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FACULTY OF INFORMATICS

Playful visualization: Evaluating data visualization in video games

Master's Thesis

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Brno, Spring 2023

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FACULTAS ARTIS INFORMATICÆ • UNIVERSITAS MASARYKIANA •

Declaration

Hereby I declare that this paper is my original authorial work, which I have worked out on my own. All sources, references, and literature used or excerpted during elaboration of this work are properly cited and listed in complete reference to the due source.

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Abstract

Data visualizations frequently communicate important information, such as election results or the current epidemiological situation. The audience must be able to interpret the visualizations correctly for them to be an effective communication tool. Educational games focused on data visualization have been used to improve the data visualization literacy of both adults and children. This thesis aims to design playful visualizations in two existing video games and evaluate them by conducting a user study in the form of interviews and tasks. The study aims to determine if the designed visualizations are usable, to discover potential issues with the design, and to evaluate if the designed visualizations could be used to educate children about data visualization in a playful way.

Keywords

data visualization, visualization literacy, video games, educational games, user study

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1 Introduction

Educational games, also referred to as serious games, are designed to facilitate learning in a playful manner [1]. Educational games also include video games, such as Minecraft: Education Edition [2], The Oregon Trail[1], and more. Video games are a medium that communicates with the player mainly through visuals. For the player to succeed, it is paramount that the necessary information is conveyed quickly and clearly. There is a wide range of visualization techniques [3] that games employ to achieve this, for example, displaying the player's health status as a colored bar or obscuring the unexplored areas of the map with the "fog of war".

Data visualizations help people to easily understand and interact with data [4]. Visualizations are frequently used to communicate important information in the media, work settings, or advertising. However, visualizations require the viewers to be able to interpret them correctly. Without the necessary skills [5], the viewers might not be able to extract the information, could draw the wrong conclusions about the data, or might even be purposefully misled by the visualization [6]. Therefore, it is crucial to improve the quality and accessibility of educational material regarding data visualization.

Educational games can be utilized to improve visualization literacy [5] in a plaful way. Games, in general, encourage exploration and learning in order to succeed at them. Furthermore, they provide an environment to demonstrate concepts that may be difficult to illustrate in the real world [7]. However, designing and developing an educational game is an expensive and time-consuming process. The design of educational games has to balance the entertainment aspect to keep the players engaged with the game while still providing educational value [8].

This thesis explores the idea of using existing games, which were not designed to be educational, as platforms to create visualizations in. Using existing games eliminates the challenges of designing and developing an educational game from scratch. However, it presents new challenges in the form of designing visualizations within the con-

1. See the official page `https://theoregontrail-game.com` (Accessed: 12 May 2023).

straints of an existing game. The thesis contains an analysis of selected games, which might be suitable for this purpose, and proposed designs of visualizations in two games. Furthermore, the thesis evaluates if the designed visualizations are usable and if they could potentially be used as educational material regarding data visualization. For the evaluation, a user study was conducted in the form of in-person sessions, which included an interview and tasks regarding the designed visualizations. The user study aimed to answer the following research questions regarding the designed visualizations:

- Are the visualizations usable?
- What are the most commonly encountered issues when using the visualizations?
- Could these or similar visualizations be used for education purposes, specifically to teach elementary school students about data visualization?

Chapter 2 provides an overview of the related work regarding educational games and playful visualization. Chapter 3 contains an analysis of selected games to determine which are the most suitable platforms for displaying data visualizations. Chapter 4 describes the proposed designs of visualizations in two games that were determined to be the most suitable in the analysis. As a part of this thesis, a user study was conducted. The design of the study is described in Chapter 5. Chapter 6 contains an overview of the results of the study, which are then discussed in Chapter 7, which also contains answers to the proposed research questions.

2 Related work

Recently, the concept of educational video games has frequently been explored. There are many documented examples where the inclusion of educational games improved the learning process. For example, Noemí and Máximo [9] review successful educational games for children for learning vocabulary and numbers or developing skills such as teamwork, problem-solving, and flexibility. Zhonggen [10] provides a review of existing literature related to educational games and discussed both their positives, such as achieving more effective learning and improved attitude towards learning, and negatives, such as increased mental workload, which hinders learning.

There already exist educational games designed to teach about data visualization. Diagram Safari [11] is an educational game for children around the age of 10. The game is designed to teach children about bar charts, namely about how they are created, how to interpret them, and how they relate to pie charts. Learning is facilitated through solving puzzles. The puzzles involve data elements, which are represented by colored blocks, and bar charts. To solve the puzzle, the player has to assign the blocks to the correct bars in the chart.

Another educational game focusing on visualization literacy skills is a narrative game presented by Huynh et al. [12]. The target audience is children between 11 and 13 years old. The players engage with the narrative through dialog, and they can explore the game world. The learning is facilitated through questions about visualizations that relate to the narrative of the game.

The Roboviz game [13] is an educational game that was created for students to practice designing interactive visualizations as a part of a school course. The game allows players to focus solely on the visualization design process by eliminating all other problems that are typically present in visualization-related school projects, such as data cleaning. The game presents the players with design problems to solve in real time. The problems include, for example, designing visualizations for four different data types, and working with design constraints.

Regarding the design of educational games in visualization, Amabili et al. [14] propose a two-fold model for designing such games.

The model involves deconstructing and constructing visualizations. The deconstruction process allows for inspection of the components of the visualizations, and the construction process requires combining the components to create a visual representation of given data. They propose that games based on the model can facilitate learning of both interpreting and designing visualizations.

Diakopoulos et al. [15] explore the intersection of infographics and games. They present "game-y infographics" that include mechanics of play, such as a guessing game with scoring, and goals, such as achieving a high score. They propose that the inclusion of goals provides the users with motivation to explore the infographics.

Another playful approach to data exploration is proposed by Cardoso et al. [16]. They present KUbism, a prototype for the exploration of data through an interface that employs elements of the Minecraft gameplay. In KUbism, the game world contains data blocks, which can be interacted with in the same manner as in Minecraft. For example, they can be activated, picked up, and placed. Their study suggests that their approach is accessible and has a positive impact on curiosity.

With the rising popularity of video games, there is also increased interest in visualizations of various game metrics. Such visualizations can aid in making informed decisions in both gameplay and game design. Wallner and Kriglstein [17] developed a visual analytics system for time-dependent multidimensional gameplay data and demonstrated it on data from various games. Kuan et al. [18] created a visualization system for examining the gameplay of real-time strategy games, such as StarCraft II. Li et al. [19] presented visualizations of event sequence data to analyze player skill growth in puzzle games.

This thesis explores the idea of using existing games for creating various data visualizations, presents designs of such visualizations, and evaluates their usability through a user study.

3 Analysis of games as platforms for data visualization

The initial analysis aimed to determine which games are the most suitable platforms for creating and displaying data visualizations. A list of criteria was formulated to analyze the properties of eleven selected games. The criteria were based on the specifications of the goal, which was to design usable playful visualizations in existing games. The criteria were also informed by the best practices for data visualization [20].

3.1 Analysis criteria

To simplify formulating the criteria, the goal was deconstructed into the following sub-goals: creating visualizations in existing games, creating usable visualizations, and creating playful visualizations. Creating visualizations in existing games requires finding games that provide means to accomplish that – either directly in-game or via creating a tool outside of the game. To make the visualizations playful, the player has to be able to interact with the visualizations. The interactivity and playful environment of games are important aspects of the appeal of visualizations in games. Therefore, it is necessary that the selected games provide features through which the player can interact with the visualizations and modify them.

To ensure that the visualizations are usable, the best practices [20] were modified into a list of guidelines that apply to visualizations in games. The modifications were necessary because when creating visualizations in existing games, there are constraints posed by the game world and game rules, which are not typically present when using data visualization software. Following is the list of guidelines based on the best practices:

- The created visualizations should be simple, with minimal visual clutter.
- The game should provide means to distinguish categories. For example, it could provide the ability to color objects or use varied game objects to create the visualization. Every game

object used in the visualization should be easy to distinguish from the other objects.
- The game should provide means to create labels and legends.
- The player should be able to position the player character or the camera in such a way that the whole visualization is visible on the screen.

Informed by the listed guidelines and sub-goals, the criteria for the analysis were formulated.

The most important criterion is that the game provides means to display visualizations. This criterion is based on the sub-goal of creating visualizations in existing games. The term *visualization* is broad – in this thesis, the term refers to visual representations of data. Such visual representations could, for example, take the form of bar charts, scatter plots, and pie charts. Therefore, this criterion can be fulfilled in numerous different ways. In many cases, one game could display multiple different visualizations; for example, see Stardew Valley in Subsection 3.2.2, which could display both bar charts and scatter plots.

The second criterion is that the game allows players to interact with and modify the game world and, by extension, the created visualizations. This criterion is based on the sub-goal of creating playful visualizations. Creating static visualizations that cannot be interacted with would reduce the playfulness aspect of the visualizations [21].

The third criterion is that the visualizations created in the game should be usable, meaning that they should comply with the previously listed guidelines.

Visualizations created in existing games cannot achieve the levels of accuracy provided by regular visualization software. For example, when representing large numbers, the games may limit how many objects can be placed. However, the created visualizations should not distort the displayed data significantly. Whether the level of accuracy is acceptable is judged on a case-by-case basis because it depends on the type of visualization that the game would display. Because the aim is to use the visualizations for educational purposes and the target audience is children, it should be sufficient that the visualizations can display small values, such as natural numbers below 30.

Additional factors were taken into consideration, namely, what type of visualization can be created in the game, the availability and

the popularity of the game, and whether the game world is 2D or 3D. The type of visualization that can be created should be a widely used type, such as a bar chart or a pie chart, because the learner will get the most benefit from learning about the visualizations, which they are the most likely to encounter in the real world. The availability of the game was considered because if the game cannot be obtained, then the visualizations cannot be accessed. The popularity of the game was considered because popular games could have large audiences that are familiar with the game. If players are already acquainted with the environment of the game, they could potentially benefit from easily recognizing the objects in the game when interpreting the visualizations. Choosing either a 2D or a 3D game should inform which types of visualizations are suitable for the game. For example, 2D games cannot display 3D bar charts, but they could be more suitable for visualizations that are typically 2D, such as regular bar charts or pie charts.

3.2 Analysis of selected games

This analysis includes a limited number of games because the aim of this thesis is designing and evaluating visualizations in existing games rather than creating an extensive overview of games as platforms for data visualization.

3.2.1 Townscaper

The first analyzed game was Townscaper[1], a 3D town-building toy. The player can modify the game world by placing and removing colored building blocks, with a maximum height limit of 255 building blocks. Each block can be colored from a selection of 15 colors and placed on an irregular grid made up of polygons. Blocks can be removed even if there are other blocks above them. The camera angle and position are adjustable, and the game includes a highlighting feature. As a result of the listed properties of the game, it is most suitable to display bar charts.

1. See the official page `https://www.townscapergame.com` (Accessed: 12 May 2023).

Townscaper was previously used in two notable data visualization projects, Wordle2Townscaper[2] and Townscaper Dataviz [22].

Wordle2Townscaper is a tool that visualizes playthroughs of Wordle games in Townscaper. See an example in Figure 3.1.

Figure 3.1: On the left, there is a playthrough of a Wordle game (Image source: the project GitHub repository [23]), on the right, there is a visualization of the playthrough created by using Wordle2Townscaper.

Townscaper Dataviz is a tool that visualizes input data as a bar chart in Townscaper. The created visualization is displayed in a web browser version of Townscaper[3]. The recommended size of the input data is ten values. For larger data sets, a correct result is not guaranteed. Another version of the tool, Townscaper Dataviz Downloader version, enables the user to create visualizations of larger datasets; however, this version of the tool requires the user to own the full version of Townscaper. See an example of a visualization of a large dataset in Figure 3.2.

Both projects showcase that Townscaper is a suitable platform for displaying data visualizations. The individual building blocks that

2. See the project page `https://tarmo888.github.io/Wordle2Townscaper/` (Accessed: 12 May 2023) or the GitHub repository `https://github.com/tarmo888/Wordle2Townscaper` (Accessed: 12 May 2023).
3. See the browser version of Townscaper `https://oskarstalberg.com/Townscaper/` (Accessed: 12 May 2023).

Figure 3.2: An example of a visualization (Image source: *Creating Dataviz Using the Video Game 'Townscaper'* [22]) created by using Townscaper Dataviz. The visualization displays the last five years, at the time of publishing the article, of the monthly price of Bitcoin.

make up the columns are mostly uniform in size and shape, making the visualizations created by using Townscaper Dataviz easy to compare visually. The presence of either a window or a door on almost all building blocks simplifies the process of counting the exact height of the columns.

However, several issues exist with the visualizations created using Townscaper Dataviz. The columns of the visualization are not aligned in a straight line; therefore, some columns are partially obscured by others. The rotation of the columns in relation to the camera is not uniform. In the center of Figure 3.2, there are two columns of the same blue color next to each other. As a result of being the same color and height, they merge, and there is only one window displayed per two horizontally adjacent blocks, which might lead to users falsely interpreting the columns as one column. In the center of Figure 3.2, there are areas where the columns are not directly connected, which is caused by the irregular grid. These areas might be misinterpreted as the values being equal to zero.

