or instructional activities that impart knowledge or skills [12]. Playing serious games should increase players' motivation and active engagement [13].

There are several studies on how serious games have been used in agriculture. The Horizon 2020 project "GATES" focused on the creation of a serious game-based training platform aimed at training actors in the agricultural value chain in the application of smart farming technologies [14]. Kovács et al. [15] developed a farming simulator application with the main objective of introducing agriculture to students and young people while Nuritha et al. [16] described the gamification of a Social Agriculture application. That included a web-based social media application prototype used to facilitate active interaction and increase engagement among farmers, farmer communities, and professionals. A study by Markopoulos et al. [17] introduced a virtual farming game that promoted the use of best practices in rice production.

Tangworakitthaworn et al. [18] described two serious games that were designed to enhance learning for agricultural engineering education in order to promote greater awareness of nature conservation and environmental issues among children and younger generations. Jouan et al. [19] illustrated the relevance of a serious game "SEGAE" for learning agroecology. Asplund et al. [20] described the integration of social science and agricultural practice through serious games and concluded that games acted as a catalyst for new ways of thinking. Orduña Alegría et al. [21] did research by using a serious board game MAHIZ. Based on the obtained results, the authors concluded that the players increased their knowledge of water resources and crop productivity and considered the game as a promising tool for learning about social-ecological decision-making.

The abovementioned studies described the development of serious games or applications to teach people involved in related fields. Thus, the advantages of game technologies are used in serious games for non-entertainment purposes [9]. By contrast, this paper describes the incorporation of a number of PF principles into the GIANTS' Farming Simulator (FS) game (GIANTS Software GmbH, Zurich, Switzerland) through the development of two sequential versions of the PF downloadable content (DLC). FS is a video game primarily designed for entertainment purposes. Thus, the novelty of this work is in demonstrating how a popular video game that already had an established audience with millions of users globally is used as an educational tool to incorporate appropriate aspects of PF while keeping entertainment as the main goal. Furthermore, as it was initially introduced by Pavlenko et al. [22], the primary emphasis is not on educating users but rather on raising awareness amongst different stakeholders about the advantages of PF and disseminating information about its potential. Within this research, people who are not familiar with the concept of PF are also targeted. The current approach shares the aspects of edutainment and serious games but cannot be completely categorised under these terms. The educational component is used in a broader sense as an additional effect of playing the game. Also, while the game in a general sense corresponds to reality but still remains a fiction, it cannot be assigned to the training simulators. A novel aspect of the approach introduced is that people without a farming background will become familiar with farming in general and with the concepts of sustainable agriculture in particular, which could then increase their interest in farming. In addition, people already involved in farming, through the use of the DLCs, may become familiar with the benefits of PF and integrate these technologies into their farming operations.

2. Materials and methods

The current study was part of the project "Integrating Precision Farming into Computer Game" co-funded by the European Institute of Innovation & Technology (EIT-Food), a co-funded body of the European Union, under Horizon 2020, the EU Framework Program for Research and Innovation (project number 20224 and 21050) (www.eitfood.eu/projects/integrating-precision-farming-in-computer-game). The project started in 2020 and finished at the end of 2022. The milestones are depicted in Fig. 1. The three main components of the project were to decide on the list of PF features, to integrate them into the game environment, and to collect feedback. The developed PF features were co-produced with a group of academics from the participating universities, and industry representatives with relevant expertise: agricultural economics, agronomy, agricultural machinery and engineering, plant physiology, farm management, agricultural education, ecology, game development, and game design. The features were approved by GIANTS based on the feasibility of integrating them into the main version of the game. In Fig. 1, project tasks are presented in chronological order with the date indicating the completion of the main milestones of the project. More details on every step can be found in the next subsections.

In the first year of the project, four partners were involved: John Deere, Germany (industry representative, coordinator), Grupo AN (farmer association), Spain, University of Hohenheim, Germany, and the University of Reading, UK. Starting from the second year, the Institute of Animal Reproduction and Food Research, Poland, also joined the consortium. GIANTS Software GmbH was subcontracted within this project but was not an official partner of the consortium. In 2022, University College Dublin, Ireland, and Lincoln University, New Zealand, joined the initiative to conduct workshops and contribute to research paper writing. However, they were not official partners of the project.

2.1. Description of the game

The FS is a simulation video game first released in 2008. The game is available for 15 different platforms (PC, Xbox, etc.) and over 25 million copies have been sold [23]. This game allows the player to take on the role of a farmer, growing crops, raising livestock, and selling all the output produced on the farm. FS is offered in 18 languages and is available in 165 countries [24]. The two game versions that were used in this study were FS19 and FS22. The latest version of the game has a wide range of farming activities, including farm management, farming enterprises (such as livestock, crops, and horticulture), and forestry. There is a choice of over 400 machines and tools, represented by over 100 actual agricultural brands. In addition, these versions also offer seasonal cycles [25].

2.2. Student workshops

Several participatory workshops with students were organised

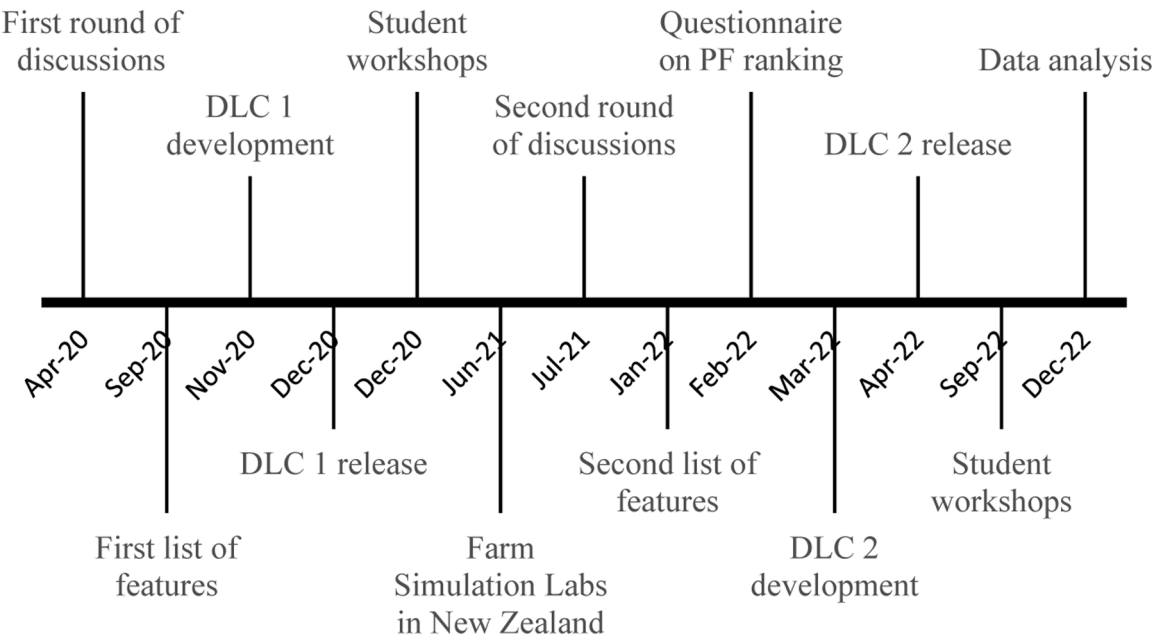

Fig. 1. Timeline of the development process of two versions of the PF DLC as a part of the GIANTS FS game.

within the development and implementation phases. They were conducted in the universities involved in the study (University of Hohenheim, University of Reading, University College Dublin, and Lincoln University). The workshops aimed to introduce the FS game to the students, to identify their opinions on the aspects of PF that they would like to see incorporated into the game, and then to gather feedback from them on their impressions of the versions of the PF DLC developed for FS19 (in 2020) and FS22 (in 2022). Students who were involved in agricultural studies and participated in courses related to PF took part. A total of 160 undergraduate and postgraduate students replied to the questionnaires. Participation was voluntary. The full list of these questions is provided in Appendix 1. It consisted of three multiple-choice and nine open-ended questions. The number of students varied from country to country: Ireland (10), Germany (22), New Zealand (94), UK (34). The replies from the questionnaires after the release of the FS19 version of the DLC and again after the release of the FS22 version of the DLC were combined and analysed as one data set. There was no difference in the data collection process across the universities.

