Can video games be an educational tool for explaining tree mortality with or without thinnings?

Michał Guzik

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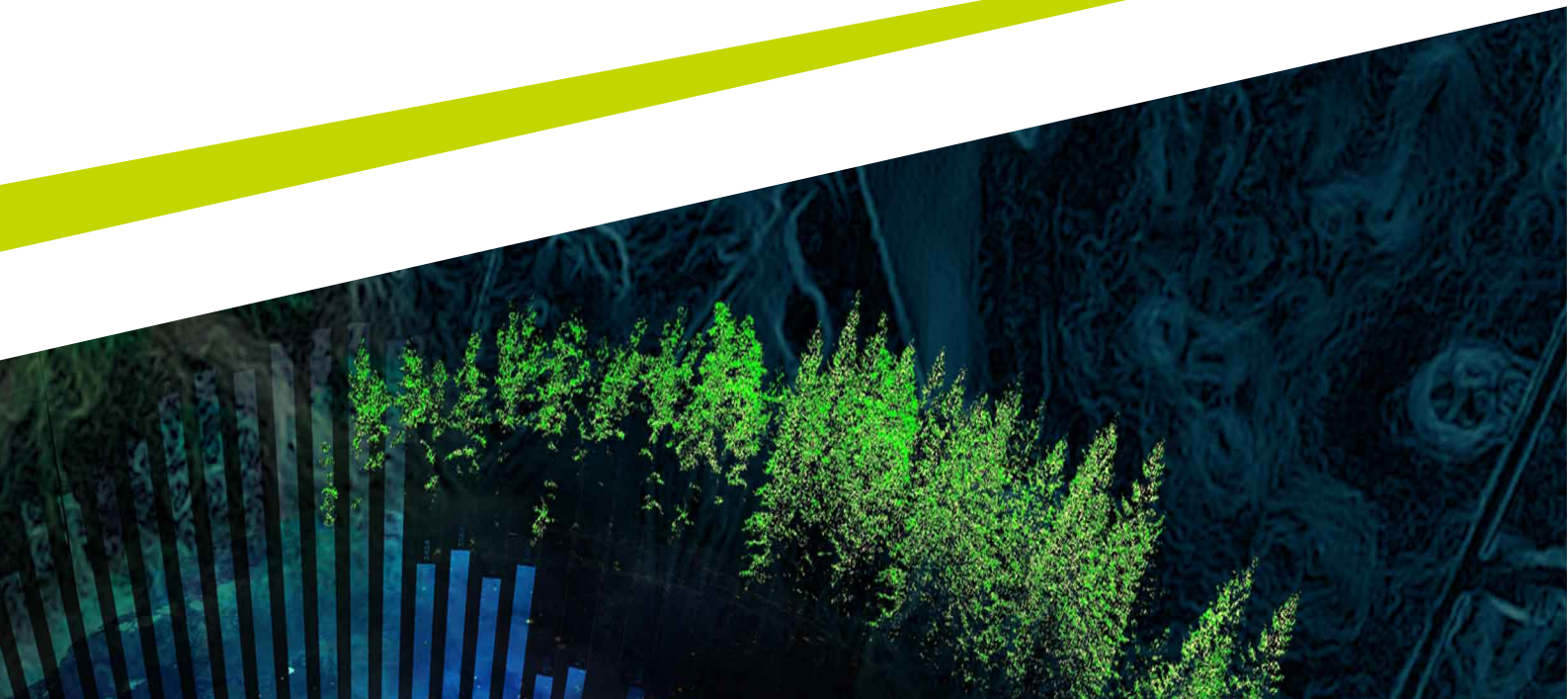

Can video games be an educational tool for explaining tree mortality with or without thinnings?

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Supervisor:	**Emily Viola Delin, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre**
Examiner:	Ola Eriksson, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre

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Swedish University of Agricultural Sciences
Faculty of Forest Sciences
Southern Swedish Forest Research Centre

Abstract

Natural mortality in the form of self-thinning and wind damages can cause substantial harm to forest stands. The thinning operations can reduce or increase the possibility of their occurrence. It could therefore be beneficial to produce an effective method of presenting this knowledge to not only forestry students and professionals, but also to a broader audience. In this paper, the author explores the possibility to use educational video games as such medium.

A PC video game about the topic called “To cut or not to cut” was created. In this game, the players are supposed to choose the trees for thinning in four different forest stands. According to the percentage of trees chosen and the specific condition of the stand, the forest will avoid the natural mortality or not. The players were, throughout the game, instructed and helped in the form of game dialogues.

Upon finishing the game, the players were asked to complete the survey, which checks the effectiveness of the game in the form of a knowledge quiz and opinion questions about the quality and educational value of the game.

The quiz answers showed that with higher completion rate of the game, a higher proportion of knowledge questions were answered correctly. The results of the opinion survey showed that the game was highly regarded as an educational tool by most players. Some of the players not connected to forestry expressed less engagement and understanding of the dialogues than other groups.

These findings show that educational video games about forestry topics could be beneficial and engaging. However, they should be correctly targeted and modified towards specific audiences, e.g. forestry professionals, people from related fields etc. The author explores the possibility of such modifications.

Keywords: educational video game, thinning, tree mortality, natural mortality, Norway spruce, self-thinning, wind damage

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1. Introduction

1.1 Thinning and natural mortality

Thinning is an important silvicultural practice, especially in even-aged forests. It is a form of controlling the stand density by cutting a portion of all the trees in the stand before they are ready for final felling. Performing thinning is used as a main tool for improving timber quality and regulating tree growth (Makinen 2004). However, the thinning can affect not only the economic value of the stand. This operation, if not done with enough precautions, can negatively change the forest's stability.

One of the challenges that forest owners face when choosing the appropriate thinning regime is to avoid natural mortality in their forests. As research shows, this type of mortality can be reduced with proper silvicultural management (Elfving 2010). On the contrary, improper thinning can increase the probability of the wind damage to the stands. This type of damage was observed after the Gudrun storm in Sweden in 2005, in which Valinger & Fridman (2011) found that the recently thinned stands were at increased risk of windthrow.

Wind affects each forest stand uniquely, depending on various stand characteristics. For example, the storm damage probability in stands is known to generally increase with stand height (Valinger & Fridman 2011). Therefore, it is often advised to thin stands at a lower height. Wind damage also increases with thinning intensity, with experiments showing that the heaviest treatments had the most damaged trees, especially a few years directly after the operation (Valinger & Pettersson 1996). However, the stands with light thinning and thinned at a young age can suffer from wind damage, even if this risk is much lower. Therefore, it could be proposed that a potential way to avoid wind damage is to avoid thinning completely (Wallentin & Nilsson 2014).

Conversely, unthinned stands can suffer greatly from other types of damage such as snow damage and competition-induced damage. The latter is often described with the "self-thinning rule", which shows how mortality in even-aged stands is affected by competition, exacerbated by high density (Westoby 1984). This rule

can be shown as a relationship between plant size and stand density. While diameter of the trees is increasing, the number of trees in the stand is decreasing, following a line called the self-thinning line. The earliest description of this rule was made by Reinneke (1933), and it models the relation between number of trees and quadratic mean diameter in even-aged monocultures (Rivoire & Le Moguedec 2012). Later research has shown that this relationship varies based on specie (Hynynen 1993), (Pretzsch & Biber 2005). Figure 1 is showing this relationship between quadratic mean diameter and number of stems for different species, both measured and with linear representation of Reineke's rule.

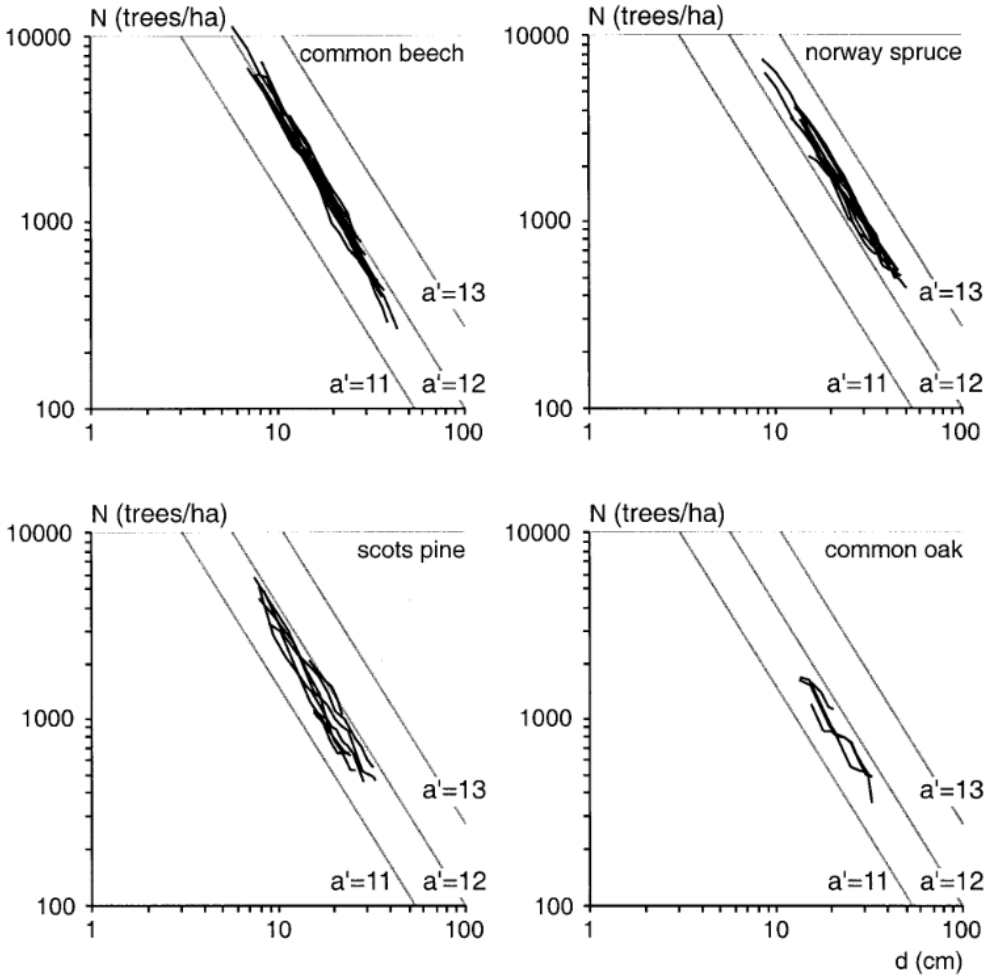

*Figure 1. Example of self-thinning lines for different tree species, where N – number of trees per ha, d – quadratic mean diameter.Straight lines variants ln(N) = a' - 1.605 * ln(d) from the equation following Reinneke's rule, whereas non-linear traces are representing measured N to d relationship in untreated, fully stocked stands (from Pretzsch & Biber 2005).*

The self-thinning rule is commonly used as a basis for growth models for assessing the need for thinning. Research shows that the highest occurrence of self-thinned trees is in unthinned stands, compared to thinned ones (Nilsson et al. 2010).

Therefore, one of the most common intentions behind thinning is to avoid self-thinning, and the consequential loss of income (Wallentin 2007).

1.2 Social aspects of forest management

The International Union of Forest Research Organizations (IUFRO) All-Division 6 Meeting at the 125th Anniversary Congress showcased the increasing importance of social issues within the forestry sector (*On Social Aspects of Forests and Forestry* 2017). This is reflected in the work of the IUFRO Division 6, which focuses on a wide range of relevant social aspects (e.g. forest conflict management, forest education, etc.) (IUFRO n.d.).

However, the human-forest relationship is still not a well-defined matter in scientific literature (Häyrinen & Pynnönen 2020). A general way to describe human connections to nature has been varying in the several studies that have been conducted in recent years. To characterize connection to nature, terms like "connectedness to nature" or "nature relatedness" were used (ibid.). When describing pro-environmental behaviour, scientific articles have presented a wide variety of terms such as: "sustainable behaviour", "ecological consumption", "environmentally friendly" or "conservation behaviour" (ibid.). The majority of the research done on this matter has been conducted in developed countries, which is consistent with raised environmental awareness among the population (ibid.). The studies have shown the existence of link between human connection to nature and pro-environmental behaviour, i.e. taking "protective actions toward the environment" (*Pro-Environmental Behavior* 2020). This led researchers to believe that increasing "connectedness to nature" can help with creating more pro-environmental society (Häyrinen & Pynnönen 2020). This can be especially prevalent in heavily forested countries, such as Sweden, which can offer many ways for people to be more related with nature (ibid.).