Townscaper provides no feature that would allow for the creation of labels and legends.

As demonstrated by the Townscaper Dataviz project, Townscaper is suitable for displaying bar charts.

3.2.2 Stardew Valley

Stardew Valley[4] is a 2D farming and life simulation game with pixel graphics, as displayed in Figure 3.3 The player controls a player character using WASD movement. The player can modify the game world by planting and harvesting crops and placing items on a regular square grid. Tools such as an axe to chop down trees, a pickaxe to break rocks, and a scythe to harvest crops are available to the player.

The visualizations could be created with crops. There are different kinds of crops, and they are visually distinct from each other. The player could interact with the visualization by using the available tools, or by harvesting crops by hand.

Figure 3.3: A showcase of a player character, crops, and tools in Stardew Valley.

4. See the official page `https://www.stardewvalley.net` (Accessed: 12 May 2023).

The player can only modify the farm area of the game world, which significantly limits the available space. Creating an in-game visualization by planting crops would be time-consuming because crops need several in-game days to grow fully. Before reaching a fully grown state, the crops are less visually distinct from each other and, therefore, less suitable for visualization purposes. Furthermore, using crops in visualizations might lead to visual clutter because the crop sprites are of various shapes and often contain multiple colors. Because the shape of each sprite is different, the crops also vary in height. The game limits which crops can be grown in each season of the year.

The top-down camera angle and absence of perspective ensure that visualizations would not be distorted. The zooming feature allows the player to change the scale only within 75 % and 200 % of the original scale. Therefore, large visualizations might not be fully visible without moving the player character.

Stardew Valley provides no feature that would allow for the creation of labels and legends – there is a *Wood Sign* object in the game. However, it can only display in-game objects and cannot display alphanumeric symbols.

Despite the limitations, the game could be suitable for displaying various visualization types, namely bar charts and scatter plots.

3.2.3 Other analyzed games

This subsection contains brief descriptions of other analyzed games. These games provide the player with tools to create visualizations; however, the created visualizations would have severe flaws. As a result, these games were determined to be less suitable for displaying visualizations than Townscaper and Stardew Valley.

Minecraft[5] is a 3D sandbox game. The visuals of the game are displayed in Figure 3.4. Similarly to Townscaper, Minecraft is suitable for displaying bar charts and, additionally, scatter plots. The combination of a regular grid and cube-shaped building blocks provides a high level of accuracy compared to all other analyzed games. Visually comparing the height of individual columns is trivial. However, determining the exact height of a column could prove challenging,

5. See the official page `https://www.minecraft.net/` (Accessed: 12 May 2023).

depending on the texture of the blocks. For example, in Figure 3.4, the stone and wooden plank textures of the blocks, which make up the house, make it nearly impossible to distinguish the individual blocks. In comparison, visualizations in Townscaper do not have this issue because there is either a door or a window displayed on each building block (with the one described exception), as shown in Figure 3.2. It was concluded that Minecraft is less suitable than Townscaper and Stardew Valley, because it is essential that the individual elements in the visualizations can be distinguished easily.

Figure 3.4: A house in the game world in Minecraft (Image source: A Deep Hierarchical Approach to Lifelong Learning in Minecraft [24]).

Terraria[6] and Starbound[7] are 2D games that contain a similar range of building features. In both games, the player can place square-shaped blocks in the foreground and background of the game world. Therefore, both games are suitable for displaying, for example, bar charts and scatter plots. See images from the games in Figure 3.5. Similarly to Minecraft, counting the individual blocks when multiple blocks are placed adjacent to each other is challenging. For that reason,

6. See the official page `https://terraria.org` (Accessed: 12 May 2023).
7. See the official page `https://playstarbound.com` (Accessed: 12 May 2023).

both games were considered to be less suitable than Townscaper and Stardew Valley.

Figure 3.5: On the left, there is an image of Starbound, on the right, there is an image of Terraria (Image source: `https://terraria.fandom.com/wiki/Terraria_Wiki?file=Terraria+house.png`, accessed: 12 May 2023).

Animal Crossing: New Horizons[8] is a 3D social simulation game. The game is only available on a single platform, the Nintendo Switch[9]. Visualizations could be created by the player modifying the outside terrain by placing items, planting flowers, and changing the terrain texture. The game is most suitable for displaying bar charts and scatter plots. The created visualizations would be significantly distorted because of the visible curvature of the game world, as shown in Figure 3.6. The curvature of the game world was the main contributing factor for determining that the game was not suitable for displaying visualizations. A lesser contributing factor was that the game is available only on one platform.

Raft[10] is a 3D survival multiplayer game. The player can modify a modular raft by building and removing the floor, walls, and various items. The most suitable element for displaying visualizations is the

8. See the official page `https://www.animal-crossing.com/new-horizons/` (Accessed: 12 May 2023).
9. See the official page `https://www.nintendo.com/switch/system/` (Accessed: 12 May 2023).
10. See the official page `https://raft-game.com` (Accessed: 12 May 2023).

Figure 3.6: The game world of Animal Crossing: New Horizons (Image source: `https://animalcrossingworld.com/guides/new-horizons/how-to-plant-grow-and-harvest-pumpkins-farming-guide/`, accessed: 12 May 2023).

floor, which is comprised of individual square-shaped floorboards, as shown in Figure 3.7. Each floorboard can be colored. The floor could be used to display, for example, bar charts or scatter plots. However, the first-person camera would significantly limit the size of visualizations that can be viewed without moving the player character. In comparison, Townscaper allows the player to move the camera freely, and Stardew Valley displays a top-down view of the area around the player. Therefore, both selected games allow for a much easier viewing of the visualizations.

Dorfromantik[11] is a 3D building strategy puzzle game. In Dorfromantik, the player places hexagonal tiles that represent a certain landscape, as shown in Figure 3.8. Each tile can contain up to 6 different biomes. Examples of biomes are a city, a forest, a field, and a lake. The selection of biomes is very limited. This game is most suitable for approximating maps and displaying geospatial data. It is not suitable for displaying bar charts, scatter plots, and many other visualizations because of the hexagonal grid. Because the goal is to create

11. See the official page `https://toukana.com/dorfromantik/` (Accessed: 12 May 2023).

Figure 3.7: The game world of Raft.

educational visualizations focusing on widely used visualizations, such as bar charts and pie charts, Dorfromantik was determined to be unsuitable for that purpose.

Slime Rancher[12] is a 3D life simulation adventure game. In the game, the player can catch slime creatures and place them in corrals. There are several types of slime creatures. The number and type of creatures in corrals could visualize a comparison of values. However, visualizations comparing values have limited applications. Therefore Slime Rancher was considered to be less suitable than Townscaper and Stardew Valley, which can display bar charts, and thus provide a wider range of applications.

Factorio[13] and Satisfactory[14] are factory-building games. Factorio is a 2D game, and Satisfactory is a 3D game. In both games, the player builds factories to refine resources and produce various items. These games can visualize finite automata because items move between factories, which would represent states, and an item can be transformed into a different item in a factory. In both games, the visualizations

12. See the official page `https://www.slimerancher.com` (Accessed: 12 May 2023).
13. See the official page `https://www.factorio.com` (Accessed: 12 May 2023).
14. See the official page `https://www.satisfactorygame.com` (Accessed: 12 May 2023).

Figure 3.8: The game world of Dorfromantik.

might contain severe visual clutter. Visualizations of automata are likely too complex for children, and therefore, the games were considered unsuitable for the purpose of creating educational visualizations for children.

3.3 Summary

From the analyzed games, Townscaper and Stardew Valley are the most suitable platforms to display data visualizations. Despite both games having limitations that could negatively impact the quality of the created visualizations, they both provide the following beneficial features: The objects used in the created visualizations in the games would be easy to distinguish, in Townscaper by color, and in Stardew Valley by color and shape. The objects, building blocks in Townscaper and crops in Stardew Valley, are nearly uniform in size. Both games provide features to interact with the visualizations. Small visualizations could be viewed on the screen without the need to move the camera or the player character.

The other analyzed games all exhibited at least one significant issue, and did not provide enough other benefits so compensate for it.

4 Approach to creating visualizations

The initial analysis concluded that Townscaper and Stardew Valley are the most suitable platforms to display data visualizations. Subsequently, designs of visualizations in both games were created. Two tools were implemented to automate the creation of concrete visualizations in the two selected games.

4.1 Design

A bar chart is a widely known type of data visualization. Both Townscaper and Stardew Valley are suitable for displaying them. Therefore, to allow for comparison between the games, the decision was made to design bar charts in both games. The goal was to design visualizations that meet the sub-goals and follow the guidelines described in Section 3.1.

Initially, a single variable bar chart was designed. In Townscaper, similarly to the approach of Townscaper Dataviz, each building block represents one unit of the data values. The columns in the single variable bar charts are separated by gaps. If a value of a column is equal to zero, a gap is created to represent such a column.

The issue present in visualizations created with Townscaper Dataviz, with the columns not being placed in a straight line, was eliminated. The process is described in Subsection 4.2.1. As a result, the maximum horizontal length is limited to 100 building blocks. Because in this chart, all columns represent the same variable, they are all of the same color, which the user can select.

Two variants of the single variable bar chart were created, one with gaps between the columns and one without gaps. By visually comparing the two variants, it was determined that the gaps increase clarity and prevent undesirable visual effects from occurring. See an example of such effects in Figure 4.1.

When placing the first building block on the ocean, Townscaper always generates a grey base block. The color of the base block cannot be changed. To determine if the design should contain the grey base blocks, an example visualization was created where the base blocks were removed. The removal causes the blocks directly above it to

Figure 4.1: On the left, there is an example of a bar chart with gaps. On the right, there is an example of a bar chart without gaps. As a result of the absence of gaps, the windows are not aligned with the individual blocks. Both bar charts display values: 2, 4, 2, 3.

become significantly smaller when compared to the other blocks in the visualization. See the visualization without base blocks in Figure 4.2. The size distortion caused by removing the blocks is severe and could prove detrimental to the readability of the visualization. Therefore, this modification was not included in the final design.

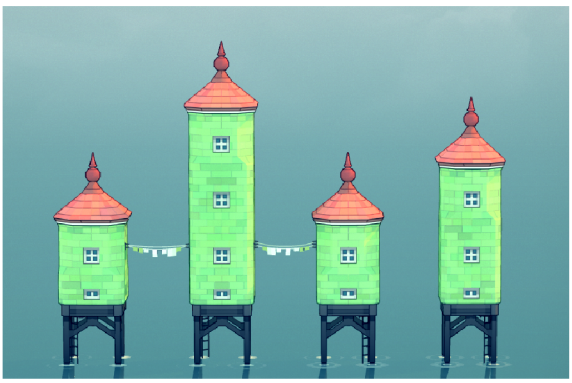

Figure 4.2: An example of a bar chart without the grey base blocks. The bar chart displays values: 2, 4, 2, 3.

In Stardew Valley, the design follows a similar approach to the design in Townscaper. Columns of a bar chart are created by placing crops. Each crop represents one unit of the data values. The size limitations are more strict than in Townscaper because the available space is limited by the size of the farm in Stardew Valley. The maximum horizontal length is 54 crops, and the maximum height of a column is 23 crops. One crop corresponds to one square of the grid.

In Stardew Valley, the design contains no equivalent of the base blocks that were present in Townscaper. The designed bar charts contain only the columns representing the values. The base blocks are not required because the grid is 2D. Adding a representation of the horizontal axis in the form of tilled soil or pavement was considered. See an example of a bar chart that contains a representation of a horizontal axis in Figure 4.3. Both variants could potentially be usable. Without user feedback, it could not be determined which variant is preferable. Because a representation of a horizontal axis is present in the Townscaper visualizations, it was determined to omit the horizontal axis in Stardew Valley. Therefore, both variants can be present in the study and compared, albeit not in the same game.

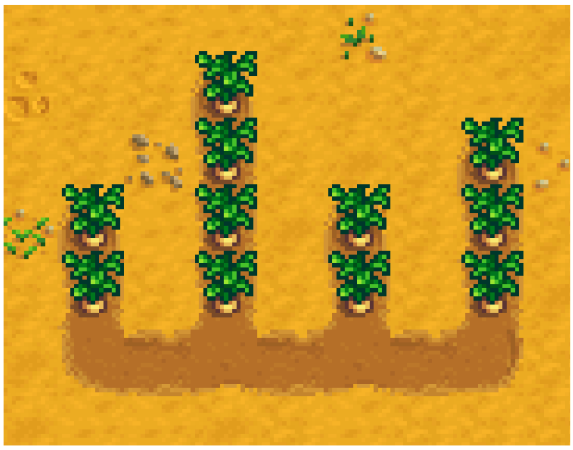

Figure 4.3: An example of a bar chart with tilled soil representing the horizontal axis. The bar chart displays values: 2, 4, 2, 3.