2.3. PF DLC 1 development and release for FS19

The PF DLC 1 was released on 8th December 2020. The DLC was free to download for all FS19 license holders and included the following eight PF features: (1) automatic steering with a real-time kinematic global navigation satellite system (RTK GNSS) receiver; (2) introduction of soil heterogeneity based on different soil texture classes and pH levels; (3) different yield potentials corresponding to the soil texture classes; (4) soil sampling and soil properties based on laboratory analysis; (5) site-specific variable rate lime application; (6) site-specific variable rate nitrogen (N) fertiliser spreading using either organic fertiliser or dry and liquid mineral N fertiliser; (7) yield logging on the combine harvester for grain crops and creation of yield maps; and (8) farm financial performance analysis.

2.4. Mathematical calculations

The rationale behind the calculations introduced in the DLC was to find a compromise between simplicity, which makes the game more fun, and the more complex reality of agricultural fields. Therefore, they were formulated based on the agronomic knowledge of the project partners and communication with other experts. The calculation of the effect of N fertilisation on crop yield was based on the Fertiliser Impact on Yield (FIY) as follows:

$$(FIY) = \frac{N\_organic\_fertiliser \ + \ N\_mineral\_fertiliser}{N\_demand} \quad (1)$$

if $FIY \leq 1$: Increasing yield until yield potential is reached (linear from 40% to 100%)

$$Yield = Yield\ potential \times \ (0.4 + 0.6 \ \times FIY) \quad (2)$$

if $FIY > 1$: 3% reduction per 10% over-fertilisation (only for cereals)

$$Yield = Yield\ potential \times (1 - (FIY - 1) \times 3) \quad (3)$$

The economic analysis was designed to compare the uniform application of a single rate of fertiliser across the whole field with site-specific variable rate according to soil variability determined by soil sampling and analysis. To maintain the interest of the players, this function was kept fairly simple by limiting the scope to the variable costs of lime and N fertiliser, as only these can be changed:

$$\begin{aligned} Gross\ margin\ in\ soil\ zone\ (€ha^{-1}) = {} & Yield\ (t\ ha^{-1}) \times price\ (€t^{-1}) \\ & - \ Variable\_costs\ (€ha^{-1}) \\ & - \ Lime\ (t\ ha^{-1}) \times lime\_costs(€t^{-1}) \\ & - \ N\_fertiliser\ (kg\ ha^{-1}) \\ & \times N\_cost\ (€kg^{-1}) \end{aligned} \quad (4)$$

where *Variable_costs* were those that vary in terms of scale: seed, sprays and casual labour for picking or harvesting. Fixed costs for inputs such as machinery, permanent labour and capital were not included as they persist for all crops on the farm.

2.5. Questionnaires on PF features ranking

A total of 92 out of 160 participating students in the workshops responded to a questionnaire asking them to rank PF features in order of importance. The number of students per country varied: Ireland (9), Germany (27), New Zealand (45), United Kingdom (11). The questionnaires were emailed to the students either as a Word or Excel form or as a

link to Google Forms. Students' feedback on PF features was collected regardless of whether they had played the game or not. Students were given a list of features and asked to rank them from "1" to "5", with "5" being the highest priority. The list contained a total of 26 PF features and can be found in Appendix 1.

The same questionnaire was also distributed to representatives of the scientific community, who were related to the area of PF, as a Google Form. This was done by: i) providing the link to the audience during the presentation of the paper at the 13th European Conference on Precision Agriculture (ECPA) [26]; ii) inclusion of the link to the survey in the ECPA newsletter, which was distributed by e-mail; iii) individual e-mail contacts; and iv) dissemination of the link through university networks. In total, 73 replies were obtained from the scientific community.

2.6. DLC 2 release for FS22

The implementation of the first DLC version was reported as a successful case story by GIANTS. The high interest from the general public, the increasing number of website visits and game downloads, as well as numerous comments on the forums and spreading video tutorials, also carried out by the users themselves, brought into discussion a need to proceed with an increased number of PF features to be integrated into the game. This resulted in an extension of the project and a new round of discussions within the consortium and with the students. The second version of the PF DLC was released on 22nd April 2022. The DLC 2 can be downloaded for free by license holders of FS22 from the GIANTS website [27]. Next to the eight existing PF features from DLC 1, six new ones were added to the game: (1) purchase of soil/nutrient maps from a service provider; (2) variable rate seeding/drilling; (3) variable rate weed control with a camera and individual nozzle control; (4) variable rate organic fertilisation with HarvestLab™ Manure Sensing; (5) definition of crop N demand/variable rate fertilisation with an online crop biomass sensor; and (6) environmental score.

2.7. Multiple-choice questions

Two types of questions were used in the questionnaires: multiple-choice and open-ended. The replies to multiple-choice questions were limited by the questionnaire and, depending on the question consisted of either two or more options. Further analysis of the obtained results was straightforward since the replies were directly transformed into percentages in relation to the total number of replies, and no further actions were required. Thus, in this type of question, "n" represents the number of replies.

2.8. Open-ended questions

To analyse the answers to the open-ended questions, a coding

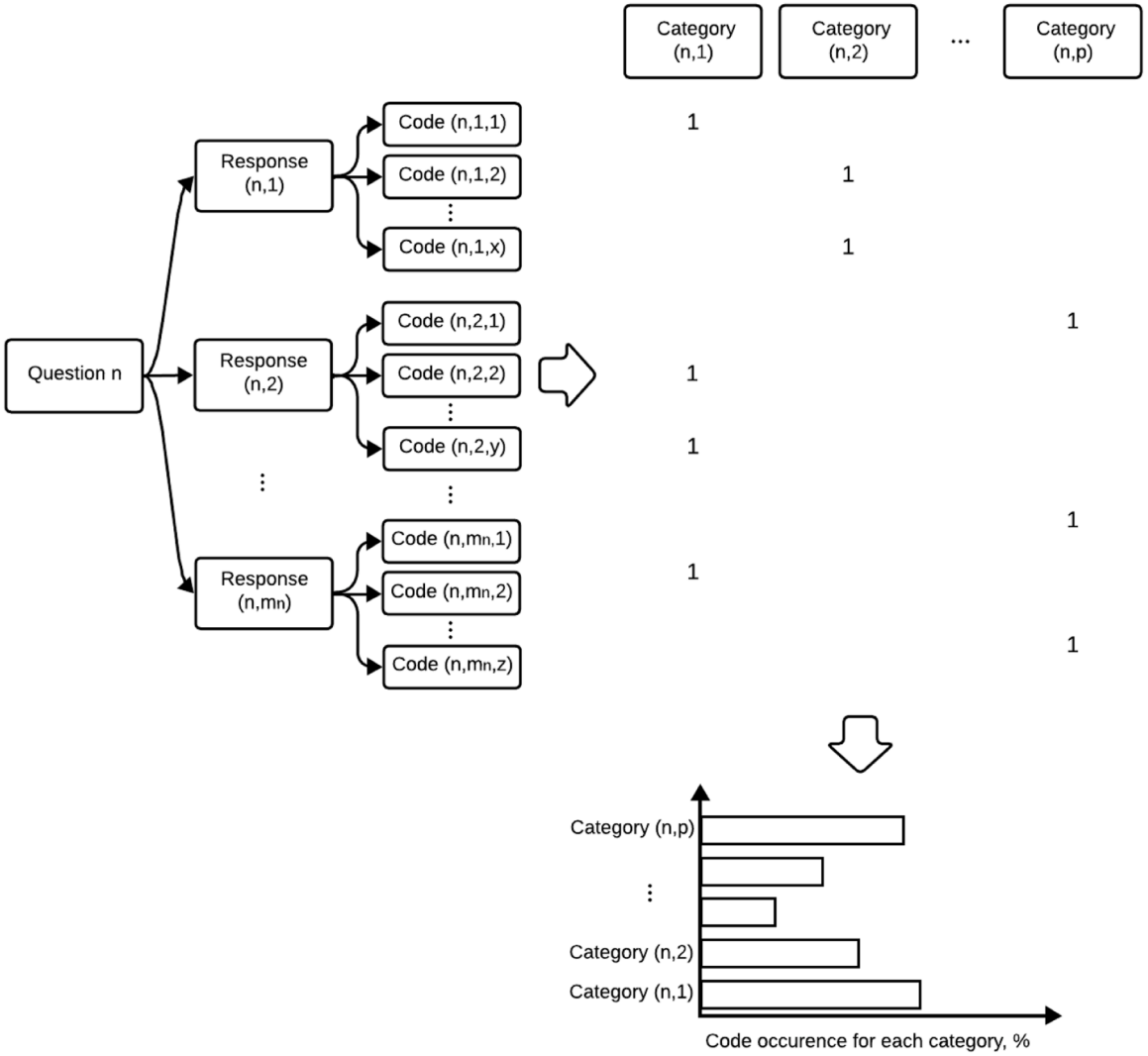

Fig. 2. Coding methodology.

methodology was applied. The process of the coding methodology in a generalised manner is presented in Fig. 2. For the common questionnaire that was used in all participating universities, first, all replies to the open-ended questions were transferred to the corresponding Excel sheets. Each question had a separate Excel sheet. Then, one or several codes were created for each response. In a qualitative analysis, a code is a word or a short phrase that summarises an open-ended survey response [28].