Raised awareness for environmental issues without increased education may lead to conflicts between nature conservation and forest management. This conflict may be strengthened by the idealized and romanticized view of nature induced by alienation from the natural environment (Zabel & Kollender 2014). In addition, certain forms of mental attachment to the land can led to unfounded emotional and psychological ownership (Matilainen et al. 2017). This psychological attachment may occur in contrast with legal ownership of forests and the stakeholders involved in performing forestry activities. This may lead to increased enthusiasm to protect natural resources such as forests (Preston & Gelman 2020). Certain forestry practices, such as thinnings and harvests, can pose as a threat to such personal attachments.

1.3 Forest education and educational games

There is a pressing need for soothing the aforementioned conflicts. One way to do so is to educate all the involved sides with unbiased, professionally prepared tools adapted for different needs. The ecological, environmental and, more specifically, forestry education can and should be used in such way. However, studies show that certain aspects of forestry education are neglected – namely, social sciences education. The areas that should be more focused on in professional forestry education are conflict management, human dimensions in natural resource management and effective communication (Sample et al. 2015).

Another important part of forest education is the field experiences, in which students can have hands-on approach on specific forestry management aspects. This way of teaching is highly regarded by students from many countries and continents (Arevalo et al. 2012). However, it can be often a tough task to conduct fieldwork in many remote places due to costs, time constraints and other physical difficulties. To mitigate it, researchers developed a virtual forest for walk-through simulation, created using omnidirectional images (Abe et al. 2005). This form of education was highly evaluated by the participants, among other things, for enjoyment and educational value.

This research proves that there can be use for combining virtual media and forest education. One of the ways this combination can be achieved is through educational video games. A systematic literature review of studies that integrated video games in the curricula of teaching system from preschool to college stated that games can be used as an effective tool in almost all disciplines, proving to be exceptionally useful in foreign languages and science topics (Martinez et al. 2022). Successful games describing scientific topics have been developed by 4ga Studios (Figure 2) and are being used in American schools to teach various concepts (4ga Studios 2023). However, there is still a need for more studies on the value of educational video games, particularly in the field of environmental sciences (Martinez et al. 2022).

Figure 2 Screenshots from an educational video game "Invasive Frogs" co- developed by Author at 4ga Studios, which describes topics about ecosystem stability, invasive species and interactions in the ecosystem to elementary school students (4ga Studios 2023)

1.4 Educational games in other fields

There are many examples of successful (and moderately successful) uses of video games in education. A physics educational game has been evaluated as a good tool both to teach the subject and to assess knowledge (Shute et al. 2021). Study for first and second grade students assessed that games have improved the classroom dynamics (Rosas et al. 2003). As suggested by the study on language learning games, they could be especially beneficial with the teacher's guidance (Newcombe & Brick 2017). Educational video games have been created in various scientific topics such as chemistry (Nantakaew & Srisawasdi 2014), space research (Sedláček et al. 2019), mechanical engineering (Coller & Scott 2009) and urban hydrology (D'Artista & Hellweger 2007). Even the act of creating games in itself can be used as a form of teaching in schools (Seralidou & Douligeris 2020). The games can be used as a motivation tool in remote settings, when meeting in person is not possible (Seralidou & Douligeris 2021). In addition, using the educational game as a teaching approach could improve higher-order thinking skills in science subjects. (Awang Noh et al. 2021). However, difficulties implementing games (such as technological problems or lack of proper equipment) in classrooms make them less widespread, despite the learning and motivational effects (Papadakis 2018). Games

that are not educational by design can also have slight positive cognitive effects (Squire et al. 2023). The more useful feature of this type of casual game, however, could be the effect on creating engagement with other forms of learning. A study on using casual games to motivate workers to use the learning platform suggests that it not only can increase motivation and engagement for workplace training, but also helps in learning through using the platform (Kapp et al. 2020).

1.5 Research aim

The aim of this thesis is to analyse how using educational video games in forestry education could increase the knowledge of the players while simultaneously being a more engaging way of learning than traditional methods. The survey amongst the players is aiming to provide results to the research questions:

- Is the video game a suitable tool to introduce a non-forester to the forestry issues and concepts?
- Would this video game be used as an effective tool during forestry education?
- Does the game have differing educational impact on players from different (education, professional, cultural) backgrounds?

2. Methods

2.1 Game creation process

In order to investigate the usefulness of video games in explaining forestry issues, a game "To cut or not to cut" about the consequences of different thinning regimes on the natural mortality of forest stands with a built-in survey was programmed. After finishing the creation cycle, the game was released for windows computers and made available for free at: https://wilkobyl.itch.io/to-cut-or-not-to-cut, where it is publicly accessible.

2.1.1 Game engine and tools

Unity 3D game engine

A game engine is a software that enables the creation of video games. The goal of a video game engine is to extract common features of video games and allow the reuse of code and game assets (Andrade 2015). To do this, most game engines implement the following functionalities: a rendering engine for 3D or 2D graphics, input management, game loop for calculating game events, physics engine, sound, animation for 2D sprites and 3D models, and scripting (ibid.).

The game created for this thesis was developed using Unity 3D game engine. Unity is a cross- platform game engine, designed for creating 2D and 3D games, film and animation projects and industry applications to turn CAD and 3D data into immersive apps (Unity 2023). It allows developers to create games and simulations for computers, virtual reality, mobile and console apps.

Scripting and Integrated Development Environment (IDE)

Integrated Development Environment (IDE) is software that allows developers to create code in one place. The IDE used during the game development was Visual Studio 2022 (Microsoft 2023). This software was used for writing and editing

scripts (such as instructions for the program) with game logic and mechanics using C#, an object-oriented programming language that is used in Unity Engine.

Other tools

The game was developed with the help of a version control system integrated within Unity Engine: Unity Version Control, formerly called Plastic SCM (Unity Technologies 2023). This system helps with managing changes within the game, allowing tracking, reverting, and merging updates.

Other tools used during the creation of the game was a vector graphics editor and generative AI tool for creating 2D art (e.g., the characters in the game and graphics used on the website for downloading the game).

During the game development cycle, Unity Asset Store plugins were used to speed up creation of certain game elements such as forming a realistic looking trees and making a dialogue system.

2.1.2 Virtual forest stands creation

Trees were modelled using procedural vegetation creation tools that are built into Unity Engine. The tool was used to create different visual variations of the trees. As the Norway spruce (*Picea abies* (L.) Karst.) is known for its wind damage susceptibility and to simplify the gameplay mechanics, only this species' trees were constructed and used in the game. Two height variants of the trees were created: "smaller" (12 meters) and "higher" (22 meters). Next, the diameter of each tree was adjusted to represent real trees, especially considering realistic diameter: height ratios. To do this, results and graphs from individual tree height growth models for Norway spruce were used (Sharma & Brunner 2017). A special component called "collider" was added to each individual tree, enabling physical collision and interaction from the player. The cylindrical shape of this component (invisible during gameplay) was adjusted to fit the tree trunk at the player's height and was used to determine the diameter of the tree (Figure 3). The diameter of the fitting collider was taken as the diameter of the tree. Additionally, the C# script was attached to each individual tree to calculate the basal area. For more varying look, several visual variants of each tree were created, e.g. with alternating branches look.

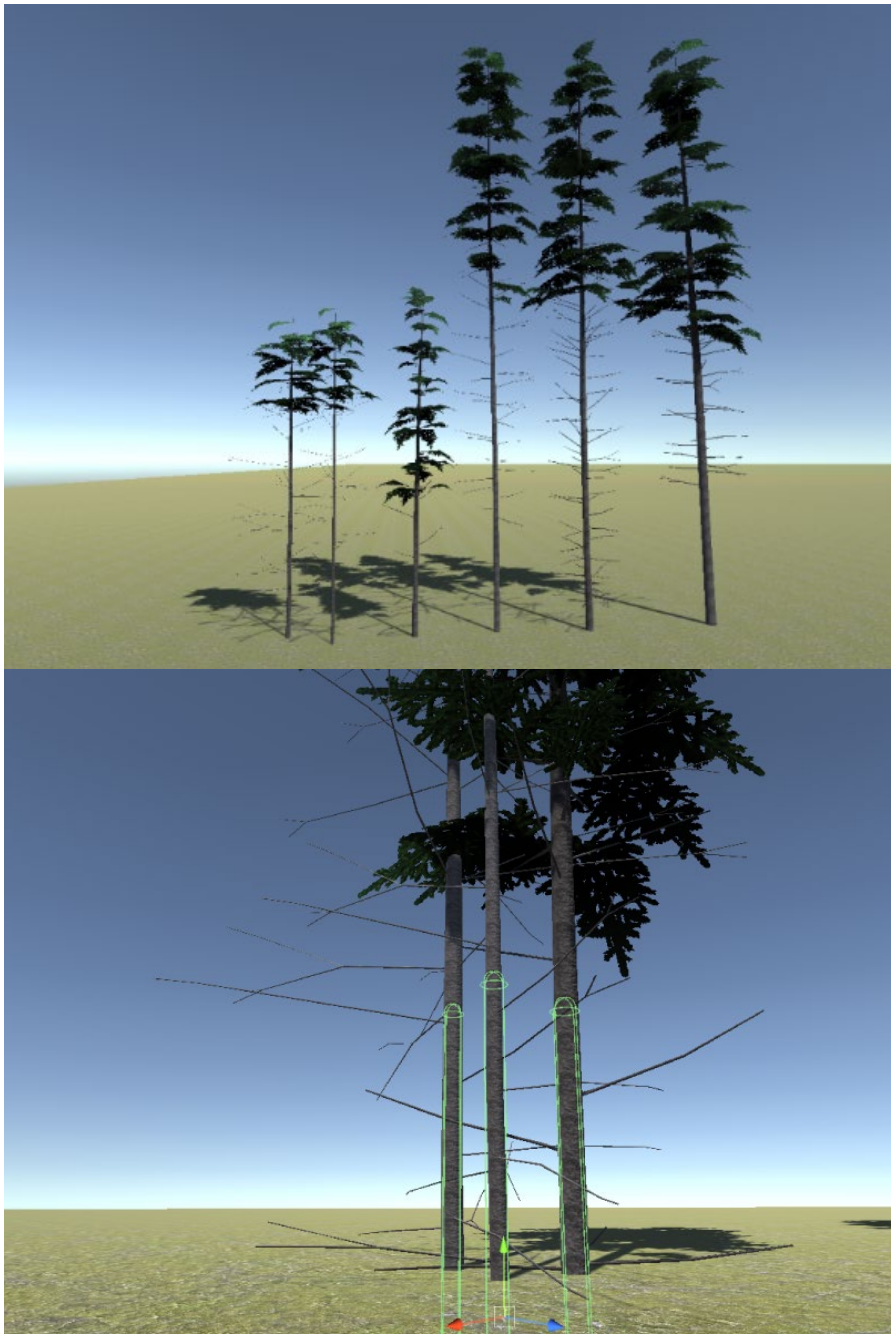

Figure 3 Screenshots from the development process of creating trees. First picture shows few of the models used in the game, with different height and diameter and visual. Second picture shows the Unity Engine components - colliders, with which the player is interacting.

After each height, diameter and visual variant of the trees were modelled, the full stand was prepared. For gameplay purposes, and to limit tedious walking and manual interaction with too many trees, each stand area was set to 0.1 hectares. In total, four different stands were prepared, serving different educational purposes. Each of the stands was an even-aged monoculture of Norway spruce. For each height variant of the tree, two stands were prepared (i.e., two smaller stands and two higher stands) (Figure 4). Each variant of the stand differed in stand basal area

and number of trees. A C# script was written to determine the basal area of the stand at two moments: before and after thinning.