Subsequently, grouped and stacked bar charts were designed in both games. They follow the same principles as the single variable bar

chart designs. Stacked bar charts contain columns composed of multiple sections stacked on top of each other. Sections are distinguished by their color in Townscaper and by the type of crop in Stardew Valley. There are gaps separating the columns. Grouped bar charts contain groups, which are sequences of directly adjacent columns. The groups are separated by gaps. Each column within a group is distinguished by color in Townscaper and by crop type in Stardew Valley. See examples in Figure 4.4.

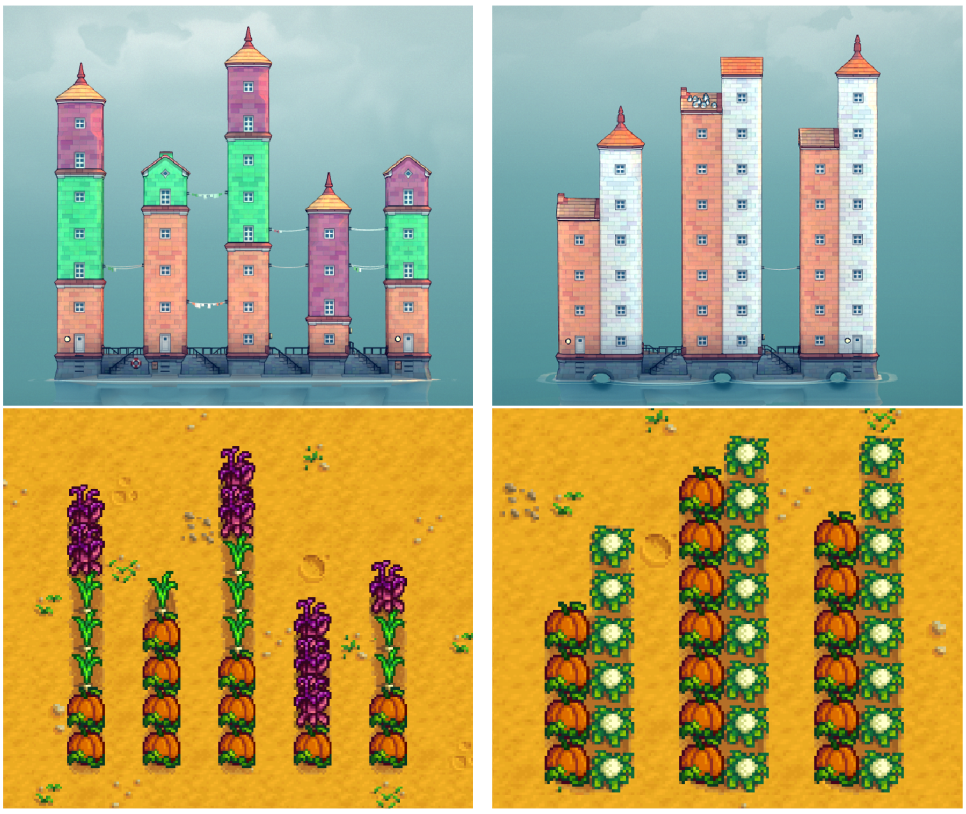

Figure 4.4: On the left, there are examples of stacked bar charts, on the top in Townscaper, and on the bottom in Stardew Valley. For easy comparison, both bar charts display the same data. On the right, there are examples of grouped bar charts, on the top in Townscaper, and on the bottom in Stardew Valley. Again, for easy comparison, both bar charts display the same data.

Additionally, 3D bar charts were designed in Townscaper. The 3D bar chart design is composed of multiple bar charts placed next to each other with gaps between them. The individual bar charts can vary in the number of values that they contain. See an example in Figure 4.5. This type of visualization cannot be created in Stardew Valley because its game world is 2D.

Figure 4.5: An example of a 3D bar chart. It consists of three bar charts, which are distinguished by colors, namely red (with values 4, 3, 4, 2), yellow (with values 2, 2, 1, 0), and purple (with values 1, 2, 1, 2).

4.1.1 Limitations

The described designs have the following limitations: The size of the visualizations is limited by the space available in the game worlds, and all designed visualizations can only display non-negative values. Townscaper and Stardew Valley do not contain features that would facilitate the creation of labels for the visualizations. Therefore, all designed visualizations rely on additional information being communicated outside of the game.

There are also game-specific limitations. In Stardew Valley, there is a day and night cycle in the game, which means that the visualizations

cannot be viewed uninterrupted for a long period of time. At 2:00 in-game time, the player will be forcefully returned to their house, and the next day will begin. The player cannot easily add crops to modify the visualization in-game, and they cannot undo their actions easily. The only means to revert changes to the visualization is to exit the game without saving and then load the save file again. The zooming feature is limited to a certain range, as described in the analysis in Subsection 3.2.2.

In Townscaper, the camera can rotate so that the visualization can be viewed from an arbitrary angle. This causes an issue for the viewer because they cannot distinguish the front side of the visualization from the back. This issue can be solved by communicating additional information to the viewer outside of the game.

4.2 Implementation

Two tools were implemented to simplify creating visualizations based on the designs described in Section 4.1. The tools, *Towncharts* and *Stardew Charts*, create visualizations in Townscaper and Stardew Valley, respectively.

4.2.1 Towncharts

Townscaper contains a feature that allows the player to copy a town that they have built in the game as an encoded string to the clipboard. Inversely, the player can load a town from the clipboard into the game. This feature provides means to easily share created visualizations.

The encoded strings can be transformed into other formats. Townsclipper[1] is a tool that decodes such text strings to various other formats, for example, JSON files. Townsclipper can also encode the other formats that it produces back to a text string that can be loaded in Townscaper. *Towncharts* creates a JSON file that represents a visualization specified by the user and uses Townsclipper to encode the file to a text string that can be loaded to Townscaper.

1. See the GitHub project `https://github.com/alvaro-cuesta/townsclipper` (Accessed: 12 May 2023).

In Townscaper, the grid for placing building blocks is infinite and consists of various polygons. In the visualizations created with Townscaper Dataviz, the columns were not aligned in a straight line because the underlying grid contained polygons other than rectangles and because the grid was curved. To prevent the issues caused by these irregularities, the grid was explored, and subsequently, several areas were discovered where the grid is only made up of rectangles, which are mostly uniform in size and lie in a straight line. The coordinates of these areas were then extracted. *Towncharts* uses these coordinates to create all visualizations. Using specific coordinates ensures that the produced visualizations are consistent and compliant with the design specifications. However, it limits the maximum width of the visualizations to 100 building blocks for the single variable, grouped, and stacked bar charts. The 3D bar charts are limited to the width of 40 building blocks and length of 7 building blocks or vice versa, including the gaps.

Towncharts is a Python 3[2] program. *Towncharts* requires Townsclipper and PySimpleGUI[3] to execute. Using the graphical user interface (GUI), the user selects the type of bar chart, inputs their data, selects colors, and optionally can set a maximum height limit. See the GUI in Figure 4.6. See the available colors in Figure 4.7.

4.2.2 Stardew Charts

For creating the visualizations in Stardew Valley, two approaches were considered: modding and save file editing. Modding could potentially provide a better user experience. For example, it would allow the user to create the visualizations in-game. However, the modding approach would require the user to install mod-loading software and the mod itself. The save file editing approach only allows for creating visualizations when the game is not running. After consideration, the save file editing approach was determined to be preferable because it does not require any setup, unlike the modding approach.

To avoid any issues, the user should use a newly created save file for generating the visualizations. The required farm type, selected during the creation of a new save file, is Standard Farm.

2. See the official page `https://www.python.org` (Accessed: 12 May 2023).
3. See the official page `https://www.pysimplegui.org/` (Accessed: 12 May 2023).

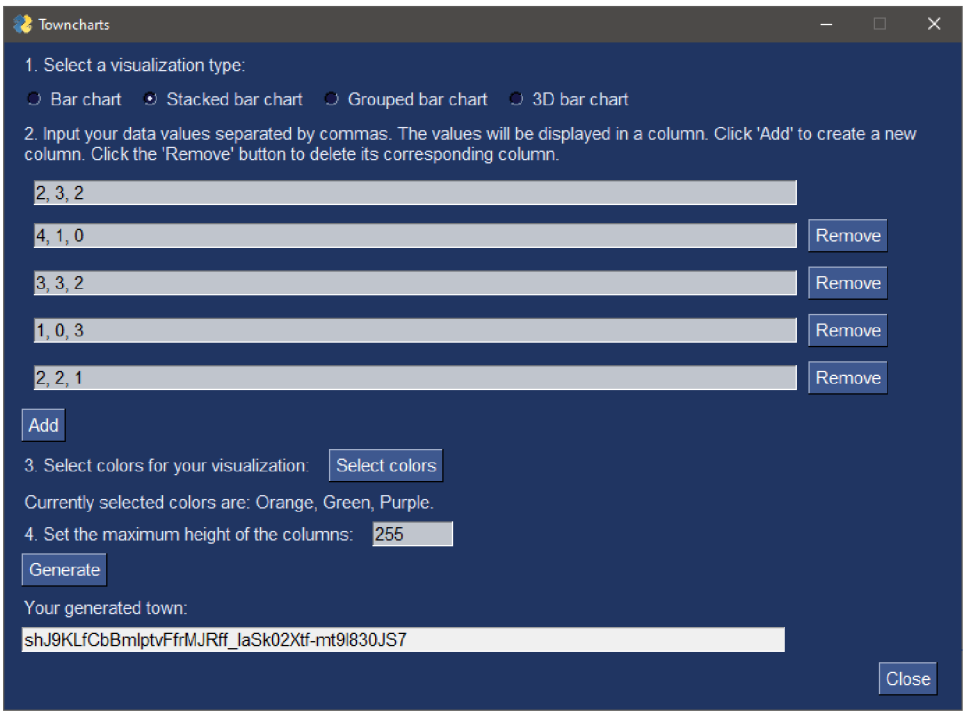

Figure 4.6: The graphical user interface of *Towncharts*. The displayed configuration and data generate the stacked bar chart in Figure 4.4.

The visualizations created in *Stardew Charts* can contain up to 12 different crops. The crops are not limited by in-game seasons – any available crops can be used in any season. There are more crops available in Stardew Valley, *Stardew Charts* includes only an illustrative sample. See the crops available in *Stardew Charts* in Figure 4.8.

Stardew Charts is a Python 3 program and requires PySimpleGUI[4] to execute. The *Stardew Charts* GUI is similarly structured to *Towncharts* GUI, except it does not generate a text string; it edits a save file that the user provides a path to. See the GUI in Figure 4.9.

4. See the official page `https://www.pysimplegui.org/` (Accessed: 12 May 2023).

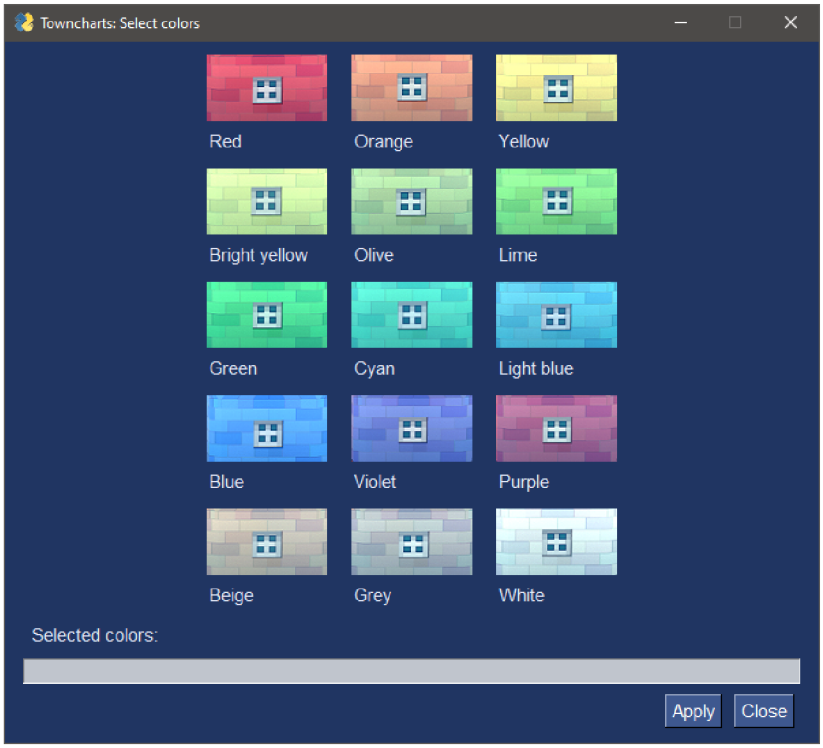

Figure 4.7: The color selection screen of *Towncharts*.