The same codes may be created out of responses to one question, while the maximum number of codes is not limited. The process of code creation is an individualised approach that is based on the area of research and the developed questionnaire. The code and categories were formulated based on the experience and knowledge of the responsible researchers. After the code creation, based on the information from the replies, several categories were generated, to which the codes were assigned. The process of code and category creation was done manually and took place in parallel, e.g. as soon as a new code did not fit already existing categories, a new category was added. In the end, the final number of codes for each category was divided by the total number of codes for each question and then transformed into percentages. The same procedure was followed for the questionnaire that was used in New Zealand for the Farm Simulation Labs, except that the generated codes were transferred directly to the Excel sheets (and not the complete responses) due to the large number of Word and PDF files collected. Therefore, the number of responses for this case cannot be given in the table in Appendix 1.

A simple example of this coding methodology for one question can be seen in Fig. 3. The question "What did you learn about PF as a result of playing with the PF DLC?" was taken as an example. For this question, 69 responses were obtained. To simplify the explanation, only six responses are given in the figure. The responses 1–6 were brought together in one column. The next step was to create the codes based on the main messages from each response. For example, Response 1: "The importance of soil testing in fields when growing arable crops". Considering that the question was about what a person learned after playing the game, the main message of this response was soil testing. Therefore, "soil testing" as a code was derived from this response. Response 2 sounded as "Learned lots from the economic analysis also the overall impact fertilisers and lime have on crops". Out of this response, it was clear that a person stated several points as a learned outcome. This led to the codes "economic analysis", "impact of fertilisers", and "impact of liming"; thus, three codes were created within one response. The same procedure was applied to the next four responses. It ended up with 11 codes in total. To make it simpler, the next step was to sort the codes in an alphabetic order. That was done for better visualisation of the resulting codes. After that, the categories were created. The naming of categories is a rather creative approach. While going through more codes, already created categories can be renamed to unite more codes with similar topics to reduce the number of categories. Thus, for the first code from the list, e.g. "accuracy of spraying", a category "spraying" was created. The code was assigned to the category by placing "1". The next code was "economic analysis". Since this code did not fit the category "spraying", the new one "financial aspects" was added. The third category was "fertilisation". As by logic, fertilisation and spraying might be united under one topic, the first category ("spraying") was renamed into "fertilisation/spraying". As the fourth code "field mapping" did not fit either "fertilisation/spraying" or "financial aspects", the next category had to be added (that was named "soil testing/soil mapping" after the next codes were considered). This process was applied to all 11 codes resulting in 3 created categories. In the end, the number of codes was calculated for each of the three categories (four, two, and five respectively), and by knowing the total number of codes (11), it was turned into percentages.

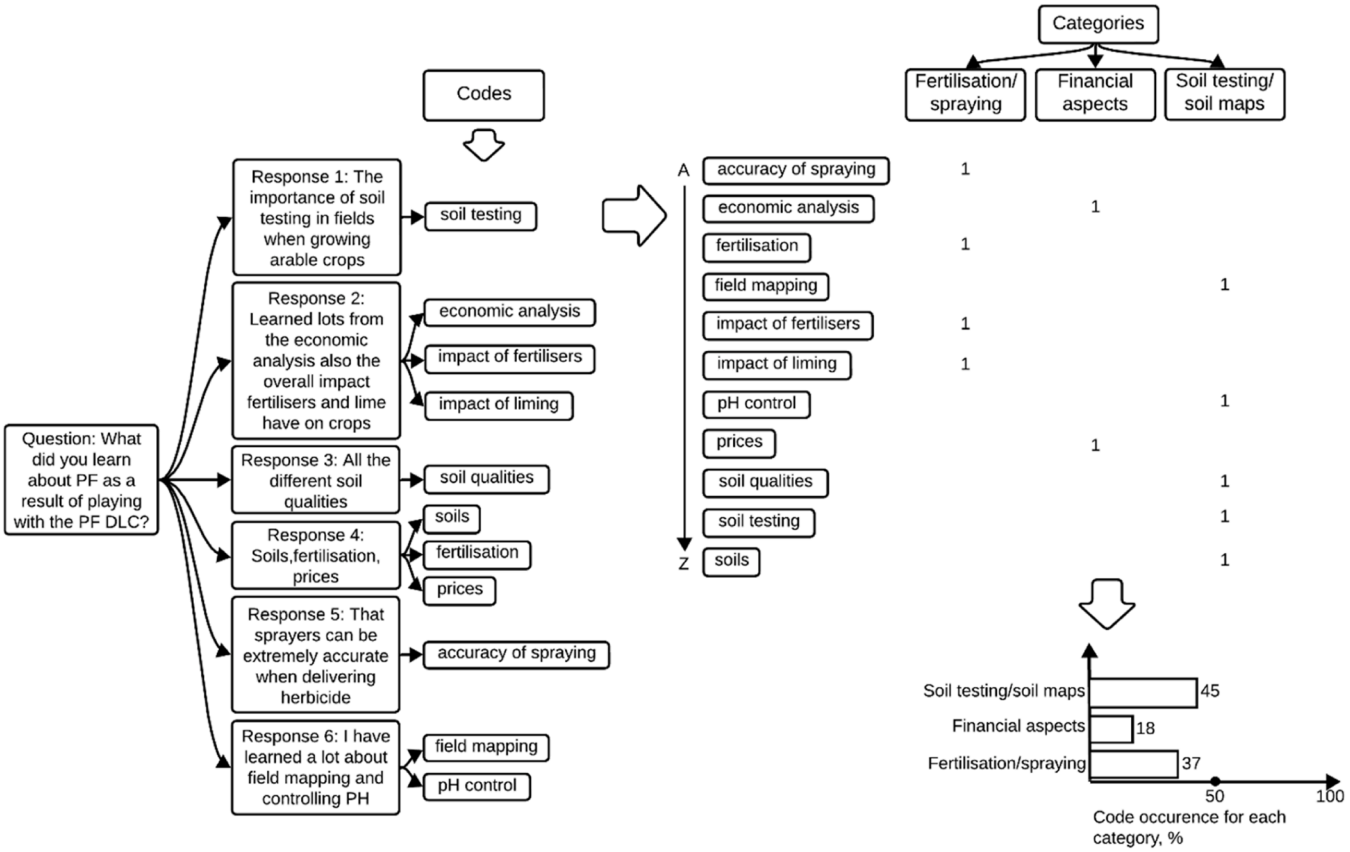

Fig. 3. Coding methodology with an example from the questionnaire.

2.9. Farm Simulation Labs in New Zealand

Since the conditions at Lincoln University in New Zealand were more favourable in terms of student numbers, one step further was taken and the Farm Simulation Labs were organised as part of an undergraduate Analysis of an Agriculture Systems course in which FS19 and the PF DLC 1 were used as teaching tools. Originally, the idea was adopted during the COVID-19 time as it was not possible to visit the farms due to lockdowns. Thus, in order to enhance students' learning experience, the FS was used. The Labs were run once per week. All Labs were linked to the teaching and actual farm visits. The students were divided into groups of five with the task of building a farm in the game using different PF practices. A questionnaire with nine multiple-choice and nine open-ended questions was distributed to the students at the end of the course to collect feedback on the course and the game itself. A full list of questions is given in Appendix 1. In the study 143 second-year bachelor students took part. In total 118 forms (as Word or PDF files) were collected and after an initial screening of them, 115 were used as three included no response.