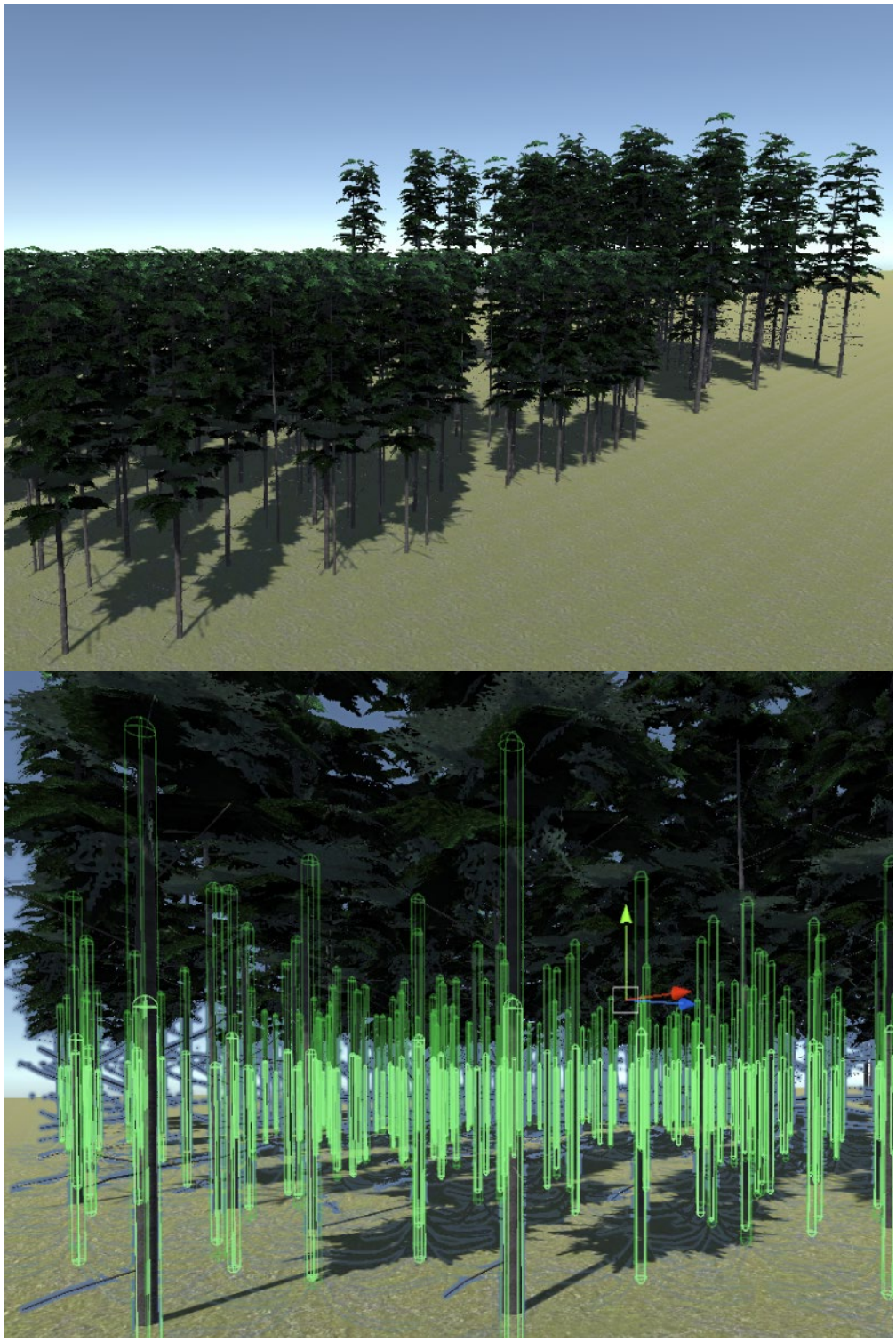

Figure 4 Screenshots from development of stands: a comparison of height between different variants and a stand with visible colliders.

2.1.3 Gameplay Loop

"Gameplay loop" is the term used to describe the actions of the player thorough the whole game. In the scope of this game, the gameplay loop is encompassing all the actions and events from the start of the game until the end (Figure 5).

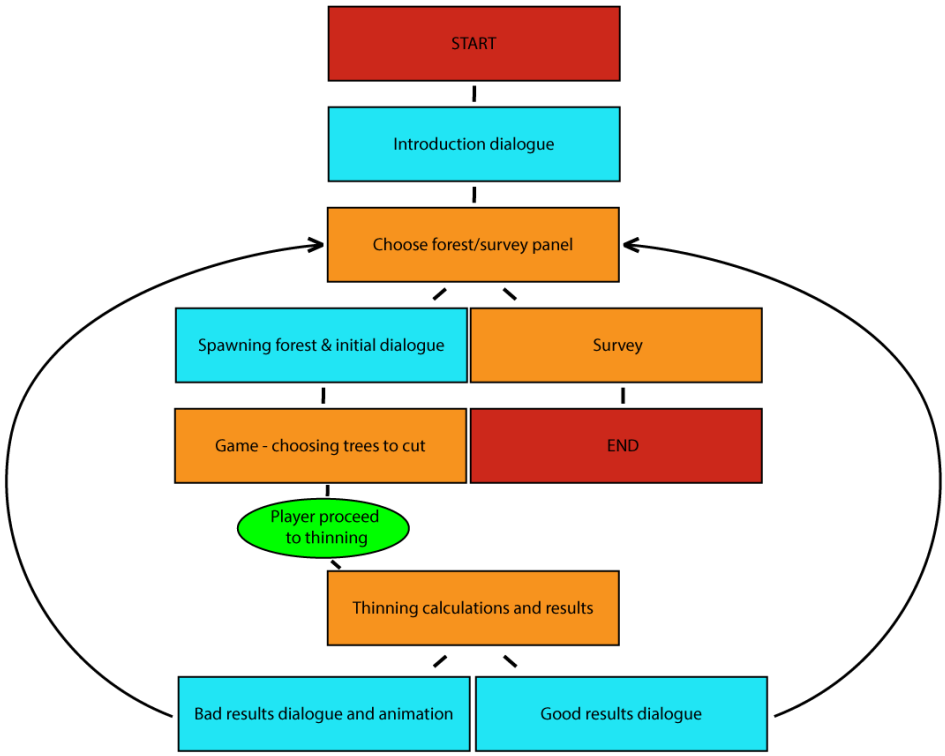

Figure 5 Illustration showing the gameplay loop from starting the game to ending after completing survey. Blue colour steps indicate dialogues parts, orange steps – player choices, core gameplay and game events, green step – singular player action.

After launching the game and choosing the "Start Game" option from the main menu, the player is presented with an empty field and introduction dialogue with the narrator/game advisor. During this dialogue, the player is introduced to the game rules and conditions to win. In addition, by choosing certain answer options, the player can be presented with a more detailed introduction in which thinning and its implications to the forest are explained. Dialogues in the game are presented in written form.

When the initial dialogue ends, the "Choose Stand/Exit to Survey" panel is shown (Figure 6). On this stage, the player is given the possibility to choose which stand he/she wants to play first, while the survey button starts the questionnaire panels.

Figure 6 The "Choose Stand/Exit to Survey" panel, in-game screenshot.

Upon making the choice, a respective stand spawns in the game world and another dialogue with the stand owner initiates. The conversation introduces the player to the conditions of the stand and the forest owner's plans for thinning. Using different dialogue options, the player can present his/her opinion on how to conduct the thinning operation.

After finishing the stand dialogue, the core gameplay begins. The player now can freely inspect the forest from first-person perspective. Using arrows or WASD keys, the player can walk around the forest. Approaching a tree enables a popup window with the message "Press E to mark this tree" (Figure 7). Pressing the mentioned button changes the tree colour to red and sets its status to "marked", with no possibility to reverse the action. When the player is ready to proceed with the thinning, they must press the key "P" to advance to the next stage. Throughout the marking stage, the "H" key prompts a help window (called the "Thinning Almanac" in-game) where the player can learn more about different thinning definitions and practices.

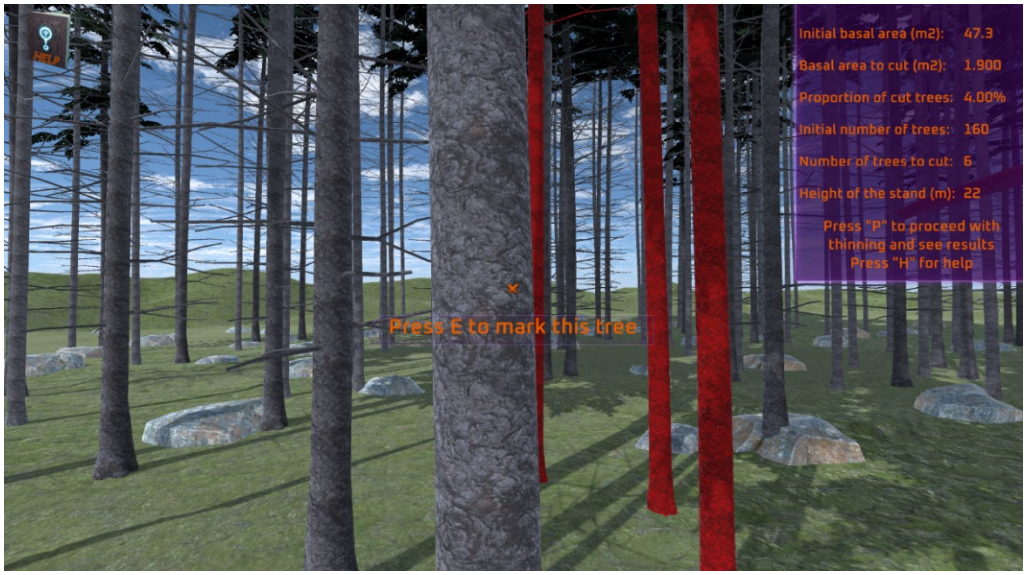

Figure 7 Marking stage of the game, with visible help button, mark tree popup and statistics window, in-game screenshot.

After ending the marking stage, the marked trees are removed from the stand and the game checks whether the player performed a successful or an unsuccessful thinning (see Winning conditions in Game mechanics section). Depending on the result, either winning or losing dialogue sequence is prompted, where the narrator explains why the thinning operation was performed correctly or not. In addition, certain animations and sounds indicating the type of losing conditions (i.e. self-thinning or wind damage) starts before the dialogue initiation.

Finishing the dialogue sequence leads the player back to the "Choose Stand/Exit to Survey" panel. At this stage, the player can decide whether they want to repeat the same stand, change the stand, or exit directly to the survey.

When selecting survey button, the player is presented with six consecutive survey panels (see Questionnaire in Survey section). On the sixth panel, upon selecting the submit button, the game stops running.

2.1.4 Game mechanics

Calculating basal area

Two scripts written in C# were used to calculate basal area, one for the stand basal area and another for the individual trees. When the game spawns the stand that the player has chosen, it performs two actions: First, a script for each tree in the stand calculates individual basal area (Formula 1), and then the script attached to the stand component summed each individual basal area to calculate the total stand basal area before thinning, referred to as "initial basal area" within the game.

$$ba = 0.00007854\ x\ dbh^2 \quad (1)$$

Where ba stands for basal area of singular tree in square meters, and dbh is a diameter at breast height in centimetres, derived from diameter of the tree model (*Basal Area Calculator* 2024).

During gameplay, when the player marks a tree to cut, the individual basal area is added to the batch of other selected trees. The total basal area of this batch is called "basal area to cut". In addition, the game calculates the ratio of the basal area of selected trees to the initial basal area, which is presented in percent, and called "proportion of cut trees".

These values describing stand characteristics and chosen management are displayed in the top-right corner of the screen during gameplay (Figure 8).

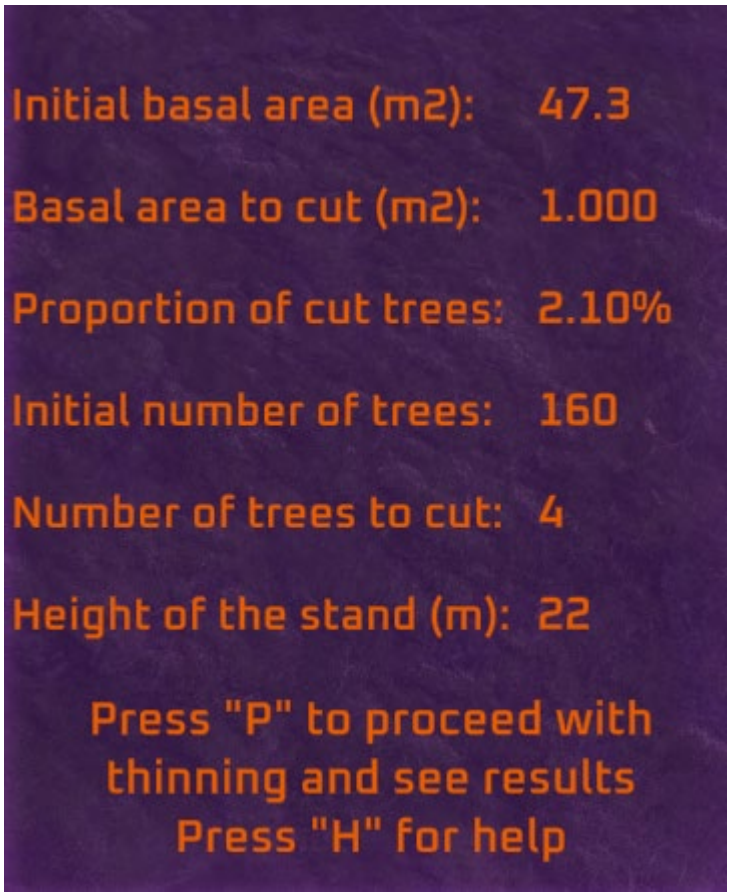

Figure 8 Statistics panel showing data from one of the stands after selecting few trees to be cut, fragment of an in-game screenshot. Note that proportion of cut trees is calculated from basal area not number of trees.