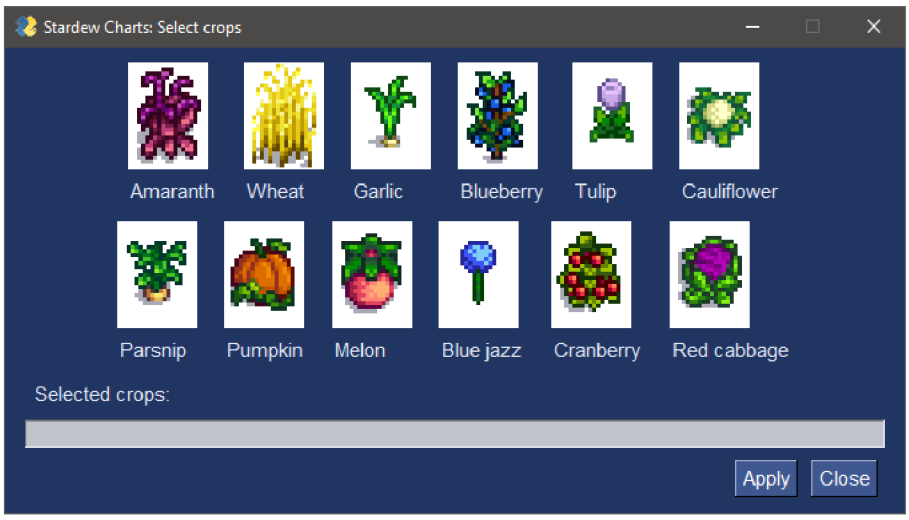

Figure 4.8: The selection of crops in *Stardew Charts*.

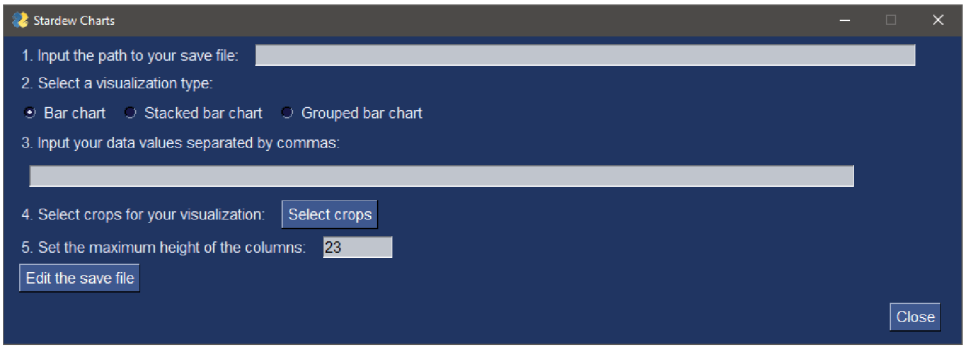

Figure 4.9: The graphical user interface of *Stardew Charts*.

5 User study

The designed visualizations are bar charts, but they contain visual elements that might distract or confuse the user, for example, in Stardew Valley, the shapes of the crops vary, and in Townscaper, some building blocks contain windows and some contain a door. These elements might be confusing because typically, in bar charts, each unit is of the same size and shape.

The interactive features of the visualizations differ from the typical interactivity present in visualization-focused software, such as Tableau. For example, in Stardew Valley, to remove one unit from a column in the bar chart, the player has to determine the correct approach to remove the crop. Some crops, such as parsnip, can be removed without a tool by the player character harvesting it. Other crops, such as wheat, have to be harvested with the scythe tool. All crops can be destroyed by using the pickaxe and axe tools. Because the player has to interact with the visualization through the interface of the game, players who are unfamiliar with the game might consider the interactions difficult. The goal of the user study was to investigate how users react to and utilize the in-game interactivity when working with the visualizations.

Playfulness in data visualization is typically not a quality that people seek in a professional or academic setting. However, the benefits of playfulness in learning are frequently discussed and researched, for example, by Parker et al. [25]. Therefore, the user study also aimed to explore the feasibility of utilizing the designed visualizations in education.

In summary, the aim of the user study was to investigate and answer the following research questions:

- Are the visualizations usable?
- What are the most commonly encountered issues when using the visualizations?
- Could these or similar visualizations be used for education purposes, specifically to teach elementary school students about data visualization?

The last question cannot be adequately answered solely based on this study because the participants of the study were adults, which are not the target audience. The target audience for the designed visualizations used for educational purposes are children. In this regard, this study aimed to determine if the idea is feasible and, therefore, if further research is plausible.

5.1 Study design

To answer the proposed research questions, it was determined that the most suitable method would be conducting a qualitative study in the form of in-person sessions that included interviews and tasks. The sessions included the participants performing tasks regarding the designed visualizations. During the tasks, the following methods were employed: the think-aloud method, as described by Lewis and Rieman [26], and the observation method, as described by Carpendale [27].

Task-based evaluation is commonly used to evaluate various types of visualizations [28, 29, 30]. The tasks were included to simulate real-life scenarios of interacting with visualizations. The designed visualizations included in the tasks are single variable bar charts, grouped bar charts, and stacked bar charts. Furthermore, for both games, each of the bar chart types is included to allow for comparison. The 3D bar charts were omitted because they can only be created in Townscaper.

The tasks were divided into two parts. Part 1 consisted of four tasks that required the participants to draw a bar chart that contained the same data as the visualization presented to them in a game. There were two tasks per game (Townscaper and Stardew Valley), and for each game, one task contained a stacked bar chart, and the other contained a group bar chart. After consideration, tasks regarding single variable bar charts were omitted from Part 1 in order to keep the sessions within the time limit of two hours. Omitting tasks in Part 1 was the logical solution because the tasks included drawing, which could be time-consuming. The single variable bar charts were omitted in favor of keeping both stacked and grouped bar charts, which contain multiple variables. The advantage of visualizations with multiple

variables is that the participants can familiarize themselves with a wider range of visual elements of the games, such as different crops. See the task sheets with instructions for each task in Appendix E and the visualizations associated with the tasks in Figure 5.1. To interact with the visualizations in the game in the same way as the participants did during the session, follow the instructions in Appendix A. The participants completed the tasks within Part 1 in random order to prevent any order effects.

The goal of tasks in Part 1 was to incentivize participants to explore the visualization in detail, to observe their interactions with the visualization, and to learn what is the intuitive interpretation of the visualizations for the participants. The instructions were purposefully minimalistic in order to allow participants some flexibility with their approach to the task and interpretation. The tasks had no strictly correct solutions.

The drawing method was included in the tasks to encourage exploration and to ensure that the participants engaged with the whole visualization, because they were tasked to draw a bar chart that contains the same information, instead of focusing on only a portion of the visualization.

Part 2 contained task types based on the analytic task taxonomy [29]. Namely, it included *retrieve value* tasks, *find extremum* tasks, *filter* tasks, and a combination of the listed task types. There were three tasks per game, and for each game, there was one task containing single variable bar charts, one task containing a stacked bar chart, and one task containing a grouped bar chart. See the task sheets with instructions in Appendix F and the visualizations associated with the tasks in Figure 5.2. To interact with the visualizations in the game, in the same way as the participants did during the session, follow the instructions in Appendix A. Similarly to Part 1, the participants completed the task within Part 2 in random order.

Tasks P2Q1 and P2Q4[1] required the participants to perform the *retrieve value* task. The added difficulty in these tasks was that at least one value in the visualizations in each task was equal to zero. In single variable bar charts, such values are represented by a gap. Tasks P2Q2

1. See the task sheets of all tasks in Part 2 in Appendix F, and still images of the correponding visualizations in Figure 5.2.

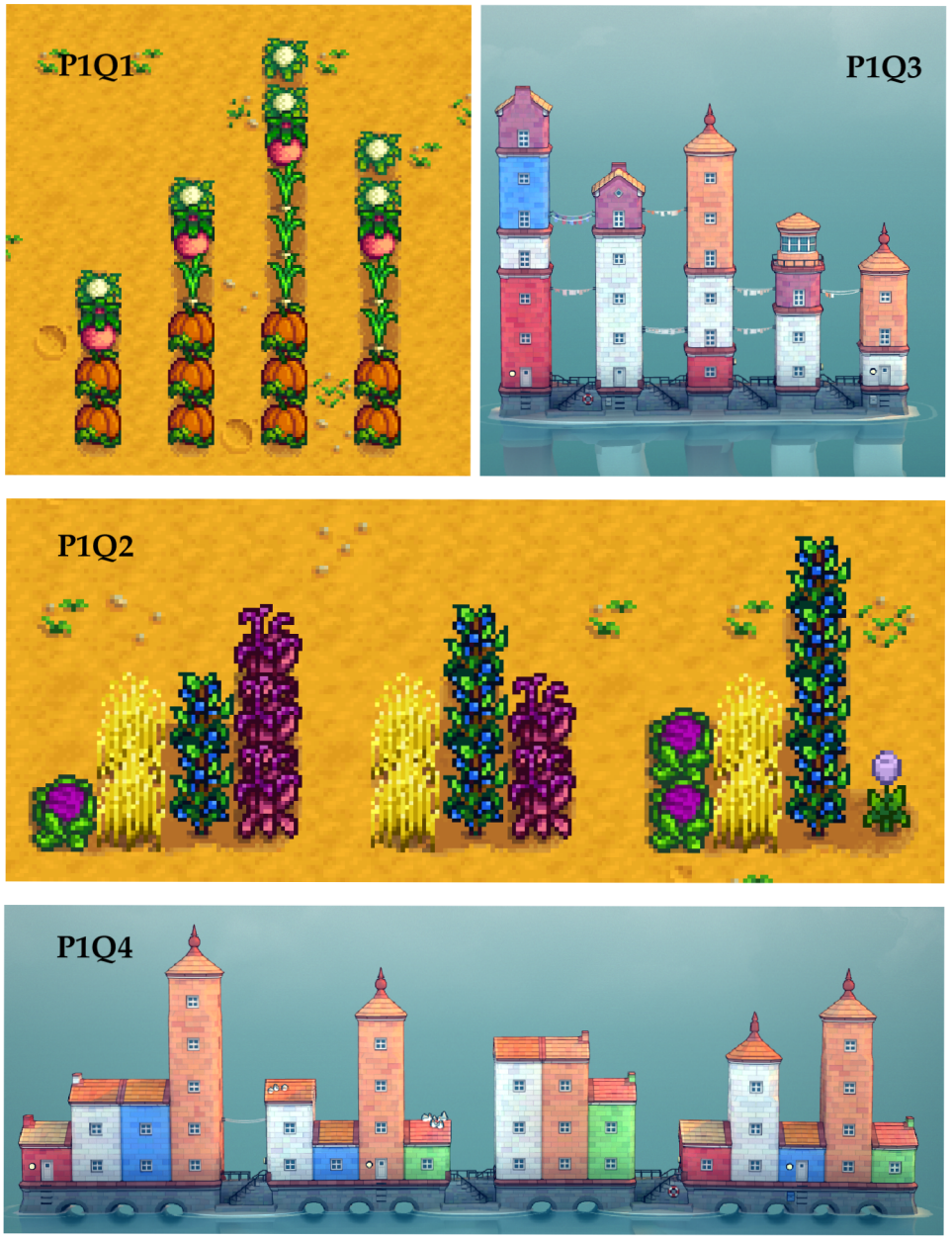

Figure 5.1: Still images of the visualizations in Part 1 tasks. Each visualization is labeled with the corresponding task reference.

and P2Q5 required the participants to perform the *find extremum* task. Both tasks contained stacked bar charts, which should simplify the tasks and ensure that the participants were not required to perform mathematical operations. Evaluating the performance of such operations was not the focus of the study. Tasks P2Q3 and P2Q6[2] required the participants to perform the *filter* and *find extremum* tasks.

The goal of tasks in Part 2 was to observe how the participants performed the listed tasks from the analytic task taxonomy. The tasks did not require the participants to perform any mathematical operations such as addition or subtraction.

After each task, the participants rated the following two statements on a seven-point Likert scale:

- The task was easy to complete.
- I am confident that I solved the task correctly.

To rate the statements, they selected from the following options on the seven-point Likert scale: Strongly disagree, Disagree, Slightly disagree, Neutral, Slightly agree, Agree, Strongly agree. The participants were also asked to explain the reasoning for the ratings. The statements were included after the completion of each task to allow participants to provide additional feedback and commentary while they were not fully focused on completing the task.

The time that it took participants to complete each task was measured. The completion times were determined from the recordings. The measured period started when participants finished reading the task instructions and ended when they declared that they finished the task in Part 1, or wrote down the answer in Part 2. At the time of performing the tasks, the participants were not aware that such metrics were measured. Participants were encouraged to complete the tasks at their preferred pace. This approach most closely simulates how the participants would interact with visualizations in real-world scenarios. The participants displayed varying approaches when working on the tasks. For example, one participant focused on time-efficiency and completed each task in Part 1 in less than 6 minutes. Conversely, another participant spent at least 7 minutes on each task in Part 1 because they were exploring the visualizations, experimenting with the

2. See the task sheets of all tasks in Part 2 in Appendix F, and still images of the correponding visualizations in Figure 5.2.