3. Implemented PF features

The PF features that were integrated into the game can be summarised into four main categories: navigation, soil characteristics, variable rate, and economic and environmental aspects (Table 1). More detailed information on each of the features is presented in Appendix 2.

3.1. Environmental score

The environmental score (Fig. 4) indicates whether a player is growing crops in an environmentally friendly and sustainable way. There is a total score for all fields, but the player can also get a score for each field. The score directly affects the market value of the crop in the game. The maximum score of 100 increases the price a player receives for the crop by 15.0%. Several aspects of farming affect the score: N application, liming, weed control, soil sampling, and tillage. More information on the points awarded can be seen in Table 2.

As can be seen in Table 2, different scenarios of rewarded points were introduced. These scenarios were essential to reward practices that did not fully use the implemented PF technologies. During the discussion with the partners of the project, it became clear that the points rewarded should correspond to realistic agricultural practices, but at the same time fit in with the specific characteristics of the game and the playing strategies. Since the main purpose of this game is to provide fun, the idea behind it was not to overload the game and the player with scientific information but to present the concept of the environmental score with its components in an easily digestible way. Thus, to understand the message, a player does not need to have any specific background. As the game is not designed for scientific purposes, a way to allocate the points was chosen to be rather relative. It cannot be compared to farming in real life but it was a possible solution for the game.

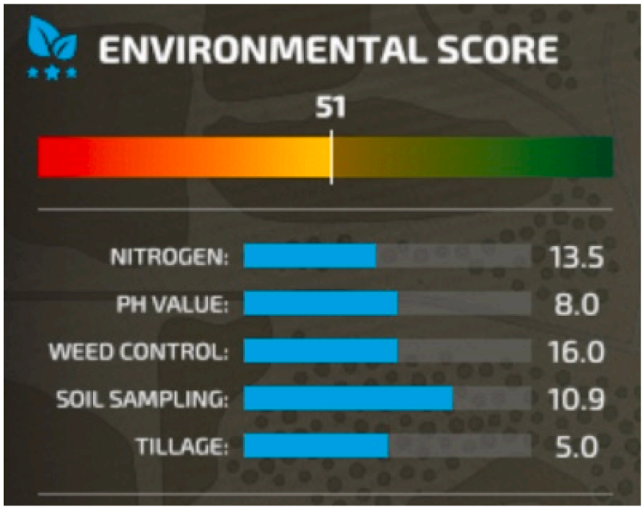

Fig. 4. An example of an environmental score in the game.

Table 1
PF features developed and implemented in the game.

Category	PF Feature
Navigation	RTK base station
Soil characteristics	Soil texture classes
	pH value
	Soil sampling
Variable rate	Site-specific variable rate lime application
	Site-specific variable rate N application
	Variable rate seeding/drilling
	Variable rate weed control and individual nozzle control
	Variable rate organic fertilisation with HarvestLab™ Manure Sensor
	Definition of crop N demand/Variable rate fertilisation
Economic and environmental aspects	Yield mapping
	Financial analysis
	Purchase of soil/nutrient maps from a service provider
	Environmental score

Table 2
Allocation of points for the environmental score in the game.

Step or Field State	Maximum points	Rewarded points
N application	30	
Over-fertilised (+20 kg)		0
Over-fertilised (+10 kg)		15
Optimal (0 kg)		30
Under-fertilised (−10 kg)		25
Under-fertilised (−20 kg)		20
Liming	15	
pH too high (+2)		0
pH too high (+1)		7.5
pH optimal (0)		15
pH too low (−1)		7.5
pH too low (−2)		0
Weed control/herbicides	30	
Spot spraying (See&Spray™)		30
Mechanical weed control		20
100% sprayed		15
No weed control		10
Soil sampling	15	
0% of field samples		0
50% of field samples		7.5
100% of field samples		15
Tillage	10	
Plough/deep cultivation		0
Shallow tillage		5
Direct tillage		10

4. Stakeholders' feedback and discussion

4.1. Feedback on PF features

Fig. 5 shows the results of the ranking of PF features by students and scientists. The survey results revealed that the PF features with the highest priority for both scientists and students, and with the smallest gap in their ratings, were the following: implementing controlled traffic farming, leaving weed patches in the field, accounting for residual N, having one layer of soil density, and acquiring biomass images from satellite providers.

There was a difference in preferences between scientists and

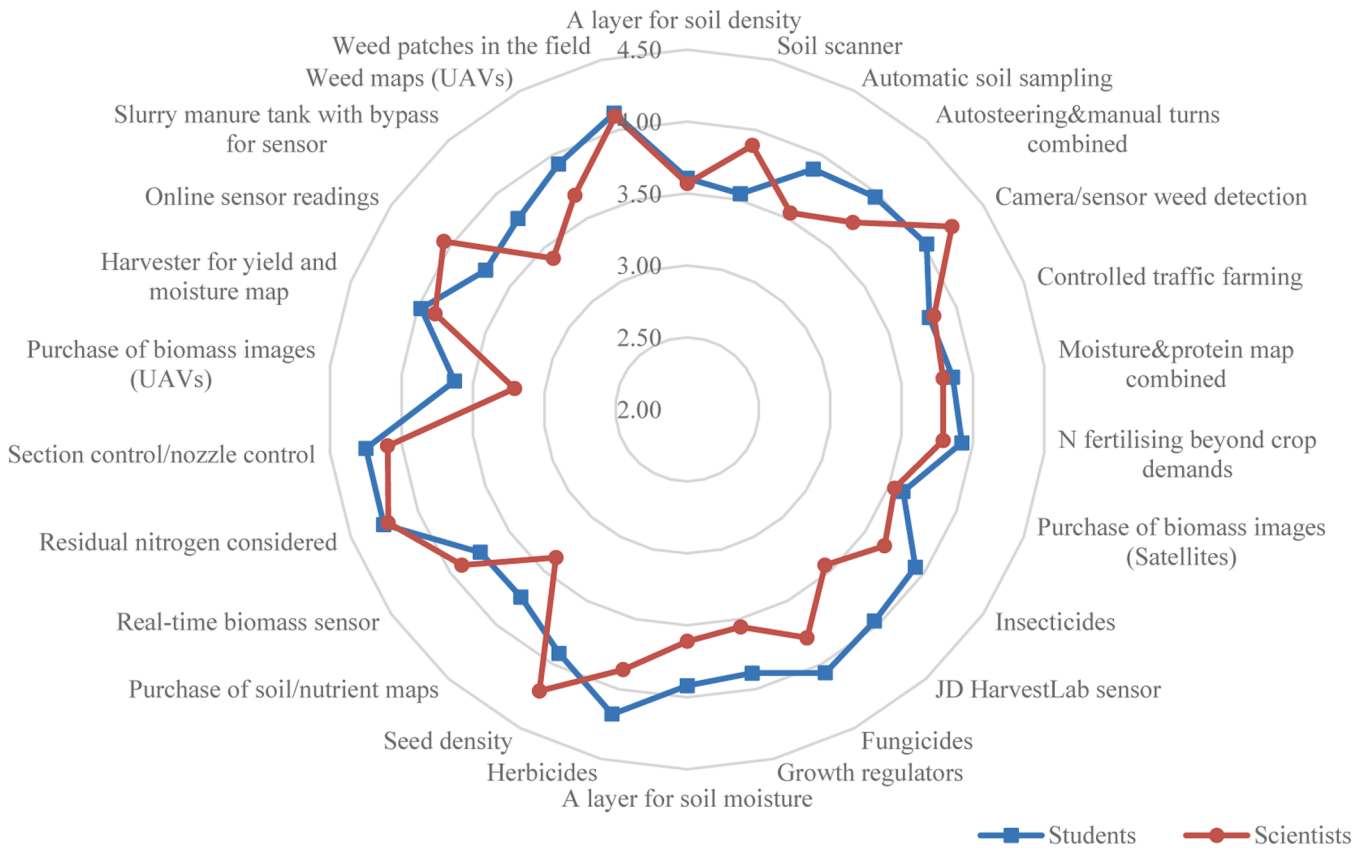

Fig. 5. A spider graph illustrating students' and scientists' ranking of the importance of the PF features (with "5" being the highest priority).

students. The PF features ranked highest by the scientists were camera/sensor weed detection, residual N considered, and seed density. At the same time, students preferred residual N with consideration of boom/nozzle control and herbicide application. Compared to the scientists, the purchase of biomass images (using unmanned aerial vehicles (UAVs)), the purchase of soil/nutrient maps, and a slurry tank with sensor bypass were the least preferred PF features. The lowest-ranked features by the students were the soil scanner, the purchase of biomass images (via satellite), and the soil density layer. All PF features that were ranked highest by both groups of respondents were in line with the decision of the consortium and formed the majority of the feature list that was implemented in the second version of the DLC.