Self-thinning rule

Self-thinning is one of the two natural mortality conditions that the game checks whether it occurred. One of the prepared stands was specifically created to be susceptible to this type of damage. In order to avoid it, the player must correctly thin the stand, i.e. with enough intensity.

To check this, the game is simulating stand development over ten years and then calculating a self-thinning line to see whether a self-thinning occurred. To calculate the line, a modified version of Reineke's rule was used (Formula 2).

$$N = a * QMD^b \quad (2)$$

In this equation N is a maximal number of trees in the stand, a and b are constants and QMD is quadratic mean diameter (Pretzsch & Biber 2005). The a constant value of 87,480 and b constant value of -1.301 were derived from the self-thinning models for even-aged stands of *Picea abies* (Hynynen 1993). The quadratic mean diameter was calculated with the following equation (Formula 3).

$$QMD = \sqrt{(\sum d_i^2)/N} \quad (3)$$

The variables used in this equation were the sum of the diameters of each tree in the stand d_i and total number of the trees N (Curtis & Marshall 2000).

For the simplicity of calculations and because of overall similarities between stands, the mean annual increment (MAI) of the quadratic mean diameter was set to 0.2 cm/year, which was estimated from age-independent diameter increment model (Ciceu et al. 2022). This value served as a simulation for the basal area growth used later for calculating whether self-thinning occurred in the stand.

The procedure of self-thinning calculations in game is as follows: at first (before the player starts the tree marking procedure), the game calculates the initial quadratic mean diameter of the stand and with the modified Reineke's rule, it sets the current maximum possible number of trees. After the player completes the marking procedure and starts thinning, the game simulates the growth of the stand for 10 years by increasing the quadratic mean diameter with the annual increment (Formula 4).

$$QMD_{i+y} = QMD_i + (MAI * y) \quad (4)$$

In this equation, y is years and MAI is mean annual increment. When the QMD in ten years is calculated, the game checks for the occurrence of self-thinning. This is done by using the new QMD in the Reineke's rule equation and determining the current maximum possible number of trees in the stand (N_{max}). At this point, the game checks for condition: if the maximum possible number of trees is greater than

number of trees left after thinning. If the condition is true, then self-thinning is not occurring. If the condition is false, the game event of self-thinning occurred, in which trees "disappear", i.e. get self-thinned following the Formula 5 equation:

$$N_{self-thinned} = N_{left\ after\ thinning} - N_{max} \quad (5)$$

Wind damages

Another cause of natural mortality that is present in the game is that from wind damages. To simulate windthrow affecting the forest, the game considers the height of the stand and the number of trees the player has selected to be thinned.

To simulate this damage, multiple descriptions of wind damage in the forest were taken into consideration. These examples included research showing linear relationship between intensity of thinning and the percentage of damaged trees (Wallentin & Nilsson 2014). This finding was applied to all the stands in-game. On top of that, the findings from analysing the Gudrun storm (Valinger & Fridman 2011) about the increase of the windthrow probability with stand height was also considered.

One of the stands was tailored to represent the effect of the thinning, called "Inherited and neglected" in-game. It is a high (22 meters) stand which is described as poorly managed, i.e. too many trees are left. However, if the player decides to thin the stand, he will cross the threshold and "cause" the windthrow to occur (as seen in Figure 9).

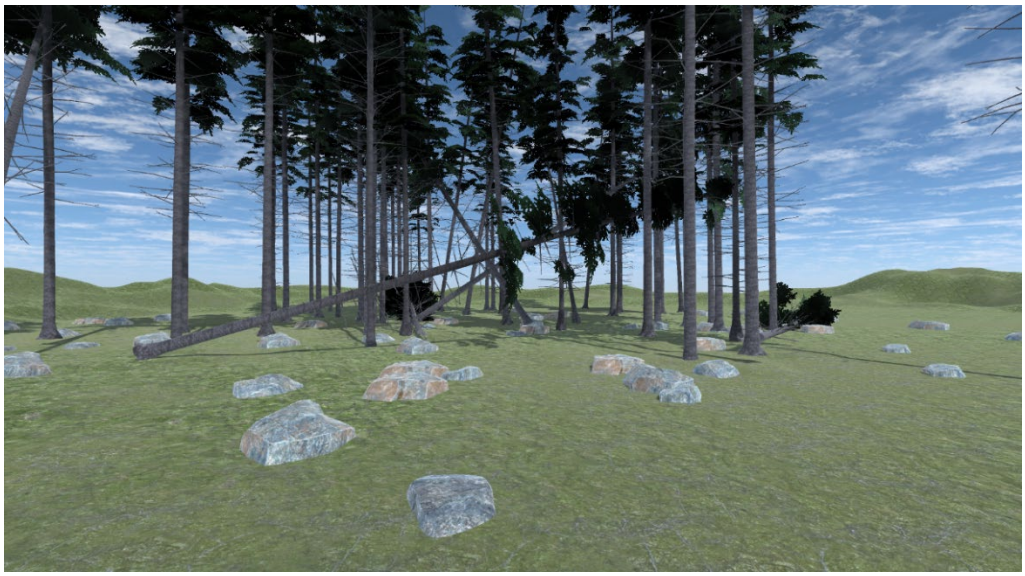

Figure 9 Windthrow animation, in-game screenshot.

To achieve this result, the threshold for the windthrow in high stands was set to 10% of basal area thinned. For low 12 meters stands, the threshold was set to 60%

removal to ensure that the general message (high intensity of thinning increases probability of windthrow for Norway spruce) is conveyed effectively.

Winning conditions

After the player finishes the tree selection process, the game checks for correctness of player's choice. To succeed, the selection must match the criteria for both wind damages and self-thinning. If both conditions are fulfilled, the game executes the good/winning dialogue sequence corresponding to the selected stand. If at least one of the conditions is not met, the bad/losing dialogue sequence starts.

Each of the stands has different conditions to fulfil. First stand called "Never enough spruces" has a small stand with very high density. Therefore, to succeed the player must thin it with sufficient intensity to avoid the self-thinning.

Second stand, "Newly bought land" has same height, but much lower number of trees. Here, the player wins in most cases, apart from thinning above 60%. In such case, a windthrow would occur and the player would be notified about the consequences of high thinning to the probability of wind damage.

In both high stands, called "Inherited and neglected" and "Fast money needed" the losing factor is windthrow and crossing the low thinning threshold of 10% removal. The difference between these stands is in the number of trees – the latter is less dense. In both scenarios, player is encouraged to not thin the stands – this is addressed in dialogues after selection.

Built-in survey

After completing any of the stands, the player has the possibility to repeat the same stand, attempt a different stand, or finish the game and proceed to survey questions. The questionnaire answers are anonymously sent using Unity Web Services to a spreadsheet for further analysis.

2.2 Survey

2.2.1 Questionnaire

The survey questions were divided into six thematic groups. Each of the groups was presented individually one after another to the respondents. The answers to all but two questions were prepared beforehand to get more structured answers.

The first group consisted of introductory questions that allowed for further grouping of the responses. Respondents were asked about their country, age group

and if they regularly play video games. Next, the respondents were asked about their educational and professional background, for classification into three background-related groups: forestry background, related field background and other backgrounds. The last questions in this group allowed for sorting the responses based on the game completion rate, i.e., how many plays(stands) they finished and if they repeated any of them. These questions allowed filtering of responses from non-participants (i.e. if the player answered the question: "How many stands did you complete?" with "0").

The next section of the survey was a quiz covering topics presented in the game. Each of the five questions had one correct answer and two wrong answers to choose from. The questions can be found in the Appendix: Table 1.

The third group of questions aimed to get the players' opinion about the educational values of the game. The first question checks whether the players used the information presented in the game to answer questions from the quiz group, or rather have referred to their previous knowledge. The second question was aimed to provide a more detailed, open-ended type of answer about the educational value of the game.

Both fourth and fifth group of questions covered respondent opinion about the clarity of the message contained within the game (fourth group), the overall enjoyment and engagement in gameplay as well as the thoughts on using this game as a teaching tool (fifth group). The latter group used numeric scale from 1 (the worst) to 4 (the best) to indicate the players opinion.

The last group consisted of one open ended question that offered a possibility to add individual thoughts and suggestions about the game in general.

2.2.2 Respondents

For recruiting respondents, the game was published online at a public site commonly used for game publication (*itch.io* 2024) on November 2023 and made publicly available (Guzik 2023). The game was advertised on places such as Swedish forestry forum website (Skogsforum.se 2024) skogsforum.se and various international student groups to attain more players. The responses were gathered over a span of four months and then subjected for further analysis.

2.2.3 Data Analysis

The analysis method was chosen based on pre-existing studies on educational video games (Muntean et al. 2017; Go et al. 2022). Two separate topics were analysed: (1) the players' engagement and opinions about the game and (2) player's knowledge.

The responses were categorized into three groups based on professional background: “forestry background”, “related background” and “other”. The first group consisted of respondents who were either studying or working in the forestry field (both commercial and academic). Within the second group, the player must have been either studying or working in a forestry-adjacent field (i.e. agriculture, biology etc.). The third group consisted of respondents who, at any time, were not students and/or working in those fields. ANOVA tests were conducted to determine the significance of group answers.

In order to measure the educational effectiveness of the game, the quiz responses from section two of the survey (Appendix: Table 1) were analysed. The answers were grouped based on the game completion rate (i.e. how many levels have the player accomplished). ANOVA test was conducted to determine the significance of differences.

3. Results

3.1 Data structure

The game was downloaded 46 times during the data-gathering period. In total, 39 players who downloaded the game have also responded to the survey. Out of this group, 3 responses were omitted for not having at least one level played.

The players were from eleven different countries, with the highest number of participants coming from Poland (11) and Sweden (5). Other respondents came from Lithuania, Ukraine and Germany (three from each country), Croatia, Hungary and France (two from each country) and one participant from Albania, Austria, Italy and Kazakhstan. Regarding the professional background, fourteen respondents were assigned to "forestry background" group (also referred to as "forest" group), ten of the respondents to "related background" (referred to as "related"), and twelve – "other".

Most of the respondents were people below twenty-eight years old: one respondent below eighteen years old, eight from the range 18-23 and nineteen between 23-28. Seven people assigned themselves to the 28-33 group, and only one person was from the range 33-40. There were no older respondents. All respondents have been studying previously (16) or have already finished the studies (20). Vast majority of the respondents have stated that they are playing video games (23).

3.2 Players' attitude towards the game

The first question, "Was the aim of this game (show how thinning affects a natural mortality caused by wind damages and self-thinning in the spruce forests) clearly visible from the gameplay?" was answered positively (no negative answers) by all professional background group (Figure 10). The answer "Yes, very clearly" was chosen the most by "forest" group (64%), whereas "Yes, quite visible" was most frequently chosen within the "other" group (58%). The p-value derived from the ANOVA test was determined to be 0.53.

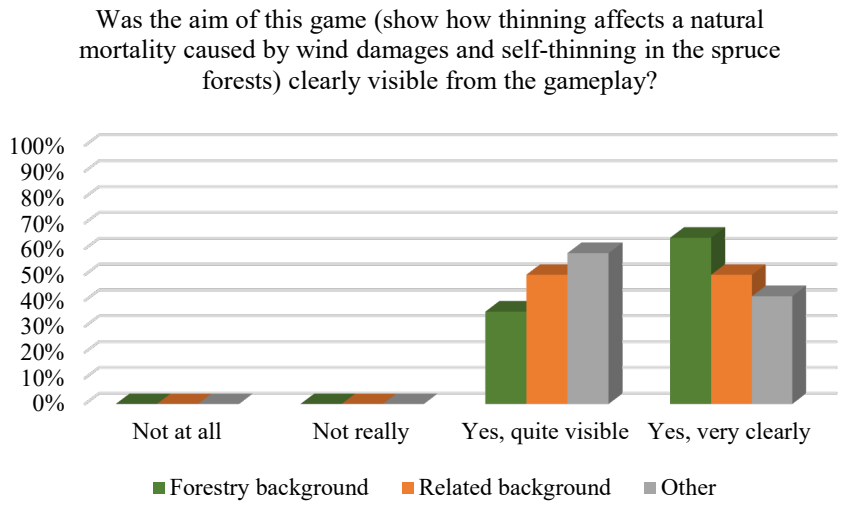

Figure 10 Answers to the first opinion question divided into professional groups.

The second question, "Were the dialogues understandable for non-forestry audience?" was most positively answered by "related" group, with 80% of responses saying the dialogues were very understandable (Figure 11). The least positive response to this question was given by the "forest" group, with 29% of the players choosing the "Yes, very understandable" answer, 64% "Yes, quite understandable" and 7% stating the language was not understandable for non-forestry audience. The p-value was determined to be 0.06.