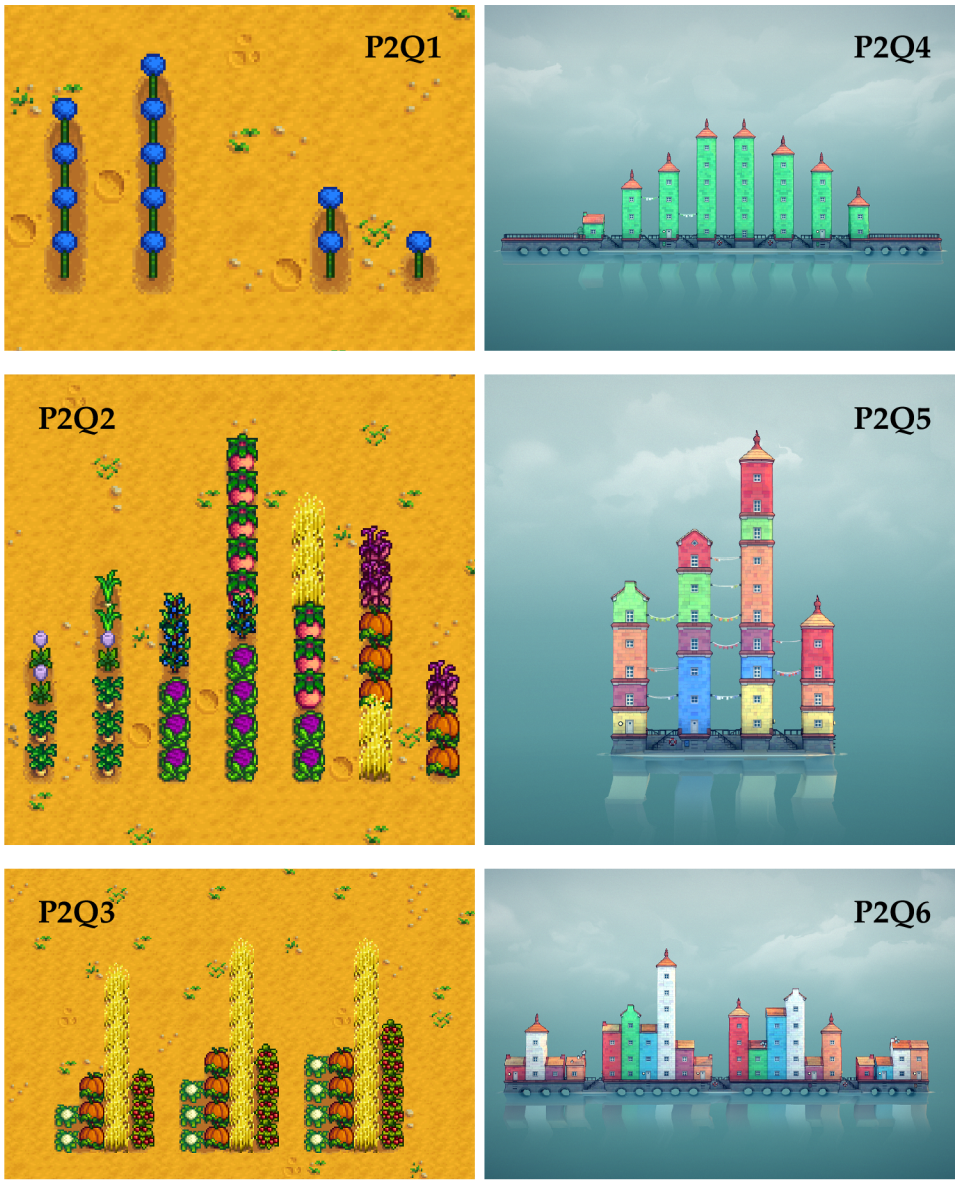

Figure 5.2: Still images of the visualizations in Part 2 tasks. Each visualization is labeled with the corresponding task reference.

interactive features, and provided detailed commentary. As a result, the completion times cannot be considered a precise metric, but they provide a general estimate of the task completion times.

5.1.1 Task solutions

The tasks in Part 1[3] do not have only one single correct solution, the participants could interpret the visualizations in many different ways and could choose to draw any type of bar chart. However, the designs of the visualizations, as described in Section 4.1, define the intended interpretations of those visualizations. The focus of tasks in Part 1 was to determine if participants would interpret the visualizations in accordance with the intended interpretations and to observe how they interact with the visualizations.

The task instructions of task P1Q1 are the following: "This visualization represents the production of crops on a farm in 2019, 2020, 2021, and 2022. Please draw a bar chart that represents the same data. Explain your process." See the still image of the corresponding visualization in Figure 5.1. In task P1Q1, the intended interpretation is the following: The farm produced two units of pumpkins, one unit of melons, and one unit of cauliflowers in 2019. In 2020, they produced three units of pumpkins, one unit of garlic, one unit of melons, and one unit of cauliflowers. In 2021, it produced three units of pumpkins, three units of garlic, one unit of melons, and two units of cauliflowers. In 2022, it produced two units of pumpkins, two units of garlic, one unit of melons, and two units of cauliflowers. The columns are not labeled with the corresponding years. The columns from left to right correspond to the years in ascending order; for example, the leftmost column corresponds to the year 2019. The exact units are not specified; therefore, the participants may choose any concrete interpretation, such as units of mass, or choose to keep the units abstract.

The task instructions of task P1Q2 are the following: "This visualization represents the production of crops on a farm in 2012, 2013, and 2014. Please draw a bar chart that represents the same data. Explain your process." See a still image of the corresponding visualization in Figure 5.1. The intended interpretation of task P1Q2 is as follows:

3. See the task sheets of all tasks in Part 1 in Appendix E, and still images of the correponding visualizations in Figure 5.1.

The farm produced one unit of red cabbages, two units of wheat, two units of blueberries, and three units of amaranth in 2012. In 2013, it produced two units of wheat, three units of blueberries, and two units of amaranth. In 2014, it produced two units of red cabbages, two units of wheat, four units of blueberries, and one unit of tulips. The groups are not labeled with the corresponding years. The groups, which are a series of adjacent columns, with individual groups being separated by gaps, from left to right, correspond to the years in ascending order. Similarly to the interpretation of the visualization in task P1Q1, the exact units are not specified.

The task instructions of task P1Q3 are the following: "This visualization represents the color distribution of newly constructed buildings in a village from 2003 to 2007. Please draw a bar chart that represents the same data. Explain your process." See a still image of the corresponding visualization in Figure 5.1. The intended interpretation of task P1Q3 is as follows: In the village, they constructed three units of red buildings, one unit of white buildings, two units of blue buildings, and one unit of purple buildings in 2003. In 2004, they constructed four units of white buildings, and one unit of purple buildings. In 2005, they constructed one unit of red buildings, two units of white buildings, and three units of orange buildings. In 2006, they constructed two units of white buildings, one unit of purple buildings, and one unit of orange buildings – despite the building block being visually different, it represents a regular unit of orange buildings. The building block is visually different as a result of Townscaper's feature that makes the buildings visually varied. This feature cannot be disabled, and the window-covered building block cannot be changed to display a regular window. In 2007, they constructed one unit of white buildings, and two units of orange buildings. Similarly to the stacked bar chart in task P1Q1, the columns are not labeled. The columns from left to right correspond to the years in ascending order. Because Townscaper contains the adjustable camera feature, the visualization can be viewed from either side. The side which is facing toward the camera upon loading the visualization in Townscaper is considered to be the front side by the intended interpretation. However, the front side is not labeled or marked in any way. The same process of determining the front side applies to all visualizations in Townscaper. The exact units that the building blocks represent are not specified. The participants

may choose any concrete interpretation, such as each building block representing one building in the real world, or they may choose to keep the units abstract.

The task instructions of task P1Q4 are the following: "This visualization represents the color distribution of newly constructed buildings in a village from 2019 to 2022. Please draw a bar chart that represents the same data. Explain your process." See a still image of the corresponding visualization in Figure 5.1. The intended interpretation is as follows: In the village, they constructed one unit of red buildings, two units of white buildings, two units of blue buildings, and five units of orange buildings in 2019. In 2020, they constructed two units of white buildings, one unit of blue buildings, four units of orange buildings, and one unit of lime buildings. In 2021, they constructed three units of white buildings, three units of orange buildings, and two units of lime buildings. In 2022, they constructed one unit of red buildings, three units of white buildings, one unit of blue buildings, four units of orange buildings, and one unit of lime buildings. Similarly to the interpretation of the visualization in task P1Q3, the exact units are not specified.

In all tasks in Part 1, the participants could draw any type of bar chart of their choosing. Their choice did not impact the results of the tasks because the aim was to observe how they interpreted the visualizations rather than assess the participants' ability to draw bar charts.

In Part 2, the visualizations are interpreted in the same way as demonstrated with the visualizations in Part 1. The questions and answers regarding tasks in Part 2[4] are the following:

- P2Q1: "This visualization represents the amount of blue jazz flowers grown on a farm from April to August. What amount was grown in July?"
  In July, the farm grew two units of blue jazz flowers.
- P2Q2: "This visualization represents the amount of crops grown on a farm from April to October. In which month was the third highest amount of crops grown?"
  The third highest amount of crops was grown in September.

4. See the still images of all visualizations in tasks in Part 2 in Figure 5.2. See the task sheets in Appendix F.

- P2Q3: "This visualization represents the amount of crops grown on a farm in 2006, 2007, and 2008. In which year was the lowest amount of pumpkins grown?"
  The least pumpkins were grown in 2006.
- P2Q4: "This visualization represents how many green buildings were constructed in a city in each month of 2010. How many green buildings were constructed in April?"
  In April, three green buildings were constructed.
- P2Q5: "This visualization represents the color distribution of buildings completed in a small town in each quarter of 2011. Which quarter has the second highest amount of completed buildings?"
  The second highest amount of completed buildings was in the second quarter of 2011.
- P2Q6: "This visualization represents the color distribution of buildings completed in a town in each quarter of 2012. In which quarter was the highest amount of light blue buildings completed?"
  The highest amount of completed light blue buildings was in the third quarter of 2012.

In all tasks in Stardew Valley, namely P1Q1, P1Q2, P2Q1, P2Q2, and P2Q3, the participants had to move the player character to the visualization at the beginning of each task. This was required because when the game starts, the player character is located in their house and the visualizations were outside of the house. The participants were informed where the visualizations were located. The visualizations were always in the same location, south of the house where the player character is when the game starts.

5.2 Procedure

Each session, including the tasks and interview, took between one and two hours and followed the same overall structure, but the exact form depended on the participant. If the participants provided detailed commentary during the tasks, they were not interrupted unless a statement required clarification. If the participants' commentary was

sparse, they were asked additional questions about their approach to completing the task or about their understanding of the task.

In each session, one participant and one interviewer were present. The interviewer was the same in all sessions. The sessions were conducted in Czech or English, depending on the preference of the participants. All task sheets and the personal information questionnaire were available in both Czech and English. See the English variants of the task sheets for Part 1 in Appendix E, the task sheets for Part 2 in Appendix F, and the personal information questionnaire in Appendix C. The Czech variants of the task sheets are available in the thesis archive as described in Appendix A.

Before the session, participants signed the Informed consent form, see Appendix B. Each participant was assigned a unique 8-digit number. All collected data was stored with this number as the only identifier.

The participants were informed that they could ask questions at any time during the session; however, that during the tasks section of the session, the interviewer could not answer questions that would reveal the solutions or, in any form, affect the outcome of the tasks. The participants were asked to confirm that they were ready to proceed, and subsequently, the video recording was commenced.

Participants filled out a brief personal information questionnaire, see Appendix C. Then they were asked questions about their attitude toward video games and about their experience and familiarity with games and data visualizations. See the full list of questions in Appendix D.

Then participants completed the tasks, first in Part 1, and then in Part 2. The visualizations in the games for each task were accessible on a laptop, and the participants also had access to a mouse and the laptop keyboard. During tasks in Part 1, participants were drawing directly on the task sheets. See the task sheets in Appendix E. The participants could use their own stationery, and they also had access to fifteen different coloring markers. Before starting their first task in each game, participants were given an explanation of the game controls. The goal was to ensure that the participants were familiar with the controls and the interactive features of each game.

After the participants completed all tasks, they were asked about their experience with the tasks and visualizations. See the full list of questions in Appendix G.

After the sessions, the recordings were transcribed into text form. Subsequently, the recordings were deleted, as was declared in the Informed consent form[5].

5.2.1 Pretest

A pretest session was conducted with one participant. The goal of the pretest was to reveal potential flaws in the design of the interview and tasks.

During the tasks in Part 1 of the pretest session, the participant focused their commentary on describing the drawing process and did not explain how they interpreted the displayed visualizations. In subsequent sessions, if the participants did not explain their interpretation of the visualization during the task, they were asked to do so after they completed the task.

The observation method revealed that the participant did not often engage with the interactive features during the tasks. For example, when solving task P1Q2, the participant asked what the names of the crops were instead of harvesting the crops to learn this information in-game. In subsequent sessions, more emphasis was put on encouraging the participants to use the interactive features. A more detailed explanation of the controls was provided, and the participants were asked to test the controls in-game. The participants were allowed to spend as much time as they wanted to test the controls and only proceeded to the tasks after they confirmed that they were ready.