4.2. *Students' feedback*

4.2.1. *Multiple-choice questions*

Most of the respondents stated that they were "very likely" (24.0%) and "somehow likely" (32.2%) to adopt PF on a farm (Fig. 6a, $n = 145$). According to Fig. 6b ($n = 137$) the accessibility of the PF DLC was "very easy" for 17.0% of the students; "quite easy" for 5.0%; "easy" for 20.0%;

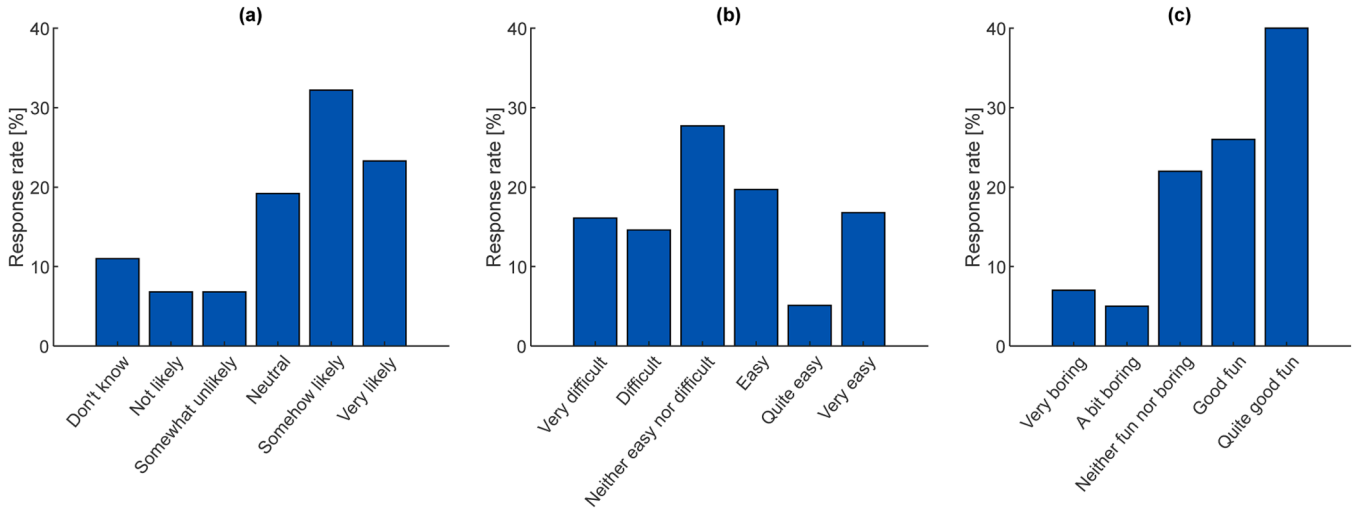

Fig. 6. Results of the replies to the common multiple-choice questions: (a) "How likely are you to adopt PF on a farm?" ($n = 145$); (b) "How did you find the process of accessing the PF DLC?" ($n = 137$); (c) "What was it like playing with the PF DLC?" ($n = 134$).

and "neither easy nor difficult" for 28.0%. The remainder chose "difficult" (14.0%) and "very difficult" (16.0%). Students were asked what it was like to play the PF DLC ($n = 134$). Among all the replies, 40.0% of the respondents stated it was "quite good fun"; 26.0% selected "good fun"; for 22.0% it was "neither fun nor boring"; and for 5.0% and 7.0%, it was "a bit boring" and "very boring" respectively (Fig. 6c).

4.2.2. Open-ended questions

In the figures presenting the results for the open-ended questions, "n" refers to a number of codes (not the number of replies as it was for the multiple-choice questions). The cases when the number of generated codes is lower than the number of replies can be explained by the fact that such responses as "couldn't play", "nothing", "did not work", "don't know" etc. were not coded and not considered in the final results.

Students were also asked about the best and worst aspects of the PF DLC. Among the main positive aspects were PF itself and the implemented principles (44.0%); realism (13.8%); running a farm (10.3%); and financial aspects (6.9%) as can be seen in Fig. 7a ($n = 116$). Conversely, several negative aspects of the PF DLC were mentioned by the students ($n = 32$) which can be grouped into three categories: (1) negative impressions about specific aspects of the DLC (40.6%), such as too confusing to operate the technology involved, loss of player interest; (2) feature-related issues (31.3%), such as cost of equipment, too simplified farming practices; and (3) time-consuming (28.1%), mostly related to the manual soil sampling process in DLC 1 (Fig. 7b).

The main comments on what made the access to the DLC easy were helpful instructions, easy to find, saving farmer's time, and a user-friendly interface. More difficult aspects mentioned included: learning to play the basic game, controls and navigation, layout, and some implemented features. When asked how access to the PF DLC could be improved ($n = 24$), the majority (83.3%) said that more instructions and explanations were needed.

The main aspects that could make the PF DLC more fun ($n = 39$) were: improved functionalities (33.3%); introduction of new technologies (23.1%); improved soil sampling process (12.8%); navigation (12.8%); crop-related aspects (10.3%); and more instruction (7.7%) (Fig. 8a). Of the 28 additional comments about the PF DLC, 35.7% said they would like to see more simplified functions in the game, and 26.7% would like to see more nature conservation aspects. In addition to adding new functions to the game (25.0%), 10.7% said they would like to see new enterprises such as fruit growing or viticulture added.

As one of the main objectives was to impart knowledge to the students, they were asked to share their thoughts on the PF aspects they learned about as a result of playing the PF DLC (Fig. 8b). Out of 50 generated codes, 22.0% were related to the different aspects of farm management (e.g. better understanding, improved farming practices, time management); 20.0% were related to soil testing/soil maps; and 14.0% were related to variable rate application (VRA) and spraying/fertilising. Other aspects mentioned were financial (12.0%); general benefits of PF (12.0%); and other aspects (6.0%) (for example, "different variables to run a farm with PF", "factors affecting yield"). Out of 34 responses, 88.0% agreed that PF and digitisation in agriculture can help to increase interest among younger people.

Several aspects were mentioned by the students as things that should be done to improve the DLC and make people more likely to adopt PF (Fig. 8c, $n = 42$). Over a quarter (26.2%) mentioned adding different types of functionalities (adding more specific brands, different fertilisers, more detailed maps, etc.). Another 21.4% mentioned sensors and/or section control (measuring crop components, herbicide spot spraying, near-infrared spectroscopy slurry sensing, etc.); 19.0% mentioned adding more instructions; 16.7% offered the crop/soil-related aspects (such as a wider range of crops, adding a percentage of soil organic matter, detecting compaction). The rest mentioned navigation (9.5%) and UAVs (7.1%).

4.3. Feedback from the Farm Simulation Labs in New Zealand

The main motivation of the Farm Simulation Labs was to use the game as an educational tool to virtually demonstrate to students the concepts and benefits of PF. Another important aspect was to see how gaming and communication in groups can facilitate the learning process and increase interest in PF. The results relate to the PF DLC 1. Out of 112 replies, most respondents (96.0%) had a farming background or grew up on a farm, and out of 114 replies, 64.0% of the students were playing the game for the first time. Therefore, it can be assumed that the vast majority of participants had prior knowledge of agricultural practices and it was, therefore, useful to see how they evaluated the principles and usefulness of the PF integrated in the game. The results can be divided into four different groups: (i) game impression; (ii) the game as a learning tool; (iii) Farm Simulation Labs; and (iv) the influence of the game on the students' future goals.