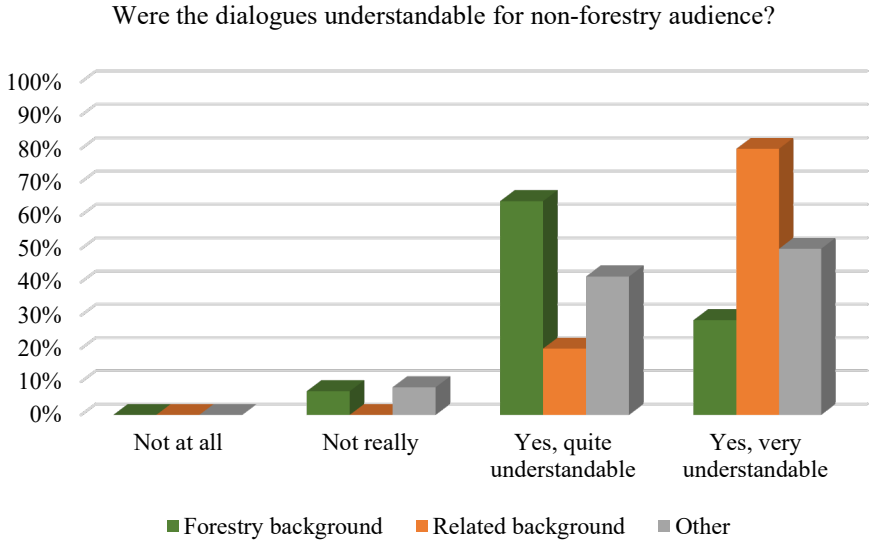

Figure 11 Answers to the second opinion question divided into professional groups.

The majority of the respondents considered the dialogues to be of appropriate length (see Figure 12). The “other” group was most likely to consider the dialogues to be too long (42%). No respondent recognized the dialogues as too short.

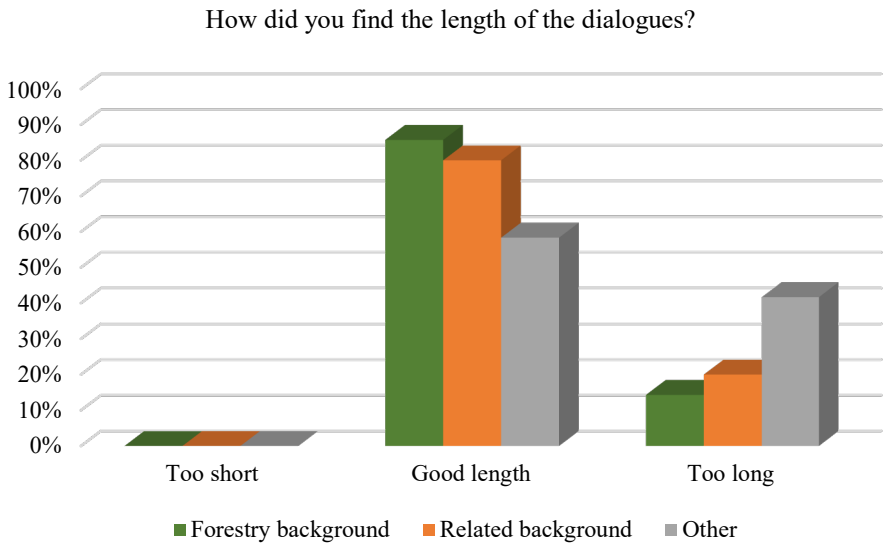

Figure 12 Answers to the third opinion question divided into professional groups.

The engagement of the players was measured on a scale from 1 to 4 with the question “Did you find this game engaging?”. Majority of the respondents found the game to be moderately engaging (see Figure 13). “Related” group declared highest engagement rate, with 40% rating the game 4 out of 4 and 40% - 3 out of 4. Only respondents from “other” group rated the game to be not engaging at all (level 1 out of 4), and none of the players from this group rated it highly engaging (level 4 out of 4). Overall, 36% of the “forest” group found the game rather not engaging (level 2 out of 4). The p-value was determined to be 0.20.

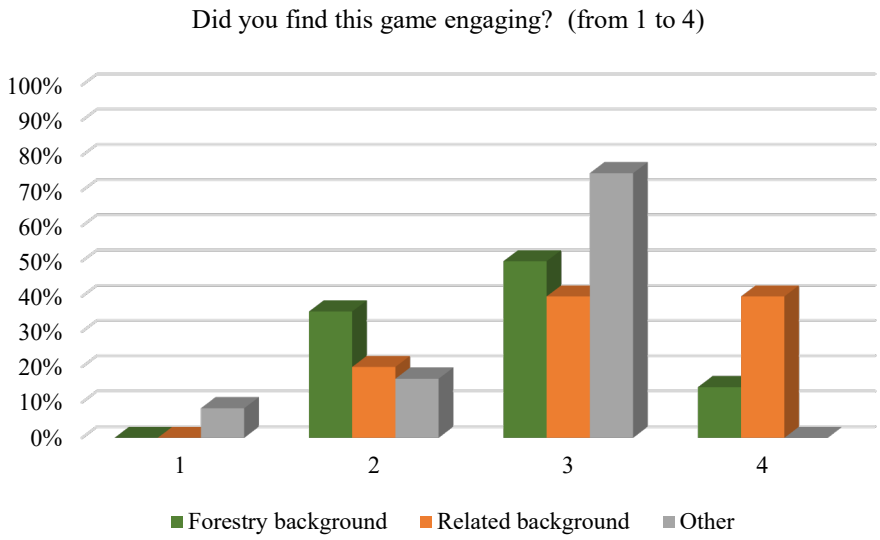

Figure 13 Answers to the fourth opinion question divided into professional groups.

Figure 14 shows responses to the question "Do you think this type of presenting knowledge (video game) is better than more traditional lecture on the topic?". Only one respondent (8%) from the "other" group strongly disagreed with the thesis presented in the question. Majority of the responses (respectively, 72% of "forest" group, 80% of "related" and 75% of "other") found the game to be either a slightly or much better way of presenting knowledge than traditional lecture. The p-value was determined to be 0.72.

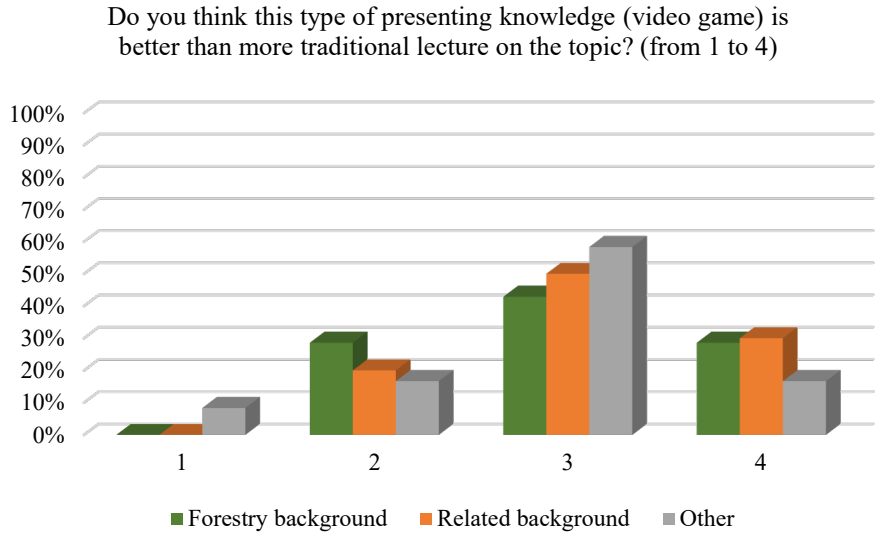

Figure 14 Answers to the fifth opinion question divided into professional groups.

The potential educational benefits for non-forestry audience were measured with a question “Do you think people not connected to forestry can benefit from this way of presenting knowledge?”. The vast majority (80%) of “related” group respondents found the game highly beneficial for presenting knowledge to non-foresters. One quarter of the respondents from “other” group highly disregarded the benefits to people not connected to forestry (choosing answer 1 out of 4) (Figure 15). The p-value was determined to be 0.13.

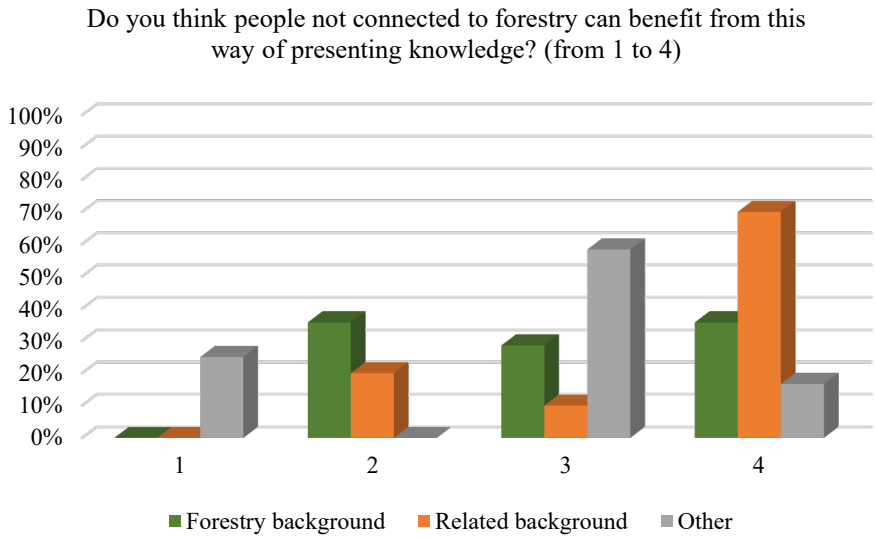

Figure 15 Answers to the sixth opinion question divided into professional groups.

Retention of the knowledge was addressed with the question “Do you think you will remember the knowledge for longer than from traditional lectures?”. The distinction between the responses from the “other” group and rest of the respondents is clearly visible (see Figure 16). 64% of the “other” group predicts that they will forget the presented knowledge much faster than after traditional lecture. On the other hand, all the players from “related” group anticipate that the knowledge retention will be longer (rated 3 out of 4). The p-value was determined to be 0.17.

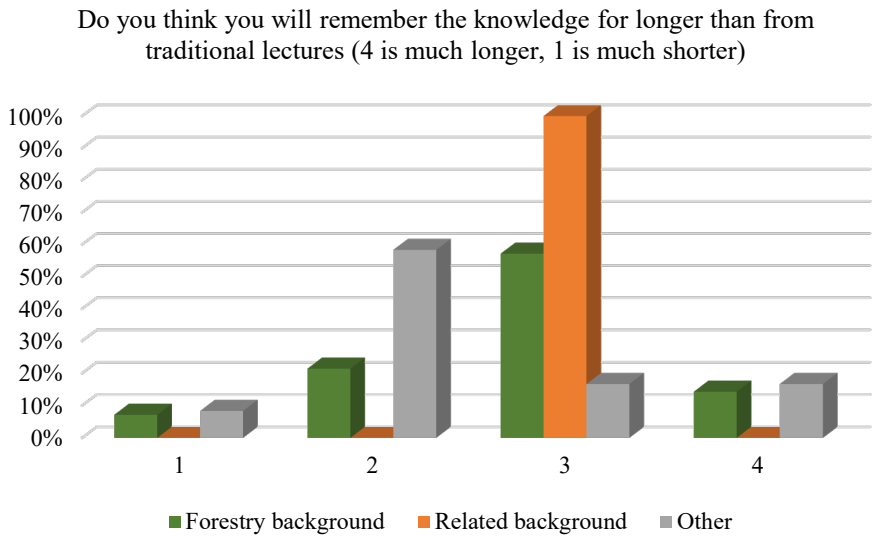

Figure 16 Answers to the seventh opinion question divided into professional groups.

Last question, "Would you see a benefit of this game if the students would play the game during lessons in their native language?" received positive responses (Figure 17). 57% of "forest" group, 80% of "related" and 50% of "other" answered this question with highest possible rating (4 out of 4). 17% of the players from "other" group find the game not suitable at all for classroom teaching, whereas around one-third of the "forest" group see only few benefits of it (2 out of 4). The p-value was determined to be 0.23.