Furthermore, before starting the first task, the participants were informed that they can use any available interactivity and that the visualizations can be reset to their initial state if the participants request it. Offering the participants the option to reset the visualizations aimed to alleviate any anxiety that might prevent the participants from utilizing the interactive features.

After the interview in the pretest session, the participant expressed interest in learning the correct solutions to the tasks. During the dis-

5. See the Informed consent form in Appendix B.

cussion of the correct solutions, the participant provided additional feedback. Therefore, it was determined to include similar discussions after the feedback questions in all subsequent interviews. Participants had the opportunity to discuss their task solutions with the interviewer. The intended solution approaches were explained to the participants if their solutions differed from the intended solutions.

5.3 Participants

Participants were recruited via directly sent invitations and word of mouth. The study was targeted at people between 18 and 40 years old. There were no other requirements that the participants needed to fulfill.

The sessions were conducted with nineteen participants. All participants were between 21 and 37 years old. The average age was 27. Twelve participants were male, and seven were female. None of the participants had a diagnosed color vision deficiency. One participant stated that they have difficulties with distinguishing blue from green, and grey from brown and from purple. During each task, this participant was offered aid with distinguishing colors. The participant was able to do so without assistance. Therefore, this issue had no impact on the session.

The participants stated that they work or study in the following fields: twelve participants in IT, two participants in psychology, one participant in construction, one participant in pedagogy, one participant in architecture, one participant in medicine, and one participant in linguistics. Seven participants stated that they work full-time, three that they work part-time, five that they are students, and four stated that they both work and study.

The highest level of education completed by the participants varied. One participant completed elementary school, five participants completed high school, five participants had a Bachelor's degree, seven participants had a Master's degree, and one participant had a doctorate.

When inquired about their attitude towards video games, fifteen participants stated that they have a positive attitude, three participants that they have a neutral attitude, and one participant that they have a

negative attitude. When asked about how frequently they play video games, among the fifteen participants with a positive attitude towards games, the answers ranged between playing at least five hours per day and playing only once per month for a few hours. Out of the participants with a neutral attitude, one participant stated that they play games at most two hours per week, and the other two participants stated that they do not play video games regularly. The participant with a negative attitude towards video games also stated that they do not play regularly. All participants stated that they have previously played at least one video game.

Twelve participants stated that they knew Stardew Valley and, out of those participants, seven have previously played the game. Out of those seven, four participants have played it for less than 10 hours, one participant played it for roughly 40 hours, and two participants played it for more than 100 hours.

Seven participants stated that they knew Townscaper. Only two of those participants have played it. Both of those participants played it for less than 10 hours.

Twelve participants stated that they encountered some form of data visualization regularly, and the remaining seven participants reported that they did not encounter visualizations regularly. When asked if they are familiar with bar charts, all participants confirmed that they are familiar with them. Sixteen participants stated that they felt confident about their ability to interpret and understand bar charts, two participants stated that they felt neutral, and one participant stated that they did not feel confident.

The participants were asked to interpret the bar charts in Figure D.1. All participants interpreted the grouped bar chart correctly. Thirteen participants expressed, without explicitly being asked, that they prefer grouped bar charts to stacked bar charts. All participants except one interpreted the stacked bar chart correctly. The one participant perceived the sections in the columns as columns overlapping one another. Therefore, they concluded that, for example, in primary school, six children chose blue as their favorite color.

The native language of thirteen participants was Czech and of two participants Slovak. The sessions with these participants were conducted in Czech. The native language of two participants was

German, of one Finnish, and of one Swedish. The sessions with these participants were conducted in English.

6 User study results

This chapter contains an overview of the task results and describes how participants interpreted the visualizations. It also contains the minimum, maximum, and median completion times of each task. It contains the Likert scale ratings of the statements after each task, including the reasoning that participants provided for their ratings. The chapter lists the discovered issues with the visualizations. It also includes the feedback provided by the participants by answering the questions listed in Appendix G. It describes the observations made during the tasks by employing the observation method.

6.1 Tasks in Part 1

For examples of drawings that the participants created in Part 1, see the following figures: Figure 6.1 displays an example solution of task P1Q1, Figure 6.2 displays example solutions of tasks P1Q2 and P1Q4, and Figure 6.3 displays an example solution of task P1Q3. All listed examples accurately depict the same data as the corresponding visualizations in games, as was required by the task instructions, and the participants who created the displayed drawings provided correct interpretations of those visualizations. Because the participants were allowed to draw any type of bar chart, these drawings do not represent the only possible solutions to their respective tasks, they only display one possible solution.

Several participants interpreted the visualizations in tasks in Part 1 differently from the intended interpretation as described in Subsection 5.1.1, namely, one participant in task P1Q1, two in P1Q2, three in P1Q3, and two in P1Q4 interpreted the visualizations differently than intended. Detailed descriptions of those cases are in Subsection 6.1.1.

In task P1Q1, nine participants drew a stacked bar chart, which was the same type of bar chart as the displayed visualization. Nine participants drew a grouped bar chart because that was their preferred type, and one participant drew a percentage bar chart because they wanted to view the data from a different perspective. In task P1Q2, which contained a grouped bar chart, fifteen participants drew a grouped bar chart, three participants drew a stacked bar chart because they

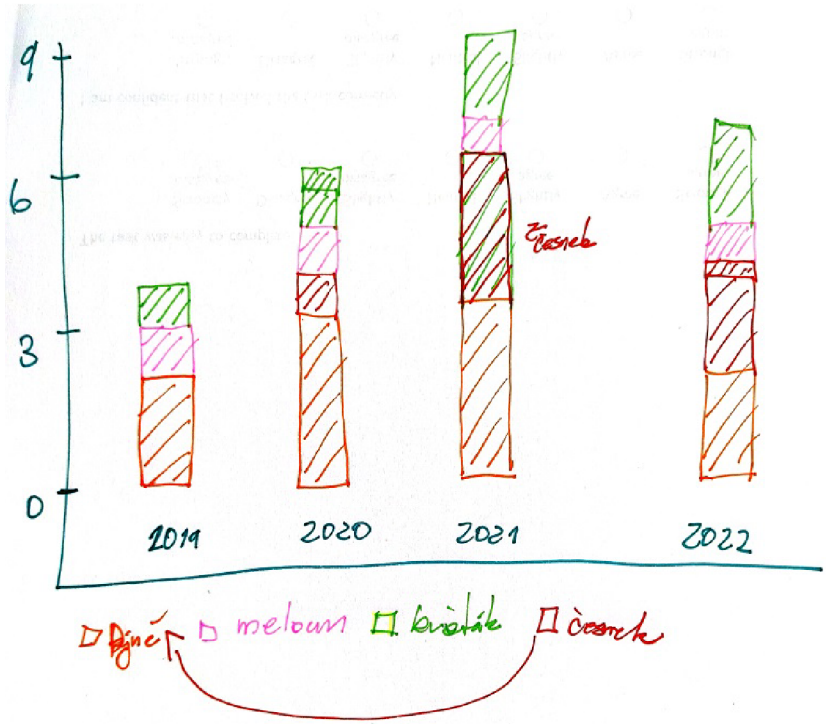

Figure 6.1: An example of a solution of task P1Q1.

did not want to draw an exact copy of the displayed visualization, one participant drew a scatter plot because they misread the instructions, which required a bar chart, and they subjectively preferred a scatter plot. In task P1Q3, which contained a stacked bar chart, twelve participants drew a stacked bar chart (one of them drew it horizontally), five participants drew a grouped bar chart because that was their preferred type, one participant drew a percentage bar chart, and one participant drew a regular bar chart – this participant did not interpret the visualization as intended[1]. In task P1Q4, which contained a grouped bar chart, fifteen participants drew a grouped bar chart, three participants drew a stacked bar chart because they did not want to draw an exact copy of the displayed visualization, and one participant drew a regu-

1. See more information in Subsection 6.1.1.

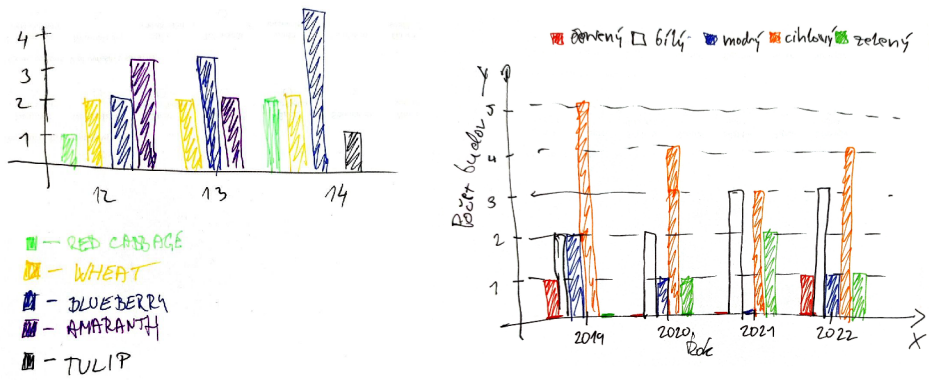

Figure 6.2: Example solutions of tasks P1Q2 on the left, and P1Q4 on the right.

lar bar chart – this participant did not interpret the visualization as intended[2].

Table 6.1 contains information about the completion times of tasks in Part 1. These tasks involved drawing; therefore, the minimum, maximum, and median completion times were longer than in tasks in Part 2, which only required the participants to answer questions.

Table 6.1: Completion times of tasks in Part 1 in minutes and seconds.

Task	Minimum	Maximum	Median
P1Q1	2:39	11:36	7:01
P1Q2	3:07	17:02	6:16
P1Q3	3:18	12:00	5:01
P1Q4	3:10	11:55	6:45

Eight participants spent the most time on the task in Part 1, which they were solving first. Six participants spent the most time on their second task, two participants on their third task, and three participants on their fourth task. Note that the order of the tasks differed between participants because they were solving the tasks in random order.

2. See more information in Subsection 6.1.1.

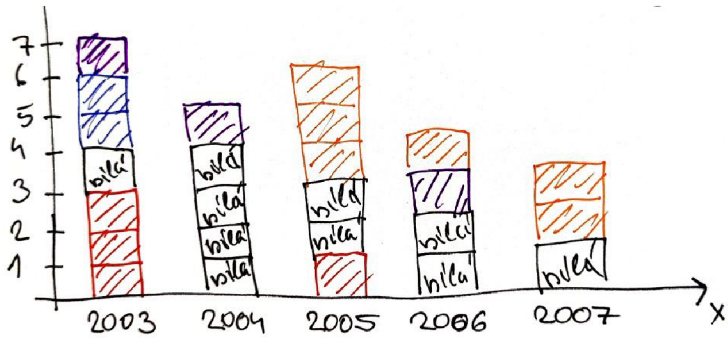

Figure 6.3: An example of a solution of task P1Q3.

6.1.1 Alternative interpretations

Following are descriptions of cases when participants presented interpretations of the visualizations in tasks in Part 1[3], that differed from those described in Subsection 5.1.1.

In task P1Q1[4], one participant stated that they did not know how to interpret the visualization because it was a stacked bar chart. They concluded that they were not able to provide an interpretation of the visualization. This participant previously interpreted the example stacked bar chart in Figure D.1 incorrectly. This issue was caused by the participant being unfamiliar with the interpretation of stacked bar charts and was unrelated to the specific visualizations. The participant subsequently interpreted the visualization in task P1Q3[5], which was also a stacked bar chart, as intended. In task P1Q3, the participant explained that their previous interpretation, which was incorrect but

3. See the instructions of all tasks in Part 1 in the task sheets in Appendix E, and the corresponding visualizations in Figure 5.1.
4. The task instructions of P1Q1 are the following "This visualization represents the production of crops on a farm in 2019, 2020, 2021, and 2022. Please draw a bar chart that represents the same data. Explain your process." See the corresponding visualization in Figure 5.1.
5. The task instructions of P1Q3 are the following "This visualization represents the color distribution of newly constructed buildings in a village from 2003 to 2007. Please draw a bar chart that represents the same data. Explain your process." See the corresponding visualization in Figure 5.1.

they were not aware of this, seemed invalid to them in task P1Q3. They reasoned that some colored sections of the columns were not present in each column. For example, in the second column from the left, as seen in Figure 5.1, the red and blue sections were not present. They reasoned that this invalidates their previous interpretation because that interpretation would, in this case, mean that some sections are "hidden" behind other sections. Therefore, the participants would not be able to determine the values of those hidden sections. They concluded that such an interpretation seems unlikely to be correct. Subsequently, they interpreted the stacked bar chart in task P1Q3 correctly.

In Stardew Valley, each fully grown crop can be harvested to obtain produce, which will be referred to as harvested items. In task P1Q2[6], one participant reasoned that the task instructions referred to the harvested items instead of crops, which was not the intended interpretation. The intended interpretation considers only the crops, as described in Subsection 5.1.1. The participant drew a graph displaying the numbers of the harvested items, which differ from the numbers of crops. See the drawing in Figure 6.4, and the displayed visualization in Figure 5.1. During the task, the participant stated:

> "This is not very intuitive to me and I don't really understand what the game is telling me." (Gender: female, age: 27)

The participant previously had no issues interpreting regular bar charts. However, they previously stated that they were inexperienced with video games and that they did not know Stardew Valley.