4.3.1. Game impression

Of the 114 responses received, 80.0% of students enjoyed playing the

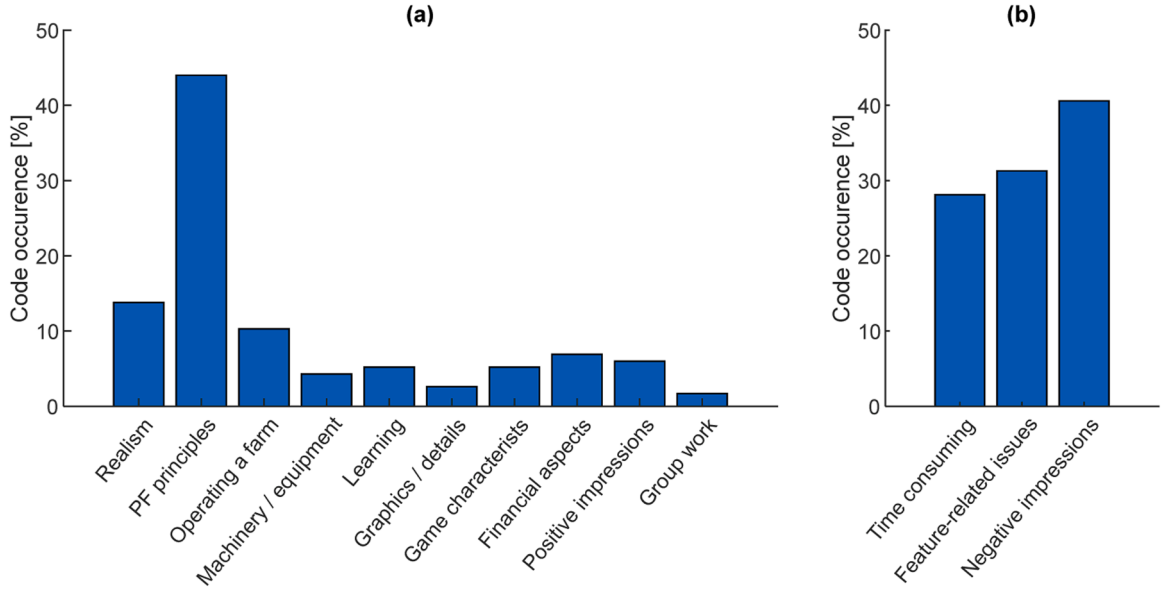

Fig. 7. Replies in terms of code occurrence to the question: (a) "What was best about the PF DLC?" ($n = 116$); (b) "What was worst about the PF DLC?" ($n = 32$).

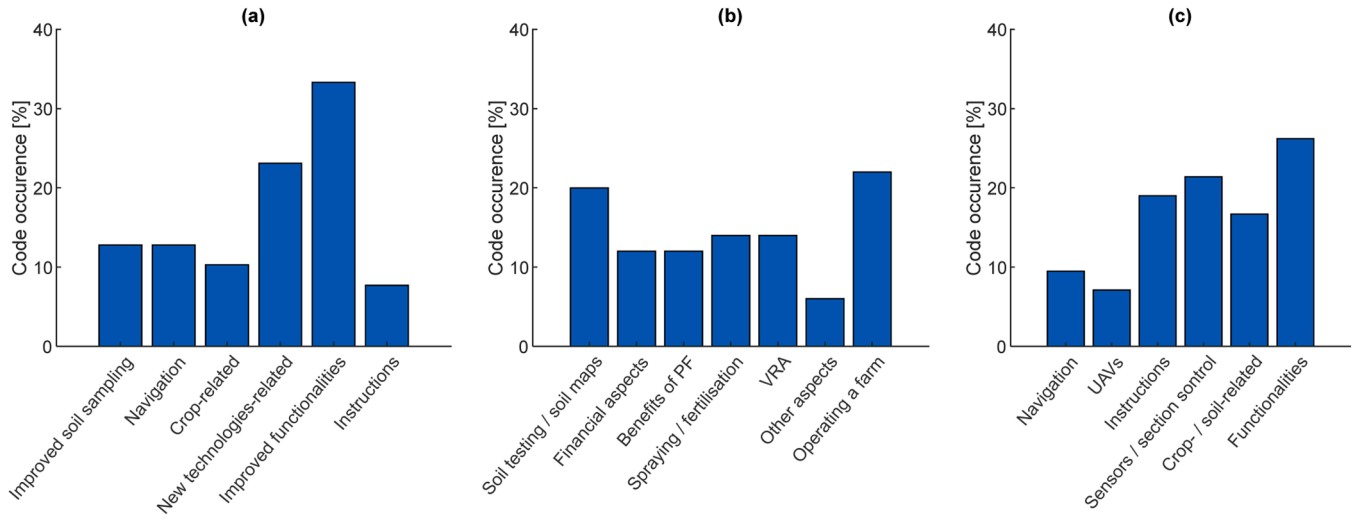

Fig. 8. Replies in terms of code occurrence to the question: (a) "How could the PF DLC be made more fun?" ($n = 39$); (b) "What did you learn about PF as a result of playing with the PF DLC?" ($n = 50$); (c) "How do you think the PF DLC can be improved to make you and others more likely to adopt PF?" ($n = 42$).

game. The main features of the game that students particularly liked ($n = 180$) were: realism (17.2%); financial aspects (16.1%); running a farm (15.0%); freedom of choice (11.7%); and machinery/equipment (11.1%) (Fig. 9a). The main aspects of the game that students particularly disliked ($n = 46$) were: navigation (30.4%); complexity (23.9%); time-consuming (21.7%); and lack of instructions (10.9%) (Fig. 9b). Students were also asked if playing FS had changed their views on farming games. Out of 113 replies, 37.0% of respondents said "yes", giving the following reasons ($n = 61$): the game helped them to understand farming systems better (34.4%); because it was realistic (29.5%); and because it was fun (13.1%).

4.3.2. The game as a learning tool

More than half of the respondents (54.0% out of 113) confirmed that the farm simulation improved their learning. Out of 112 respondents, some 65.0% stated that the farm simulation game improved their understanding of modern farm management systems. In addition, financial and management skills, general agricultural knowledge, understanding of cropping systems, knowledge of soils, etc. were mentioned as aspects that improved students' learning after playing the farm simulator game (Fig. 10a, $n = 81$).

Some 75.0% of students agreed that the FS19 game could be useful for other courses ($n = 110$). The main courses named were related to (farm) management, crop/soil science, business/accounting, and agriculture/horticulture in general (Fig. 11b, $n = 81$). The main reasons why the game could be useful for other courses were: improved understanding of farming practices (68.3%); knowledge of crop and soil management (19.0%); and knowledge of farm finance (12.7%) (Fig. 10c, $n = 63$).

4.3.3. Farm Simulation Labs

Some 65.0% of respondents ($n = 108$) found Farm Simulation Labs beneficial. The main reasons for that were: interactive/enjoyable process (49.3%); understanding farm operations (27.5%); and useful practice (23.2%) (Fig. 11a, $n = 69$). The main reasons why the laboratory was not useful ($n = 26$) can be recognised by two aspects: not useful or boring (58.0%); and challenging (42.0%).