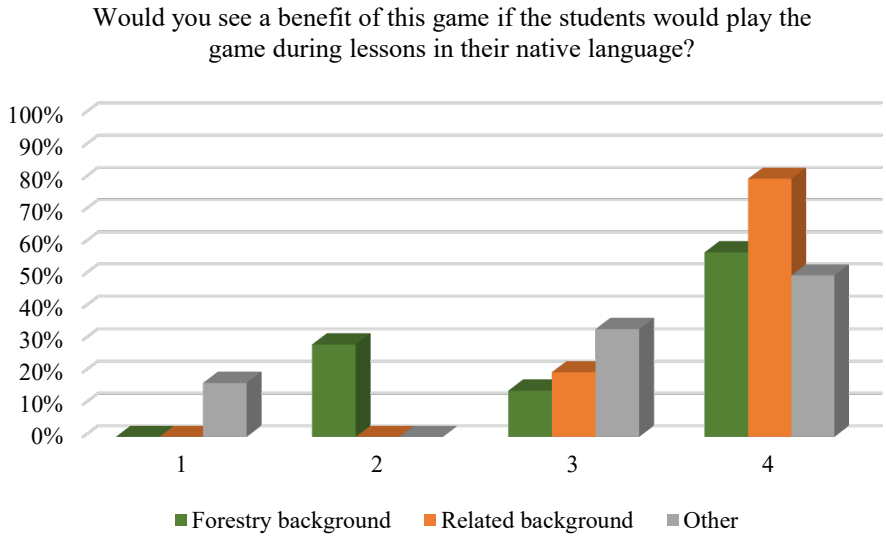

Figure 17 Answers to the eighth opinion question divided into professional groups.

3.3 Quiz results in relation to the game completion rate

As the exit to survey was available at any moment, the game completion rate (i.e. amount of stands/levels that a particular player has finished) varied significantly. Threeof the survey respondents indicated finishing zero levels and therefore their survey answers were not included. The rest on the players finished respectively: one stand/level (5 players), two stands (10), three stands (10) and all four stands (11).

Figure 18 presents the relation of finished stands and the amount of correct responses to the quiz questions. The highest difference in score can be seen on the diminishing number of 1/5 correct answer count. Starting with 80% of 1/5 correct answers coming from players that finished only one stand, the number of very low quiz results decreased with each additional stand finished by the player, up to 0% with four stands played. Similarly, players that finished only one stand did not answer correctly to more than 3 out of 5 questions. The good and very good results (4/5 and 5/5 correct answers) were achieved those players that have played more than one stand.

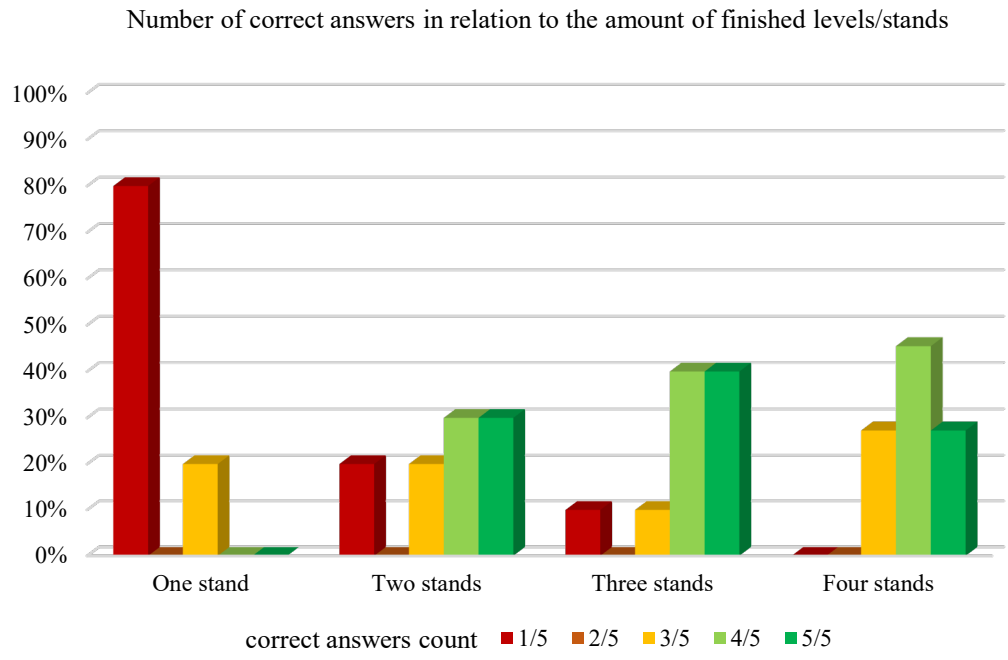

Figure 18 Relation between number of stands finished by the player and the number of correct answers.

3.4 Additional comments from the respondents

Encouraged by the free comment question, thirteen players left additional suggestions and/or opinions about the game. The comments presented in Appendix 2: Table 2 are left with original writing and thematically grouped. Some opinions were split into smaller portions to match the thematic group content.

Few of the comments expressed positive attitude towards the game and its usefulness in education. Some of the positive comments also included technical or design issues within the game.

Other players added suggestions how to improve the game further, like adding tree species variety, making the terrain less monotonous and adding a cost/income system. Two of the players reported lacking a more comprehensive evaluation system of the performed thinning. Players also reported issues with existing features, such as camera movement, lack of option to unmark the tree and walking speed/animation.

Some players expressed their discontent with tedious elements of the game. Another player (with forestry background) explained rating the lecture usefulness of the game as low and compared it with the field trips, rating them as more useful.

4. Discussion

4.1 Survey analysis

The survey analysis took the form of a modified playtest method with one survey immediately after finishing the game. This method of getting feedback from players gives insight of players' experiences and helps to elucidate specific issues in the game (Davis et al. 2005). It can also be helpful in receiving input on certain aspects that are characteristic to the type of game (which in this case are educational values). While this type of survey is very useful, it is not well established within the scientific community, as using pre-tests and post-tests is a more common approach (Girard et al. 2013). However, some of the studies researching educational video games have also used only post-test approach, e.g. the paper evaluating "Triage Trainer" incident triage training video game (Knight et al. 2010). For this game, using both pre-test and post-test could be beneficial in more accurately assessing the educational benefits of the game (e.g. having same quiz before and after playing the game). This issue was adressed by asking the participants about the source of the knowledge (the game itself or previous experiences) that was used to answer the questions. Another reason for using only post-test approach was the fact that performing two tests could also decrease the engagement factor of the game for the players, making it less appealing for the audience.

The players that participated in this study have voluntarily chosen to play the game. This type of participants selection can introduce bias towards a more positive attitude towards the game. If the playtest had taken place in more strict conditions (e.g. during classroom), opinions shown in the survey could be less positive. It is to be expected that the volunteers ready to test the game are enjoying this type of activity. Survey results show that around two-thirds of the respondents are playing video games. This could further increase the positive attitude bias in the survey. Generally younger respondents rate could have introduced bias in questions regarding the engagement and effectiveness (compared to traditional lectures).

Survey results have shown that the game "To cut or not to cut" was well received by the players. This is in accordance with various studies on educational video games, like the "Final Frontier" game about Solar system (Muntean et al. 2017) or the games "Escape from DIAB" and "Nanoswarm" about nutrition (Ledoux et al.

2016). However, the study on math video game "Club Penguin" noted that the engagement and motivation to play this particular title shrinks after just about 7-12 minutes (Barreto et al. 2017). To combat this issue, a more active (i.e. including body movement) video games could be used (Sun & Gao 2016).

This can explain the survey results that show the lack of engagement in the "other" group of players. Since this group is not connected on an educational or professional level to forestry, it can lead to the disengagement in the topic and consequently, the game. The lack of understanding of within game compounds the issue, as the "other" group has generally answered that the language lacks in comprehensibility. Inability to grasp the game message can led to loss of engagement.

It is worth noting that the results of clarity of the language were surprising for the author. The highest result was given by the "related" group of players, while "forest" group rated the clarity for non-forestry people much lower. The "forest" group could underestimate the clarity of the dialogues for the non-foresters, especially since the wording "non-foresters" could indicate people who have no connection to forestry and not the "related" field.

The ANOVA tests did not show significant differences (significance level set to 0.05) in all the opinions between the groups. However, a replication study with higher sample size could give more meaningful answers (Dahiru 2008).

As the quiz results suggest, the game may lead increase players' knowledge about natural mortality in relation to thinning for spruce stands. This is especially true or those players who have seen the game as engaging and played more than one stand. It shows how the game design, player engagement and knowledge received are connected, since the design of this game is to show different aspects of natural mortality and thinning operations with different stands. For example, if the player would choose to play only the stand where the main threat is self-thinning, they will not hear explanations and reasoning behind choosing a thinning regime if the wind damage is the main danger. The ANOVA test suggests that there is significant evidence to associate the completion rate and knowledge gain (visualized by correct answers).

However, almost all the respondents from "forestry background" group have stated that they used knowledge from previous experiences to answer the quiz questions. This may indicate that while players from "related background" and "other" groups have gained knowledge during game play, for the "forest" group this is not the case. However, this does not eliminate the possibility for beneficial effects for those foresters who are yet to have the game topics covered within their education and experience. The learning efficiency using video games has shown mixed outcomes in the scientific literature. For example, a study on major incident triage displayed enhanced performance of the participants using the video game compared to traditional learning (Knight et al. 2010). In addition, a study on the

“Final frontier” game has also shown high learning achievements (Muntean et al. 2017). However, a systematic review on educational medical video games have reported their moderate effectiveness as a pedagogical tool (Gorbanev et al. 2018). It is possible that the more advanced the knowledge that the educational video game tries to teach, the less effective it is. The survey results showed that the advancement of the game is on the good level for those who have not yet learned about the topics presented in the game. For this group, making the game more advanced would not be beneficial enough to justify the change. For the foresters who have already knew about the game topic, adding more specific and sophisticated knowledge to the game could be beneficial.

Lack of sufficient number of responses made it impossible to analyse survey results with different groups, e.g. age groups or students and workers in respective fields. Especially the effects of age can be an important factor on effectiveness not only of educational video games, but also of the casual games, i.e. simple and engaging games (Squire et al. 2023).

4.2 Potential use cases

The survey analysis suggests that with the current state of the game, the best possible way to utilize it would be to present this game during classes and/or lectures for forestry-related specializations, e.g. biology, ecology courses. This could help raise awareness of forestry-specific problems and operations, and to present the foresters’ perspective on natural mortality.

To appeal to the people classified as „other” group, the gameplay and the game language should be altered according to survey results. By simplifying the message and presenting the information with easier vocabulary, the game could be perceived as more entertaining to the people not connected in any way to forestry. This way, it could serve as a much needed communication channel between the forestry sector and the public, possibly making people aware of the multifunctionality of forestry (Riedl et al. 2019).

In the current form, the game has moderate practical use as a teaching tool in forestry education. This is not caused by the lack of educational value of the game per se, but rather the existence of other way of presenting knowledge, also noted by one of the respondents – field experience. The on-site visits and teaching in the forest is highly regarded by students worldwide (Arevalo et al. 2012). The game content could be presented in conjunction with site visits.

4.3 Limitations

One of the main limitations of the game design was using only monoculture of Norway spruce in the stands. Omission of other species in the game stands makes it impossible to pass on the information that mixed species should be promoted in the forest to reduce the risk of wind disturbances (Sanginés de Cárcer et al. 2021). It was suggested that even 10% addition of species mixture is beneficial to storm damage reduction (Schütz et al. 2006). Another study suggests that adding 25-30% of deciduous mixture to Norway spruce dominated forest can halve the storm damage (Valinger & Fridman 2011). Addition of mixed stand in the game could greatly influence the way the players choose to thin the forest and improve the overall message on causes of wind damages in forests.

As presented in the introduction section, both wind damage and self-thinning have a rather stochastic nature. In Figure 1, the difference between modelled and actual self-thinning line is evident. Considering wind damages, the stochasticity of its occurrence is even greater. This conflicts with the game design approach of showing a hard programmed events when certain requirements are met. This could create a false sense of inevitability of e.g. wind damage when the stand is thinned too hard. In reality this action increase the probability of windthrow, but do not cause it. The preprogrammed event approach

In terms of forest simulation, the game calculations in self-thinning and wind damages do not include variables such as site index. Inclusion of site index would open the possibility to use more sophisticated self-thinning models, e.g. proposed by Hynynen (1993). Because of the simplicity of the simulation elements in the game, the annual increment was only roughly estimated as having the same value for every stand. This increment was added to the quadratic mean diameter, which means the number of stems in the stand did not have any effect on the growthAs the study show, the increment should vary depending on, among others, the thinning intensity (Mäkinen & Isomäki 2004).

During the development of the game, it was evident that estimating the wind damage and windthrow risk in the forest is exceedingly challenging. However, the addition of factors influencing the wind damages such as the time before last thinning before the occurrence of storm, aforementioned mixed stands or even the individual tree height to diameter ratio (Valinger & Fridman 2011), would make the game message harder to present – especially to the players not familiar with specific forestry nomenclature. In this case, the clarity of the message was more important than the realistic simulation – the game development was focused more on ensuring a meaningful and educational experience in expense of using sophisticated computations. However, if the game would perform such simulations in the background (without players noticing them), it should not harm the gameplay experience. Including more advanced models, e.g. for assessing wind damage risks,

such as HWIND (Gardiner et al. 2008) could be beneficial if the game would be turned into a professional forestry simulator, which was not the aim of this study.