Another participant, in the same task, initially decided to draw a bar chart displaying the numbers of crops, which is the intended approach. However, after harvesting several crops, they discovered that the numbers of harvested items and the numbers of crops vary. They concluded that they had to draw two separate bar charts, as shown in Figure 6.5. In the drawing, the top bar chart is the intended

6. The task instructions of P1Q2 are the following "This visualization represents the production of crops on a farm in 2012, 2013, and 2014. Please draw a bar chart that represents the same data. Explain your process." See the corresponding visualization in Figure 5.1.

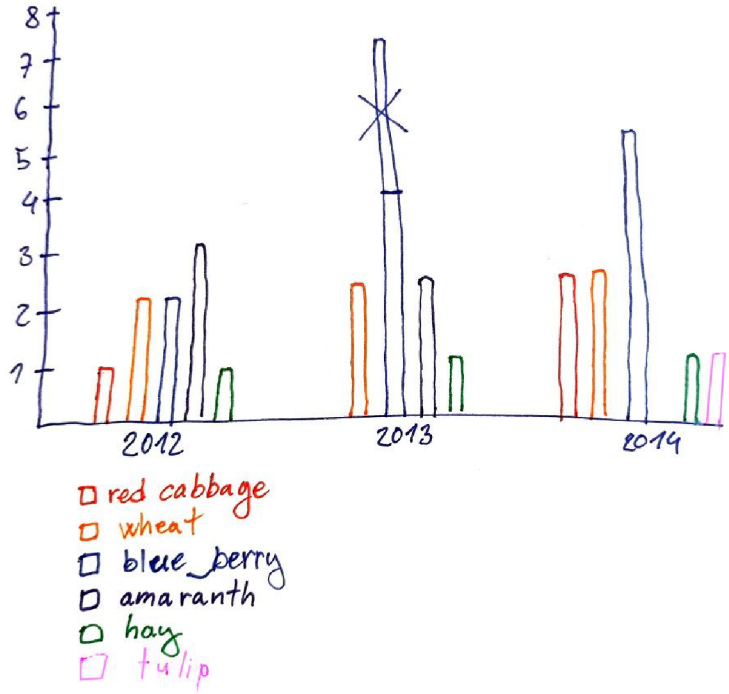

Figure 6.4: An example solution of task P1Q2. The participant drew a bar chart displaying the harvested items.

solution, as displayed in Figure 6.2 on the left. This participant reported playing games regularly and knowing Stardew Valley.

In task P1Q3, one participant interpreted each column of the bar chart as one building in the real world, and each building block of the column as one floor of the building in the real world. In the intended interpretation, each column represents all constructed buildings in a given year, with each building block of the column representing one building in the real world. The participant also debated if all the columns in the visualization are the *newly constructed buildings* described in the task instructions, or if only some of them are the *newly constructed buildings*. They correctly concluded that all the columns had to be the *newly constructed buildings* because there were no labels in the visualization to determine the age of the buildings. The participant applied the same interpretation to the visualization in task P1Q4. This

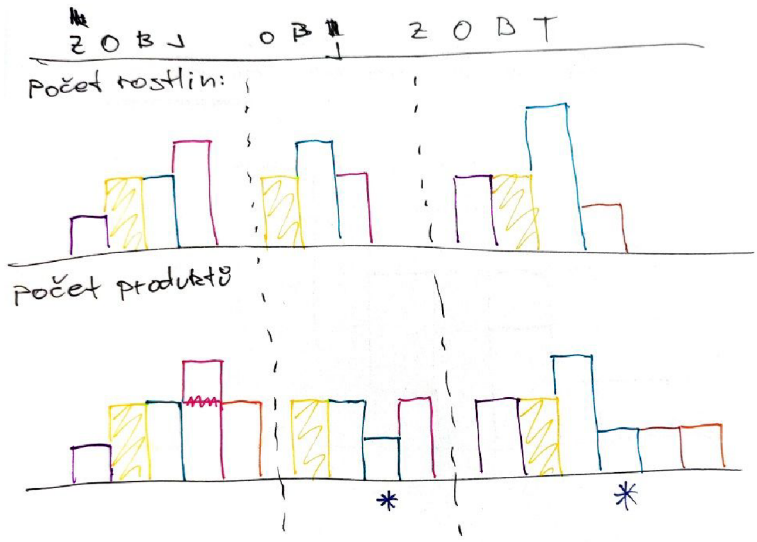

Figure 6.5: An example solution of task P1Q2. At the top, the participant drew a bar chart displaying the numbers of crops, and below it, a bar chart displaying the numbers of harvested items.

interpretation differs from the intended one, but it allows for the direct translation of real world information and minimizes abstraction.

Another participant in the same task presented a nearly identical interpretation. Additionally, they suggested that the colors could represent different time periods in which the buildings were constructed but they did not include the years specified in the task instructions into their interpretation.

In the same task, one participant reasoned that the building blocks in the columns in-game have to be built in a sequence, starting at the bottom and adding new blocks on top of existing blocks. They stated that this sequence in the visualization represents the chronological order of the buildings being constructed in the real world. In the intended interpretation, the chronological order of the buildings being built is determined only by the years, which correspond to the columns. See the intended interpretation in Subsection 5.1.1. The participant considered the years in the instructions to only provide general information about the time period of the buildings being constructed, and

did not consider that the years could correspond to the columns. This participant stated that they played games for multiple hours every day and that they previously played Townscaper. This case suggests that a high level of knowledge about the game might not provide a significant advantage when interpreting the visualizations. However, it cannot be confirmed without further research.

In task P1Q4[7], one participant interpreted the grouped bar chart with four groups as four separate bar charts, and they stated that they did not understand why there were four bar charts. The intended interpretation was that each group corresponds to one year, as described in Subsection 5.1.1. The participant drew one bar chart that contained one column for each color present in the displayed visualization. They summed together the values of the same color from all four groups. Therefore, their bar chart contained the following values: two units of red buildings, ten units of white buildings, four units of blue buildings, sixteen units of orange buildings, and four units of green buildings. When discussing the task solutions, they stated that in the instructions, the range of years appeared unimportant and that they decided to ignore the information. This participant previously reported that they were not confident in their ability to interpret bar charts and that they did not use data visualizations regularly. Therefore, it is possible that their interpretation was affected by those factors.

6.2 Tasks in Part 2

Table 6.2 contains information about how many participants solved each task in Part 2 correctly, and how many solved each task incorrectly. See the correct answers in Subsection 5.1.1. The incorrect answers are described in Section 6.4, including descriptions of how participants derived the incorrect answers and what issues they encountered.

Thirteen participants solved all tasks correctly. Five participants solved one task incorrectly, and one participant solved two tasks incorrectly.

7. The task instructions of P1Q4 are the following "This visualization represents the color distribution of newly constructed buildings in a village from 2019 to 2022. Please draw a bar chart that represents the same data. Explain your process." See the corresponding visualization in Figure 5.1.

Table 6.2: The results of tasks in Part 2. The *Correct* column displays how many participants solved the corresponding task correctly, and the *Incorrect* column displays how many participants solved the corresponding task incorrectly.

Task	Correct	Incorrect
P2Q1	17	2
P2Q2	17	2
P2Q3	19	0
P2Q4	16	3
P2Q5	19	0
P2Q6	19	0

Table 6.3 contains information about the minimum, maximum, and median completion times of tasks in Part 2. The maximum time overall, when considering all participants and all tasks in Part 2, is 3 minutes and 54 seconds. The median times of all tasks in Part 2 are below one minute. The times in Table 6.3 were derived from all measured times, including those from tasks that the participants solved incorrectly. When only including times of correctly solved tasks, the following changes occur: the median of task P1Q2 changes to 0:42, the minimum of task P2Q4 changes to 0:34, and the median of task P2Q4 changes to 0:56.

Table 6.3: Completion times of tasks in Part 2 in minutes and seconds.

Task	Minimum	Maximum	Median
P2Q1	0:21	2:18	0:38
P2Q2	0:11	1:20	0:28
P2Q3	0:07	1:52	0:11
P2Q4	0:24	2:21	0:55
P2Q5	0:05	1:38	0:41
P2Q6	0:05	3:54	0:20

6.3 Likert scale ratings

After each task, the participants rated the following two statements on a 7-point Likert scale: *"The task was easy to complete."* denoted as S1, and *"I am confident that I solved the task correctly."* denoted as S2. See the ratings in Table 6.4. The ratings of tasks in Part 1 suggest that participants did not perceive the tasks as difficult, because the majority of participants selected *Agree* or *Strongly agree* to rate statement S1. The majority of participants also selected *Agree* or *Strongly agree* to rate statement S2 in Part 1 tasks.

For all tasks in Part 2, the majority of participants selected the *Strongly agree* option to rate both statements with the following exceptions: S1 in task P2Q1, and S1 in task P2Q4. These ratings suggest that tasks in Part 2 were also perceived as easy. The two excluded tasks, P2Q1 and P2Q4, are tasks that contain single variable bar charts where some values are equal to zero. The ratings suggest that such visualizations were perceived as more difficult by the participants.

Following is a brief description of all cases where participants selected the *Neutral*, *Slightly disagree*, *Disagree*, or *Strongly disagree* options to rate any statement in any task.

In task P1Q1, one participant selected the *Neutral* option for both statements. The participant stated that their reason for the ratings is that they are uncertain how to interpret stacked bar charts. This participant previously interpreted the example stacked bar chart[8] incorrectly, and interpreted the bar chart in this task in the same way. For the same reason, this participant also selected the *Neutral* option for both statements in task P1Q3, and in Part 2, for both statements in tasks P2Q2 and P2Q5. However, in that task, they interpreted the visualization in accordance with the intended interpretation[9].

One participant in P1Q1 selected the *Slightly agree* option for S1, and *Neutral* option for S2. Their reasoning was that they decided to draw a percentage bar chart, which required them to calculate the percentage representation of each value in each column. The participant stated that they knew that this type of bar chart was not required by the

8. See the example bar chart in Figure D.1.
9. See the intended interpretations of all visualizations in Part 1 in Subsection 5.1.1.

Table 6.4: Likert scale ratings of all tasks. The statement "The task was easy to complete." is denoted as S1, "I am confident that I solved the task correctly." is denoted as S2. The columns display how many participants selected the corresponding rating.

	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
P1Q1: S1	0	0	0	1	2	7	9
P1Q1: S2	0	0	0	2	3	7	7
P1Q2: S1	0	0	2	1	0	7	9
P1Q2: S2	0	2	0	2	3	4	8
P1Q3: S1	0	0	1	2	1	9	6
P1Q3: S2	0	0	0	5	3	4	7
P1Q4: S1	0	0	0	0	4	7	8
P1Q4: S2	0	0	0	1	4	7	7
P2Q1: S1	0	0	0	0	3	8	8
P2Q1: S2	0	0	0	0	2	5	12
P2Q2: S1	0	0	0	1	1	6	11
P2Q2: S2	0	0	0	1	0	4	14
P2Q3: S1	0	0	0	0	0	2	17
P2Q3: S2	0	0	0	0	1	2	16
P2Q4: S1	0	0	0	1	6	8	4
P2Q4: S2	0	1	0	2	0	4	12
P2Q5: S1	0	0	0	2	0	6	11
P2Q5: S2	0	0	1	2	2	3	11
P2Q6: S1	0	0	0	0	0	6	13
P2Q6: S2	0	0	0	1	1	3	14

instructions but that they wanted to use it. The participant interpreted the visualization in task P1Q1 as intended.

In task P1Q2, one participant selected *Slightly disagree* to rate statement S1, and *Neutral* to rate statement S2. The participant initially debated what the visualization represented. Per task instructions, see Appendix E, it represents the production of crops on a farm in 2012, 2013, and 2014. The participant considered the following options two: it displays the production of crops, or it displays the increase in the production of crops. The participant also considered drawing two separate bar charts, one for annual crops and one for perennial crops. When starting the task, they commented:

> "I find it weird about this task that it'd be asking me to keep copying what I see, and I feel like I'm doing it wrong because it's too easy." (Gender: female, age: 21)

When discussing the intended solution later during the interview, the participant further explained that they approached the tasks as a school test and, therefore, they expected trick questions. The participant eventually decided to interpret the visualization as intended.

Another participant in task P1Q2 selected the *Neutral* option for statement S2. Their reason was that the task instructions did not specify what type of bar chart they should draw, and therefore, there were many possible approaches. They interpreted the visualization as intended.

In task P1Q2, the participant who drew two separate bar charts, one displaying the crops, and one displaying the harvested items[10], selected the *Slightly disagree* option for statement S1. They explained that they did not perceive the task as easy because the number of harvested items did not exactly correspond to the number of crops, and therefore, they had to draw two bar charts, as shown in Figure 6.5. The intended interpretation does not require harvesting; it only involves the displayed crops.