4.3.4. Influence of the game on the students' future goals

Despite a lot of positive feedback, out of 111 replies, only 22.0% of respondents said that playing FS19 would help them to achieve their long-term goals: by gaining knowledge about general aspects of farming

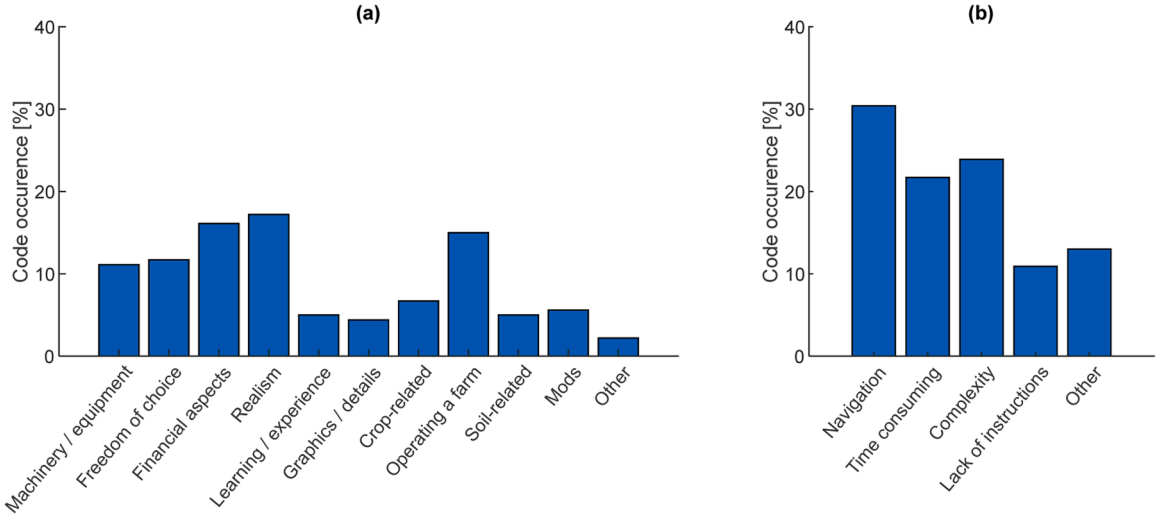

Fig. 9. Replies in terms of code occurrence to the question: (a) "What parts of the farm simulation did you particularly like?" ($n = 180$); (b) "What parts of the farm simulation did you particularly dislike?" ($n = 46$).

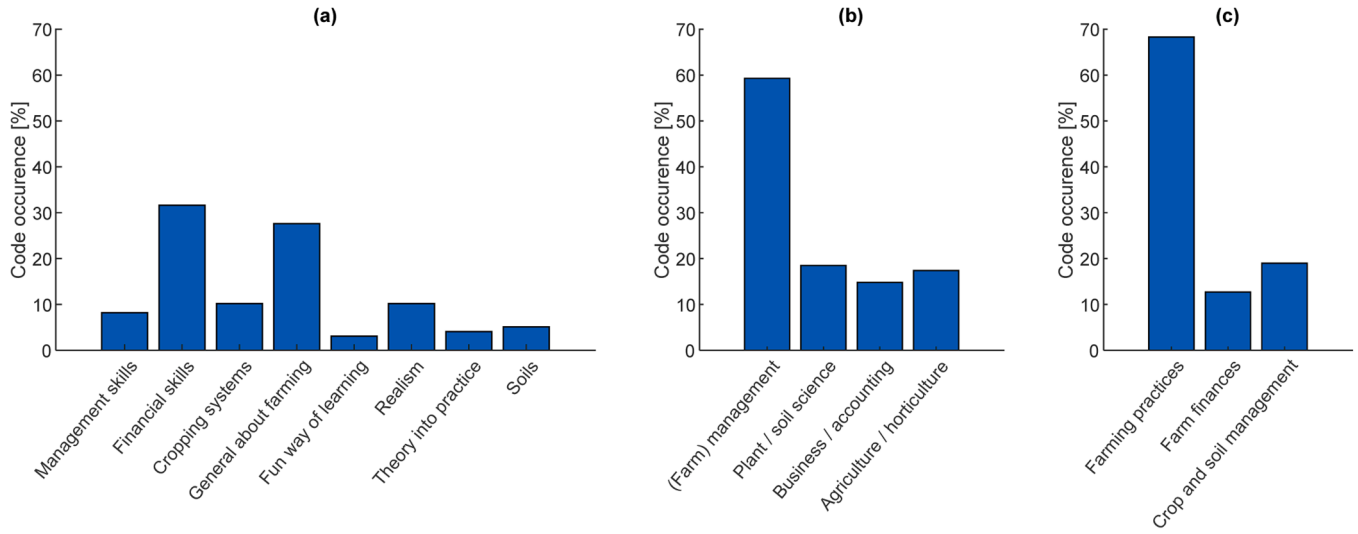

Fig. 10. Replies in terms of code occurrence to the question: (a) "How the farm simulation game enhanced your learning?" ($n = 98$); (b) "For which courses this software can be useful?" ($n = 81$); (c) "Why this software can be useful for other courses?" ($n = 63$).

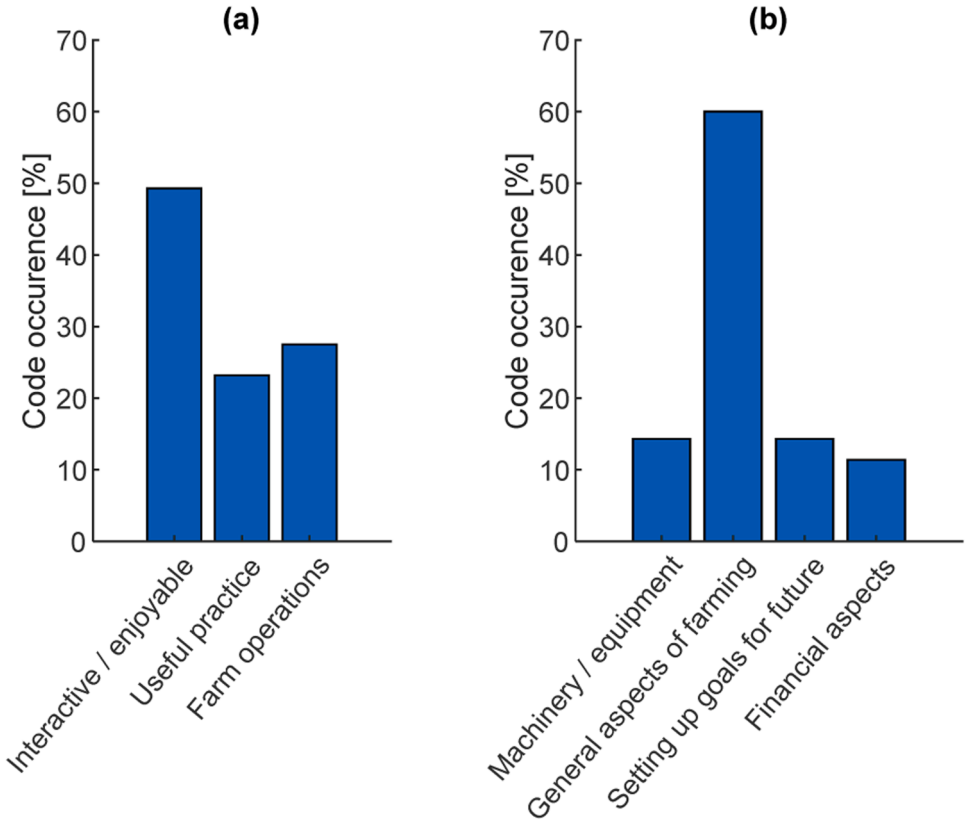

Fig. 11. Replies in terms of code occurrence to the question: (a) "Why did you find the Farm Simulation Labs beneficial?" ($n = 69$); (b) "How playing the farm simulation game will help you to achieve your long-term goals?" ($n = 35$).

(60.0%); and about machinery and equipment (14.3%); by helping to set goals for the future (14.3%); and by gaining knowledge about economic aspects (11.4%) (Fig. 11b, $n = 35$).

The New Zealand case study results serve as supportive evidence of the results that came up during the common study as they showed that the categories that appeared during the data analysis, were very similar or often even the same as those that appeared during the analysis of a common questionnaire conducted in each participating university.

4.4. Social media reach

One of the ideas of the study was to reach as broad an audience as possible to deliver the message about PF. For this purpose, Facebook reach (how many people saw a content/post) and Facebook total clicks (the number of times people clicked on a content/post) data were collected by GIANTS Software with the main results presented in Table 3.

As of 15th November 2022, the total number of downloads for FS19

Table 3
Social media reach (Facebook) of the game and the PF DLC.