Because of the initial design of the game to be available for everyone regardless of their profession, lack of specific target related functionalities is evident. For example, regarding the clarity of the language, the game did not include a better alternative of gameplay and dialogues more suited for people not connected to forestry or the related field.

4.4 Possible improvements and future projects

Apart from fixing the technical problems and issues noted by the players in the survey, the possible improvements heavily depend on the target audience of the game. Some enhancements, however, could also be used overall. One of such possibilities include the use of visualization of the GIS data from the actual forest site, similar to the Virtual Arboretum simulation (Harrington et al. 2021). This would greatly increase the immersion and engagement of the players, as they would be walking in the representation of real-life forest. This would also combat some of the complaints from players about the lack of terrain diversity in the game.

If the future version of the game would be targeted towards groups within forestry education, including statistics would be beneficial. This could include shifting the purpose of the game to more realistically simulating the effects of the thinning rather than explaining and educating primarily by the game dialogues, with just a simple simulation. It would be a valuable addition to cover the stochastic nature of the tree mortality by showing the probability percentages of certain events instead o using a predetermined events. Adding economical elements of thinning could also improve the simulation aspects of the game, since improving net income of the forest is one of the main aspects of thinning (Wallentin 2007).

For the project aiming more into non-forestry publicity, creating a more engaging experience should be top priority. This could include altering the gameplay to be more casual, e.g. by use a drone-like camera from above the stand to quickly select the trees. Reduction of the game dialogues, using more appropriate language for the target audience and focusing more on educating through the gameplay itself could also be a great improvement. With such changes, this game could be introduced to the public as a tool to better explain the reasons behind forestry practices. The study on forestry sector communication in Czech Republic (Riedl et al. 2019) suggests that for some, involvement in forestry management creates opportunity to acquire knowledge and change to a more positive opinion about forestry.

4.5 Conclusion

Videogames can be an educational tool for explaining tree mortality. In this study the videogame demonstrated how thinnings may have an impact on either self-thinning if you don't thin, or increased risk of wind damage mortality if you thin. The findings of the survey demonstrated that using the "To cut or not to cut" game could be beneficial both in terms of engaging form and knowledge. The game could be used as either a supplementary teaching method in forestry courses or as an educational game for professionals. Furthermore, the game can also be used by students from related fields and as a more engaging communication medium to introduce non-forestry public to the forestry specific issues. The survey showed that most of the players in my study found the game to be educational while they were playing.

References

4ga Studios (2023). Games. *4ga Studios*. https://4gastudios.com/games/ [2023-12-05]

Abe, M., Yoshimura, T., Koizumi, S., Hasegawa, N., Osaki, T., Yasukawa, N., Koba, K., Moriya, K. & Sakai, T. (2005). Virtual forest: design and evaluation of a walk-through system for forest education. *Journal of Forest Research*, 10 (3), 189–197. https://doi.org/10.1007/s10310-004-0131-x

Andrade, A. (2015). Game engines: a survey. *EAI Endorsed Transactions on Game-Based Learning*, 2 (6), 150615. https://doi.org/10.4108/eai.5-11-2015.150615

Arevalo, J., Mola-Yudego, B., Pelkonen, P. & Qu, M. (2012). Students' views on forestry education: A cross-national comparison across three universities in Brazil, China and Finland. *Forest Policy and Economics*, 25, 123–131. https://doi.org/10.1016/j.forpol.2012.08.015

Awang Noh, S.N., Mohamed, H. & Mat Zin, N.A. (2021). The Effects of Serious Games on Students' Higher-Order Thinking Skills in Science Education. *Proceedings of 2021 International Conference on Electrical Engineering and Informatics (ICEEI)*, October 2021. 1–5. https://doi.org/10.1109/ICEEI52609.2021.9611147

Barreto, D., Vasconcelos, L. & Orey, M. (2017). MOTIVATION AND LEARNING ENGAGEMENT THROUGH PLAYING MATH VIDEO GAMES. *Malaysian Journal of Learning and Instruction*, 14 (2), 1–21. https://doi.org/10.32890/mjli2017.14.2.1

Basal Area Calculator (2024). https://www.omnicalculator.com/biology/basal-area [2024-01-23]

Ciceu, A., Bronisz, K., Garcia-Duro, J. & Badea, O. (2022). Age-independent diameter increment models for mixed mountain forests. *European Journal of Forest Research*, 141 (5), 781–800. https://doi.org/10.1007/s10342-022-01473-5

Coller, B.D. & Scott, M.J. (2009). Effectiveness of using a video game to teach a course in mechanical engineering. *Computers & Education*, 53 (3), 900–912. https://doi.org/10.1016/j.compedu.2009.05.012

Curtis, R.O. & Marshall, D.D. (2000). Technical Note: Why Quadratic Mean Diameter? *Western Journal of Applied Forestry*, 15 (3), 137–139. https://doi.org/10.1093/wjaf/15.3.137

Dahiru, T. (2008). P – VALUE, A TRUE TEST OF STATISTICAL SIGNIFICANCE? A CAUTIONARY NOTE. *Annals of Ibadan Postgraduate Medicine*, 6 (1), 21–26

D'Artista, B.R. & Hellweger, F.L. (2007). Urban hydrology in a computer game? *Environmental Modelling & Software*, 22 (11), 1679–1684. https://doi.org/10.1016/j.envsoft.2006.09.004

Davis, J.P., Steury, K. & Pagulayan, R. (2005). A survey method for assessing perceptions of a game: The consumer playtest in game design. *The International Journal of Computer Game Research*, 5 (1)

Elfving, B. (2010). Natural mortality in thinning and fertilisation experiments with pine and spruce in Sweden. *Forest Ecology and Management*, 260 (3), 353–360. https://doi.org/10.1016/j.foreco.2010.04.025

Gardiner, B., Byrne, K., Hale, S., Kamimura, K., Mitchell, S.J., Peltola, H. & Ruel, J.-C. (2008). A review of mechanistic modelling of wind damage risk to forests. *Forestry: An International Journal of Forest Research*, 81 (3), 447–463. https://doi.org/10.1093/forestry/cpn022

Girard, C., Ecalle, J. & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning*, 29 (3), 207–219. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Go, M., Golbin Jr., R., Velos, S., Dayupay, J., Dionaldo, W., Cababat, F., Bongo, M., Troussas, C. & Ocampo, L. (2022). Evaluating digital mathematical games in improving the basic mathematical skills of university students. *International Journal of Mathematical Education in Science and Technology*, 0 (0), 1–23. https://doi.org/10.1080/0020739X.2022.2089604

Gorbanev, I., Agudelo-Londoño, S., González, R.A., Cortes, A., Pomares, A., Delgadillo, V., Yepes, F.J. & Muñoz, O. (2018). A systematic review of serious games in medical education: quality of evidence and pedagogical strategy. *Medical Education Online*, 23 (1), 1438718. https://doi.org/10.1080/10872981.2018.1438718

Guzik, M. (2023). *To cut or not to cut by wilkobyl*. *itch.io*. https://wilkobyl.itch.io/to-cut-or-not-to-cut [2024-02-21]

Harrington, M.C.R., Bledsoe, Z., Jones, C., Miller, J. & Pring, T. (2021). Designing a Virtual Arboretum as an Immersive, Multimodal, Interactive, Data Visualization Virtual Field Trip. *Multimodal Technologies and Interaction*, 5 (4), 18. https://doi.org/10.3390/mti5040018

Häyrinen, L. & Pynnönen, S. (2020). A Review of the Concepts and Measurements for Connection to Nature and Environmentally Responsible Behaviour—a Call for Research on Human-Forest Relationships. *Current Forestry Reports*, 6 (4), 323–338. https://doi.org/10.1007/s40725-020-00131-6

Hynynen, J. (1993). Self-thinning models for even-aged stands of Pinus sylvestris, Picea abies and Betula pendula. *Scandinavian Journal of Forest Research*, 8 (1–4), 326–336. https://doi.org/10.1080/02827589309382781

itch.io (2024). *itch.io*. https://itch.io/ [2024-03-01]

IUFRO (n.d.). *IUFRO: Division 6 - Social Aspects of Forests and Forestry / Divisions / Science in IUFRO*. https://www.iufro.org/science/divisions/division-6/ [2023-12-01]

Kapp, K.M., Valtchanov, D. & Pastore, R. (2020). Enhancing motivation in workplace training with casual games: a twelve month field study of retail employees. *Educational Technology Research and Development*, 68 (5), 2263–2284. https://doi.org/10.1007/s11423-020-09769-2

Knight, J.F., Carley, S., Tregunna, B., Jarvis, S., Smithies, R., de Freitas, S., Dunwell, I. & Mackway-Jones, K. (2010). Serious gaming technology in major incident triage training: A pragmatic controlled trial. *Resuscitation*, 81 (9), 1175–1179. https://doi.org/10.1016/j.resuscitation.2010.03.042

Ledoux, T., Griffith, M., Thompson, D., Nguyen, N., Watson, K., Baranowski, J., Buday, R., Abdelsamad, D. & Baranowski, T. (2016). An Educational Video Game for Nutrition of Young People: Theory and Design. *Simulation & Gaming*, 47 (4), 490–516. https://doi.org/10.1177/1046878116633331

Makinen, H. (2004). Thinning intensity and growth of Norway spruce stands in Finland. *Forestry*, 77 (4), 349–364. https://doi.org/10.1093/forestry/77.4.349

Mäkinen, H. & Isomäki, A. (2004). Thinning intensity and long-term changes in increment and stem form of Norway spruce trees. *Forest Ecology and*

Management, 201 (2), 295–309. https://doi.org/10.1016/j.foreco.2004.07.017
Martinez, L., Gimenes, M. & Lambert, E. (2022). Entertainment Video Games for Academic Learning: A Systematic Review. *Journal of Educational Computing Research*, 60 (5), 1083–1109. https://doi.org/10.1177/07356331211053848
Matilainen, A., Pohja-Mykrä, M., Lähdesmäki, M. & Kurki, S. (2017). "I feel it is mine!" – Psychological ownership in relation to natural resources. *Journal of Environmental Psychology*, 51, 31–45. https://doi.org/10.1016/j.jenvp.2017.03.002
Microsoft (2023). *What is Visual Studio?* https://learn.microsoft.com/en-us/visualstudio/get-started/visual-studio-ide?view=vs-2022 [2023-12-08]
Muntean, C.H., Andrews, J. & Muntean, G.-M. (2017). Final Frontier: An Educational Game on Solar System Concepts Acquisition for Primary Schools. *Proceedings of 2017 IEEE 17th International Conference on Advanced Learning Technologies (ICALT)*, Timisoara, Romania, July 2017. 335–337. IEEE. https://doi.org/10.1109/ICALT.2017.111
Nantakaew, N. & Srisawasdi, N. (2014). Investigating Correlation between Attitude toward Chemistry and Motivation within Educational Digital Game-based learning., November 30 2014.
Newcombe, J. & Brick, B. (2017). Blending Video Games Into Language Learning. *International Journal of Computer-Assisted Language Learning and Teaching (IJCALLT)*, 7 (4), 75–89. https://doi.org/10.4018/IJCALLT.2017100106
Nilsson, U., Agestam, E., Ekö, P.-M., Elfving, B., Fahlvik, N., Johansson, U., Karlsson, K., Lundmark, T. & Wallentin, C. (2010). Thinning of Scots pine and Norway spruce monocultures in Sweden: effects of different thinning programmes on standlevel gross- and net stem volume production. *Studia Forestalia Suecica*, 219 (219). https://res.slu.se/id/publ/29199 [2023-10-25]
On Social Aspects of Forests and Forestry (2017). *IUFRO Blog*. https://blog.iufro.org/2017/10/06/on-social-aspects-of-forests-and-forestry/ [2023-12-01]
Papadakis, S. (2018). The use of computer games in classroom environment. *International Journal of Teaching and Case Studies*, 9 (1), 1. https://doi.org/10.1504/IJTCS.2018.090191
Preston, S.D. & Gelman, S.A. (2020). This land is my land: Psychological ownership increases willingness to protect the natural world more than legal ownership. *Journal of Environmental Psychology*, 70, 101443. https://doi.org/10.1016/j.jenvp.2020.101443
Pretzsch, H. & Biber, P. (2005). A re-evaluation of Reineke's rule and stand density index. *Forest Science*, 51
Pro-Environmental Behavior (2020). https://encyclopedia.pub/entry/2546 [2024-03-02]
Reineke, L.H. (1933). Perfecting a stand-density index for even-aged forests. *J Agric Res*, 46, 627–638
Riedl, M., Jarský, V., Palátová, P. & Sloup, R. (2019). The Challenges of the Forestry Sector Communication Based on an Analysis of Research Studies in the Czech Republic. *Forests*, 10 (11), 935. https://doi.org/10.3390/f10110935
Rivoire, M. & Le Moguedec, G. (2012). A generalized self-thinning relationship for multi-species and mixed-size forests. *Annals of Forest Science*, 69 (2), 207–219. https://doi.org/10.1007/s13595-011-0158-z
Rosas, R., Nussbaum, M., Cumsille, P., Marianov, V., Correa, M., Flores, P., Grau, V., Lagos, F., López, X., López, V., Rodriguez, P. & Salinas, M. (2003).