Post	Date	Reach (as of 15th November 2022)	Total Clicks	
			(as of 15th November 2022)	(as of 15th November 2023)
Precision Farming: Features & Release-Date for Farming Simulator 22	3.03.2022	605,885	21,720	84,565
Return of Precision Farming – Precision Farming Podcast #13 (Live)	11.03.2022	111,578	855	4342
Precision Farming – Improved Features: Soil Map Purchase and More	15.03.2022	323,460	15,053	46,315
Precision Farming: Introducing Crop Sensors	24.03.2022	257,989	10,005	44,455
Precision Farming: Introducing Spot Spraying & Variable Rate Weed Control	31.03.2022	293,054	11,711	48,446
Precision Farming: Introducing Variable Rate Seeding / Drilling	5.04.2022	250,689	9484	42,116
Precision Farming: Introducing Manure Nitrogen Sensors	7.04.2022	213,356	6222	31,234
Precision Farming: Introducing The Environmental Score System	13.04.2022	215,410	7836	68,809
Precision Farming Free DLC now available for Farming Simulator 22	19.04.2022	247,669	6501	42,809
Total		2,519,090	89,387	413,091

DLC 1 was 1,461,941 with a user rating of 4.4/5 (based on 4314 votes), and for FS22 DLC 2 the number of downloads was 942,394, with a rating of 4.5/5 (based on 5911 votes). As of 15th November 2023, the number of downloads for the FS19 DCL 1 increased to 1,566,389 with a user rating of 4.3/5 (4463 votes), and the number of downloads for FS22 DLC 2 was 2,094,680 with a rating of 4.4/5 (9788 votes). Thus, the total number of downloads for both versions of the DLC crossed 3,5 million and was among the most popular downloads for FS22 [29].

According to Fig. 12, 39.0% of total clicks belong to Germany. The USA is in the second position with 16.0%. The third place is shared between France and Poland having 9.0% each, followed by the Czech Republic and Great Britain (7.0% each). These results don't consider whether and how the posts were boosted. However, they indicate that there is a clear interest in different PF technologies in Europe and the USA. The higher interest of these countries corresponds to the fact that differences in applications of PF exist between countries. Specifically, the use of PF in North America and Europe is based on more advanced information systems [30].

4.5. Discussion

PF features that were implemented in the game allow one to get a general understanding of PF practices. Thus, the features cover the main groups of PF technologies that give an opportunity for the players to experience the possibilities of their application at the different stages of farming practice. This aligns with the classification of the technologies that was described by Keskin et al. [31], in which PF technologies were classified under three groups: data collection (positioning systems, yield mapping, soil mapping, remote sensing, and crop and field scouting), data analysis and decision making (geographical information systems), and application (VRA technology). The results also correspond with the typology presented by Nowak [32] that divides PF technologies into three groups: GNSS; automatic variable rate treatment; and intra-field diagnosis tools.

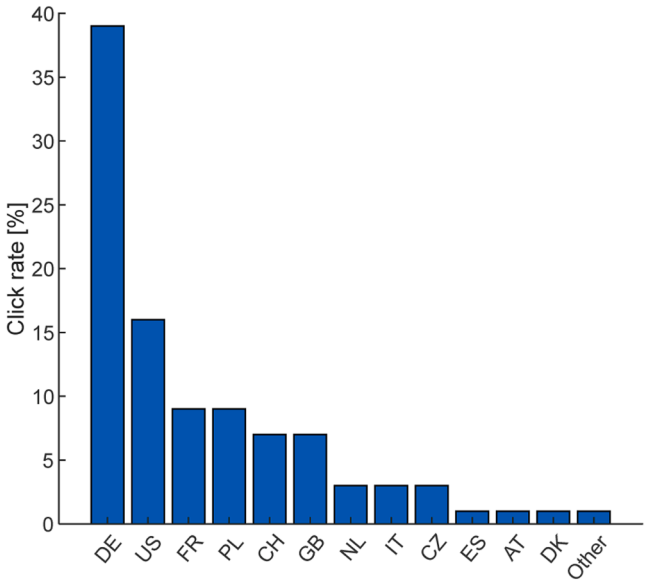

Fig. 12. Total clicks distribution per country,%.

The fact that the majority of students were likely or somehow likely to adopt PF on a farm supports evidence of a high interest of the students to accept PF and their willingness to adopt these technologies in the future. Moreover, most respondents indicated that the PF DLC was quite enjoyable. This statement demonstrates that the main aim of the gaming, e.g. delivering fun to the players, was kept even after the introduction of the DLC. This finding correlates with the study of Bilali et al. [33]. They named the determining factors for the acceptance and use of technologies in agriculture, which were the technology itself, its ease of use, as well as social, and emotional factors, attitudes, and cognition. This study presented a high interest of the students in the integrated technologies that might be connected to their younger age (as a social factor) and getting fun from playing the game (as an emotional factor).

The outcome of this research highlights that similar activities can be implemented by a wide number of educational institutions around the world. As the project started, at the beginning two universities (University of Hohenheim and, the University of Reading) participated. Over the next period, more contacts were reached to expand the network. As a result, two more universities expressed their interest in using the FS and the DLCs in their teaching and joined the initiative (University College Dublin, Lincoln University). There is a current discussion with other educational institutions to potentially implement game-based learning by using the FS game and the DCLs in their work. In the future, this might lead to an established worldwide network that would allow an exchange of knowledge and experience from different universities to improve the implementation of teaching approaches and reach higher interest among students to be engaged in farming operations. Students involved in agricultural studies can be considered as potential future farmers and farmer advisors. Therefore, their education is crucial for shaping the solution of future environmental problems. This aligns with the statements of Fihlo et al. [34], who highlighted the significance of

climate change knowledge among future professionals and stressed out the necessity of curricular innovations in order to increase a number of professionals with proper skills.

As a result of the work that was done within this study, millions of people had a chance to explore more possibilities of PF. Such a large number of people was possible to reach because the implementation of the PF principles took place in the already existing game with a broad audience. Delivering this knowledge to such a wide audience would not have been possible within a short period if there was a need to develop a completely new game or application.

Within less than nine months after the first announcement about the second DLC, more than 2.5 million people were reached. Although the data on the reach after 15th November 2022 is not available at the moment of writing, a substantial increase in total clicks can be followed over one year. At the same time, by being actively engaged, the users are more informed about the topic of PF and its benefits. Also, the game offers an opportunity for the students and other stakeholders to become familiar with PF practices in cases where the technologies are not available.

5. Conclusion

The two DLCs were a novel and innovative way of communicating the benefits of PF to reach a wider audience of potentially interested stakeholders and encourage the adoption of selected technologies. One of the challenges was to keep a balance between providing a game that was still fun to play and, at the same time, had features that reflected real-world PF principles and technologies that farmers and their advisors would recognise.

The increasing number of downloads is an important indication that the DLCs were implemented and delivered in a way that combined the fun of playing, interest to be involved, and curiosity to get to know more about the aspects of the PF presented in the game. The developed versions of the DLC contributed to increasing public awareness about environmental issues and can be considered as a facilitating tool to stimulate the adoption of PF technologies and to help current and future farmers in their everyday decision-making process.

As computer games nowadays become more realistic, the future recommendation for this work would be to expand PF features in the game to other farming systems such as horticulture, viticulture, animal husbandry, etc. This could contribute to delivering a more full picture to the game players. In addition to that, this game can be used as an educational tool to be implemented in studying curricula at different educational institutions across the continents. An increasing number of the involved countries could lead to an increased sample that, in turn, would make it possible to compare among the countries.

CRediT authorship contribution statement

Tetiana Pavlenko: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dimitrios Argyropoulos:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Data curation. **Matthieu Arnoult:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Conceptualization. **Thomas Engel:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Yiorgos Gadanakis:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Hans W. Griepentrog:** Writing – review & editing, Validation, Supervision, Methodology. **Jacob Kambuta:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Data curation. **Tamisan Latherow:** Writing – review & editing, Validation, Methodology. **Alistair J. Murdoch:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition. **Richard Tranter:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Dimitrios S. Paraforos:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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.

One of the authors (Dimitrios S. Paraforos) is a Special Content Editor for Smart Agricultural Technology and was not involved in the editorial review or the decision to publish this article.

Data availability

The authors do not have permission to share data.

Acknowledgements

The work was performed through a project co-funded by the European Institute of Innovation & Technology (EIT-Food) a co-funded body of the European Union, under the Horizon 2020, the EU Framework Program for Research and Innovation, project number 20224 and 21050.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.atech.2024.100529.

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