Beyond Nintendo: design and assessment of educational video games for first and second grade students. *Computers & Education*, 40 (1), 71–94. https://doi.org/10.1016/S0360-1315(02)00099-4

Sample, V.A., Bixler, R.P., McDonough, M.H., Bullard, S.H. & Snieckus, M.M. (2015). The Promise and Performance of Forestry Education in the United States: Results of a Survey of Forestry Employers, Graduates, and Educators. *Journal of Forestry*, 113 (6), 528–537. https://doi.org/10.5849/jof.14-122

Sanginés de Cárcer, P., Mederski, P.S., Magagnotti, N., Spinelli, R., Engler, B., Seidl, R., Eriksson, A., Eggers, J., Bont, L.G. & Schweier, J. (2021). The Management Response to Wind Disturbances in European Forests. *Current Forestry Reports*, 7 (4), 167–180. https://doi.org/10.1007/s40725-021-00144-9

Schütz, J.-P., Götz, M., Schmid, W. & Mandallaz, D. (2006). Vulnerability of spruce (Picea abies) and beech (Fagus sylvatica) forest stands to storms and consequences for silviculture. *European Journal of Forest Research*, 125 (3), 291–302. https://doi.org/10.1007/s10342-006-0111-0

Sedláček, D., Okluský, O. & Zara, J. (2019). Moon Base: A Serious Game for Education. *Proceedings of 2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*, September 2019. 1–4. https://doi.org/10.1109/VS-Games.2019.8864540

Seralidou, E. & Douligeris, C. (2020). Creating and using digital games for learning in elementary and secondary education. *Proceedings of 2020 5th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM)*, September 2020. 1–8. https://doi.org/10.1109/SEEDA-CECNSM49515.2020.9221799

Seralidou, E. & Douligeris, C. (2021). Motivating students in distance programming learning using games. *Proceedings of 2021 6th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM)*, September 2021. 1–7. https://doi.org/10.1109/SEEDA-CECNSM53056.2021.9566266

Sharma, R.P. & Brunner, A. (2017). Modeling individual tree height growth of Norway spruce and Scots pine from national forest inventory data in Norway. *Scandinavian Journal of Forest Research*, 32 (6), 501–514. https://doi.org/10.1080/02827581.2016.1269944

Shute, V., Rahimi, S., Smith, G., Ke, F., Almond, R., Dai, C., Kuba, R., Liu, Z., Yang, X. & Sun, C. (2021). Maximizing learning without sacrificing the fun: Stealth assessment, adaptivity and learning supports in educational games. *Journal of Computer Assisted Learning*, 37 (1), 127–141. https://doi.org/10.1111/jcal.12473

Skogsforum.se (2024). *Skog och maskiner i forum, blogg och bilder*. *skogsforum.se*. https://skogsforum.se/ [2024-03-01]

Squire, K., Wells, G., Anderson-Coto, M.J. & Steinkuehler, C. (2023). Casual Games, Cognition, and Play across the Lifespan: A Critical Synthesis. *Games: Research and Practice*, 1 (2), 14:1-14:25. https://doi.org/10.1145/3594534

Sun, H. & Gao, Y. (2016). Impact of an active educational video game on children's motivation, science knowledge, and physical activity. *Journal of Sport and Health Science*, 5 (2), 239–245. https://doi.org/10.1016/j.jshs.2014.12.004

Unity (2023). *Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine*. *Unity*. https://unity.com [2023-12-08]

Unity Technologies (2023). *Unity Version Control (Previously Plastic SCM) - Fast VCS | Unity*. https://unity.com/solutions/version-control [2023-12-08]

Valinger, E. & Fridman, J. (2011). Factors affecting the probability of windthrow at stand level as a result of Gudrun winter storm in southern Sweden. *Forest*

Ecology and Management, 262 (3), 398–403. https://doi.org/10.1016/j.foreco.2011.04.004
Valinger, E. & Pettersson, N. (1996). Wind and snow damage in a thinning and fertilization experiment in Picea abies in southern Sweden. *Forestry: An International Journal of Forest Research*, 69 (1), 25–33. https://doi.org/10.1093/forestry/69.1.25
Wallentin, C. (2007). Thinning of Norway spruce. *Acta Universitatis Agriculturae Sueciae*, (2007:29). https://res.slu.se/id/publ/14225 [2023-10-25]
Wallentin, C. & Nilsson, U. (2014). Storm and snow damage in a Norway spruce thinning experiment in southern Sweden. *Forestry: An International Journal of Forest Research*, 87 (2), 229–238. https://doi.org/10.1093/forestry/cpt046
Westoby, M. (1984). The Self-Thinning Rule. In: MacFadyen, A. & Ford, E.D. (eds) *Advances in Ecological Research*. Academic Press. 167–225. https://doi.org/10.1016/S0065-2504(08)60171-3
Zabel, J. & Kollender, L. (2014). Nature experience and perception of nature in Peruvian school students: Closer to nature, but still far away? (In: C. P. Constantinou, N. Papadouris & A. Hadjigeorgiou (Eds.), E-book proceedings of the ESERA 2013 conference: science education Research For Evidence-based Teaching and Coherence in Learning. (S. 1694 -1704)). 4, 1694–1704

Popular science summary

There are several ways in which the forest can be harmed naturally. When the stand is too dense (too many trees are growing in an area), some of the trees will die from being overcrowded. This process is called self-thinning. Certain tree species like Norway spruce are also easily affected by wind damages. The thinning operations (selective removing of trees before final cutting) can affect the possibility of this natural mortality.

Is it possible to present this knowledge in a form of a video game? Could that game be beneficial for both foresters and non-foresters? And be not only educational, but also entertaining? This study was aimed to answer those questions.

To do this, the author created a PC video game called “To cut or not to cut” available here: https://wilkobyl.itch.io/to-cut-or-not-to-cut . In this game players can move around the four different forests (levels) and choose the trees for cutting. With the instructions in the dialogues and seeing the outcome of their cutting (like trees falling from the wind), they learn about different aspects of thinning and natural mortality. To see how well the game was designed, the opinion survey together with a knowledge quiz was presented to the players upon quitting the game.

The survey has shown that the more players have played the game (the more levels they finished), the better their results were in the knowledge quiz. The players have also evaluated the game as moderately engaging, but at the same time as a good educational tool. However, some of the non-forestry players were less engaged in the game and complained more about too hard to understand dialogues.

The study was successful in proving that the forestry educational video game can be a useful and effective tool. At the same time, some changes in the game design should be made. One of such improvements would be choosing the target group at the start of game creation process and modifying the game for them.

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Appendix 1

Table 1 Game survey questions divided into six sections

Introduction questions							
Select your age range	<18	18-23	23-28	28-33	33-40	40-50	>50
(open) Which country are you from?							
Do you play video games?	Yes	No					
Do you have any forestry-related knowledge?	Yes, I do	No, I don't					
Are you a student?	Yes	No					
What are you studying/have studied?	Forest science	Related field	Other degree	I am not studying /didn't study			
Are you working/ Have you ever worked in a university or research field?	Yes, in forest sciences field	Yes, in related field	No				
Are you working/ Have you ever worked in the commercial forestry sector and/or field work?	Yes	No					
Are you working/ Have you ever	Yes	No					

worked in forestry related field?						
On scale 1 to 4, how much is wind damage in forests an issue in your region?	1	2	3	4		
How many stands did you complete?	0	1	2	3	4	
Did you repeat any stand at least once?	Yes	No				

Quiz questions			
Does wind cause mortality to spruce? If yes, why?	Yes, the strong wind can cause a windthrow due to shallow root system of spruces.	No, spruce is a tree species that is very resilient to wind damages due to deep root system.	Yes, wind can bring a pathogen to the spruce needles which will cause them to die.
What is self-thinning and how it affects the forest stand?	Self-thinning is a process of that leads to the tree losing its branches, affected by competition from other trees in overcrowded forest.	Self-thinning is a process of natural mortality in an overcrowded forest, where supressed trees die from competition.	
How thinning can affect the stability of a forest, concerning wind damages?	Thinning is not affecting the stability of a forest regarding wind damages.	Heavy thinning always heavily increases the wind damages in the forest.	With thinning intensity, the wind damages can increase, especially in higher stands.
How thinning can affect the stability of a forest, concerning self-thinning?	Thinning is not affecting the stability of a forest regarding self-thinning.	Self-thinning can be avoided in the stand if the thinning is carried out to reduce the	Self-thinning can be avoided if the thinning is removing at least 50% of the trees.

		density of the stand.		
Considering wind damages, what is a more important factor: the height of the stand or the age?	The age.	The height.	Both are of equal importance.	
Knowledge gain questions				
When answering previous questions, were you referring to a freshly gained knowledge from the game, or to your previous experiences?		I used the information presented in the game.	I used knowledge from previous experiences.	
(open answer) What are in your opinion the educational values of this game? What is this game trying to teach?				
Clarity of message questions				
Was the aim of this game (show how thinning affects a natural mortality caused by wind damages and self-thinning in the spruce forests) clearly visible from the gameplay?	Yes, very clearly visible	Yes, quite visible	Not really	Not at all
Were the dialogues understandable for non-forestry audience?	Yes, very understandable	Yes, quite understandable	Not really	Not at all
How did you find the length of the dialogues?	Too long	Good length	Too short	
Direct game opinion questions				
Did you find this game engaging?	4	3	2	1
Do you think this type of presenting knowledge (video game) is better than more traditional lecture on the topic?	4	3	2	1

Do you think people not connected to forestry can benefit from this way of presenting knowledge?	4	3	2	1
Do you think you will remember the knowledge for longer than from traditional lectures (4 is much longer, 1 is much shorter)	4	3	2	1
Would you see a benefit of this game if the students would play the game during lessons in their native language?	4	3	2	1

Open questions (optional)
If you have any additional thoughts, you can write them here. Otherwise, press the submit button. Thank you for your participation!

Appendix 2

Table 2 Additional comments from the survey respondents

Country	Group	Comment
Lithuania	Related field	This is a very good game for children, it is fun and educative, very good job!
Lithuania	Forest science	Just some technical thoughts :) 1. Walking animation is not stopping, I am walking in place. It is annoying. 2. Mouse movement is too sensitive, it moves too fast. Maybe have a setting for it or make it less sensitive. 3. Some trees grow out of rocks. 4. Major issue for me, after first thinning task camera shifted down for the rest of dialogues in all other tasks. I couldn't see forest, I was meant to decide thinning intensity for and what happened after. 5. This is just preference, but before giving my decision for thinning intensity with dialogue options, it would be nice to be able to walk in the stand and then decide. It would be easier to see if it needs thinning and decide intensity for it.
Sweden	Forest science	Would be nice with further development, such as simulating costs and incomes from various thinning % and thinning type
Hungary	Other degree	While I was thining the very dense stand I was following a pattern to cut more than 54% of the tree. After a while is was too much to mark all the tree but I didn't want to be lazy so I finished the process to so the end. I missed the option to unmark a tree. I lacked more specific evaluation system, that it detects the pattern in which I cut the trees - I could possibly remove the trees in one specific area and the game would still say "good job", which I guess won't be true?
Austria	Forest science	I rated the usefullness of the game in the lecture relatively low, because apart of the lecture there are usually field trips to practice it in real. This game gives in my opinion a much better knowledge about how much trees you should cut than a lecture, but field practice is of course much better. And it was my personal opinion, that I don't have enough patience to go

		through the whole stand to mark all trees I think it would be neccessary. It's good how Gustav gives always a feedback, especially for non-forestry people.
Poland	Forest science	As before, the game is overall nice but maybe adding more info during gameplay instead of dialogues woud be better.
Sweden	Forest science	I wish there would be more variety of the trees to thin, with varying quality, so they could be choosen for felling on the quality basis
Poland	Forest science	It's good you could replay the stands after performing bad thinning - it helps to retain knowledge
Poland	Forest science	Little more changes in the environment would be good
Germany	Related field	I wish there was a more visual presentation of cutting the trees. Otherwise I really liked this game!
Poland	Other degree	Game great! Could work on the accuracy of moving through the forest, it is cumbersome.
Poland	Forest science	The game is quite good for teaching! Would see it during classes
Italy	Related field	Good game!

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