Another participant, who harvested items in task P1Q2 and drew a bar chart representing those items, as described in Section 6.1.1, selected *Neutral* for statement S1 and *Disagree* for statement S2. They commented that they were certain that they had made a mistake,

10. See more information in Section 6.1.1.

and they listed the following elements that they considered confusing: harvesting wheat produces hay and wheat, some harvested blueberries are marked with a silver star, some crops are harvested by hand and some by using the scythe.

In the same task, one participant selected the *Disagree* option for statement S2. Their reason was that they considered the graph that they drew to be of poor quality. They considered the visualization to be easy to interpret, and they selected the *Strongly agree* option for statement S1.

In task P1Q3, one participant selected the *Slightly disagree* option for statement S1. Their reason was that they arranged the order of variables in their drawn bar chart differently than in the displayed visualizations, and it required increased focus to do so. They decided to rearrange the variables because of their personal preference. The task did not require it, which they acknowledged.

In the same task, two participants selected the *Neutral* option for statement S2, and one participant selected *Neutral* for both statements. All three participants reasoned that because of the ability to rotate the camera, they could not be certain which side is the front side. All of them determined the front side correctly and interpreted the visualization as intended.

In task P1Q4, one participant selected the *Neutral* option for statement S2. Their reason was that they cannot be certain if their interpretation was correct. The participant interpreted the visualization as intended.

In Part 2 task P2Q4, one participant selected the *Neutral* option, and one selected the *Disagree* option for statement S2. Both participants stated that the reason for their rating was the ability to rotate the camera. Because of it, they were uncertain how to determine which side is the front. Both participants solved the task correctly. The participant, who selected the *Disagree* option, also selected the *Neutral* option for statement S2 in tasks P2Q5 and P2Q6 for the same reason.

In task P2Q4, one participant selected the *Neutral* option for both statements. They concluded that the task could not be answered based on the displayed visualization, which was not the correct solution. They took into consideration only the visible columns, meaning the columns represented non-zero values. However, there were only eight

such columns in the visualization. Therefore, the participant could not determine which columns correspond to which months.

In task P2Q5, one participant selected the *Slightly disagree* option for statement S2. The participant explained that the task was too easy. Therefore, they expected that there was something they had missed or misunderstood. The participant solved the task correctly.

In the same task, one participant selected the *Neutral* option for statement S1. Their reason was the ability to rotate the camera made them uncertain about which side was the front side. They also considered an alternative interpretation where each colored section represented a building of that color in the real world. In the intended interpretation, each building block represents a building in the real world. Eventually, the participant decided to apply the same interpretation as they did previously, which was the intended interpretation. They solved the task correctly.

6.4 Discovered issues

Five participants stated that the absence of labels made the visualizations more difficult to understand in both games. One of those participants solved task P2Q1 incorrectly. During the task, the participant wrote abbreviations of the months given by the task instructions on the task sheet. Then they determined what the correct answer was, which was July, and attempted to find the abbreviation corresponding to that month. However, two of the abbreviations were the same, and they mistakenly selected the one that did not correspond to the correct month. When discussing this solution, the participant commented that they would not have made such a mistake if the columns in the visualizations were labeled.

With grouped bar charts in both games, three participants disliked that when a value of a column was equal to zero, that column was omitted in the visualization. For example, in the visualization from task P1Q2 in Figure 5.1, the value of red cabbages in the middle group is zero; therefore, the column is omitted. The participants suggested leaving a gap when a value of a column is zero in grouped bar charts.

In visualizations in tasks P2Q1 and P2Q4, the value of some columns was equal to zero. In task P2Q1, three participants accurately reported

that if such a value was at the beginning or at the end, the task would be impossible to solve unless additional information was provided.

In task P2Q4, twelve participants expressed that it was challenging to map the months of the given year to their corresponding columns in the visualization. One participant commented:

> "It's unclear when there are multiple zero values next to each other because there is no visual difference between columns that have a value equal to zero and gaps." (Gender: male, age: 25)

The participants who solved this task incorrectly provided the following answers: one participant answered 6 because that was the fourth non-zero value column in the visualization, one participant answered 0 because the fourth value from the left was equal to 0 when considering gaps to also be values, and one participant stated that the question in the task cannot be answered based on the visualization because they cannot determine which column corresponds to April. A possible modification to improve clarity could be to remove the base blocks in the gaps between values. See an example of this modification applied to the visualization from task P2Q4 in Figure 6.6. One participant used this approach to solve the task.

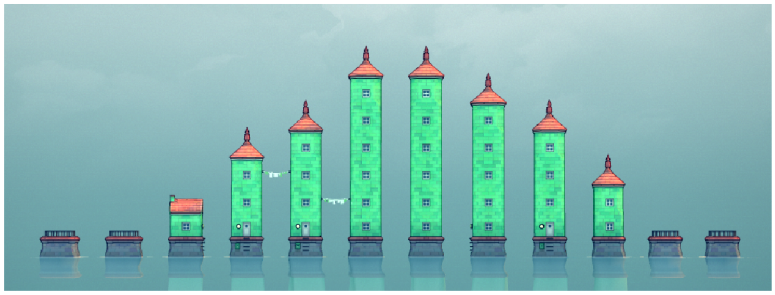

Figure 6.6: An example of the visualization from task P2Q4 without the base blocks in the gaps that separate columns.

In Townscaper, five participants debated if the base blocks are included in the values or are only a representation of the horizontal axis, which is the intended interpretation. All participants correctly concluded that the base block did not count towards the values. One

participant remarked that being able to test the controls helped them with the decision because they placed blocks themselves and knew that the first blocks built on the ocean in always the base block. On the contrary, two participants stated that the base blocks helped them interpret the visualizations more easily. The base could be removed as described in Section 4.1. However, the removal of the base blocks caused undesirable visual effects, as displayed in Figure 4.2. Because of the lack of consensus on the topic among participants, further research is required to determine if such modification of the visualizations would have a positive impact on the user experience.

Seven participants commented that because of the ability to rotate the camera in Townscaper and because the front side is not marked in any way, they could view the visualization from either side and obtain different information. However, all participants, with one exception, decided to consider the side that faces more toward the camera upon loading as the front side, which is the intended interpretation. The participant, who was the exception, in task P1Q4 drew their bar chart based on what would be considered the back side of the visualization according to the intended interpretation. The participant acknowledged that depending on the side they choose, the resulting visualization would be different. They chose one side at random because they concluded that they could not determine which side was the intended front side. However, they could have reset the visualization to its starting position to determine the front side at any time.

To easily determine which side is the intended front side, one participant suggested placing a base block in front of each column on the front side. They reasoned that it is intuitive to mark the front rather than the back. Furthermore, they commented that this modification sometimes results in Townscaper generating a door at the bottom building blocks of the columns, and that could potentially be perceived as the front side of the building and, by extension, as the front side of the visualization. See an example of this modification applied to the visualization from task P1Q3 in Figure 6.7.

Multiple participants reported that the visualizations are more difficult to interpret because the building blocks are not completely uniform. Five participants considered it distracting that the roofs were visually not all the same. Two participants inspected the front-facing

Figure 6.7: An example of the visualization from task P1Q3 with additional base blocks in front of each column used to mark the front side of the visualization.

triangle roofs more closely to determine if they were a roof or a building block. Both participants stated that those roofs look deceptively similar to the building blocks because such a large portion of the roof is colored. See an example of the roofs on the two leftmost columns in Figure 5.1 in the visualization from task P1Q3. Two participants stated that the presence of roofs distorts the visual height comparison in some cases. For example, in task P1Q4, as shown in Figure 5.1, in the leftmost group, the value of the blue column is equal to 2, but the height of the column when including the roof is nearly the same as the height of three building blocks in the adjacent orange column.

Most building blocks contain a window, but some blocks on the bottom floor have doors instead. Four participants stated that the doors make it more difficult to count the number of building blocks in a column because they focused on counting windows, which are visually different.

One participant commented that it is distracting for them that some building blocks are more rounded than others. An example of this is visible on the top blocks in columns consisting of two blocks in Figure 4.5.

Another visual element that nine participants considered confusing was the window-covered orange block. See the block on the top of the fourth column from the left in Figure 5.1 in the visualization from task P1Q3. One participant stated that it was difficult to notice because the blue color of the windows blended with the background. Another participant briefly considered interpreting the window-covered block as a representation of a different variable than the regular orange blocks.

The variability of visual elements in Townscaper is a feature of the game and cannot be disabled.

Regarding visualizations in Stardew Valley, twelve participants noted that the sprites of some crops are taller than others and that the taller sprites overlap, which makes it more difficult to distinguish the individual sprites. Participants reported the issue with the sprites of blueberry, amaranth, and wheat. See the sprites in Figure 4.8, and an example of overlapping crops in the visualization for task P1Q2 in Figure 5.1. Likely as a result of this issue, two participants miscounted the number of crops during the tasks. The miscounted crops in those instances were blueberry and amaranth.

A solution that was proposed by two participants would be to leave gaps between the vertically adjacent crops. This solution would limit the maximum height of the columns to only twelve crops because of the available space limitations of the farm where the visualizations are displayed.

In Part 1, when completing tasks regarding visualizations in Stardew Valley, three participants worked on the tasks until the in-game time reached night-time, which resulted in the game world becoming dark and the visualizations being nearly indiscernible. The fact that the visualization can only be viewed for a limited time period negatively impacts its usability. The three participants, who worked on the tasks until the in-game night-time, required more time because their drawings were detailed. See an example of one of their drawings in Figure 6.8.

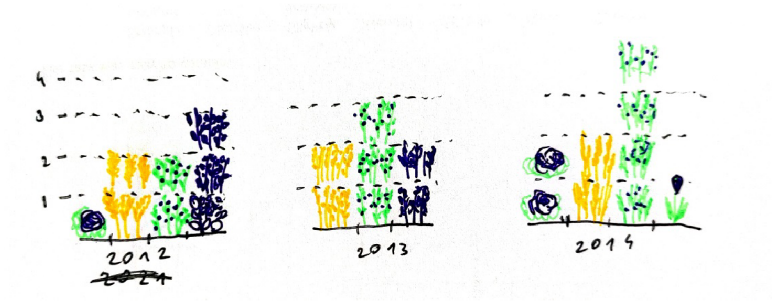

Figure 6.8: An example of a detailed drawing of the visualization from task P1Q2.

6.5 Participants' feedback

The Likert scale ratings suggest that the participants perceived the tasks as easy. This sentiment is further reinforced by the participants' feedback. When asked about how they perceived the overall difficulty of the tasks, two participants expressed that the tasks were not difficult but that the participants felt very uncertain about their performance when solving them, which suggests that they did not perceive them as easy, one participant stated that the tasks were of medium difficulty, eleven participants stated that the tasks were overall easy but some tasks were more challenging that others[11], and five participants stated that all tasks were easy with no exceptions.

The participants were asked if they felt like their understanding of the visualizations improved over time. Twelve participants answered affirmatively. They listed the following things they improved at: they determined how to interpret the visualizations, they became faster at retrieving values because they developed a routine, such as counting windows to determine the value of a column in Townscaper, they became more familiar with the visuals and with the controls of the games. Seven participants did not observe any improvement in their understanding of the visualizations. Six of those participants stated that the visualizations were easy to understand from the beginning

11. The examples of more challenging tasks that the participants provided are the following: all tasks in Part 1 for two participants, task P1Q1 for one participant, task P2Q4 for five participants.

and remained equally easy throughout. One participant stated that they did not observe any improvements, but they were not able to provide a reason.

When asked if the visualizations were easy to interpret, seventeen participants replied affirmatively. One participant stated that they were easy to interpret in Townscaper but not in Stardew Valley because the sprites of the crops varied in height and sometimes overlapped. One participant stated that it depended on the displayed values. They perceived visualizations where some values were equal to zero as more difficult, especially when the visualization type was a single variable or grouped bar chart. In single variable bar charts, they considered it difficult to determine which months correspond to which columns because the columns were not present when their value was equal to zero. In grouped bar charts, they disliked that the non-zero columns were all adjacent and there were no gaps representing the zero-value columns.

Three participants stated that there were no elements in the visualizations that made them more difficult to understand. The remaining participants all reported at least one issue with the visualizations. All reported issues are discussed in Section 6.4.

Participants were asked if the visualizations in one game were easier to understand than the visualizations in the other game. Eleven participants preferred the visualizations in Townscaper, six participants in Stardew Valley, and two participants had no preference. The participants who preferred Townscaper stated that the advantages of it were that the graphics were detailed, it had the camera movement and zooming features, there were the base blocks representing the horizontal axis, and the individual building blocks were easy to count because of the windows. In comparison with Stardew Valley, they stated that modifying the visualization was easier than in Stardew Valley, the crops in Stardew Valley were difficult to count because they visually blended together, the shapes of the building blocks were less varied than the shapes of the crops, and the controls were easier or more intuitive than in Stardew Valley.

The participants who preferred Stardew Valley stated that the height levels of columns were easier to visually compare than in Townscaper, each crop of the same type was visually the same, unlike the varied building blocks in Townscaper, and there was only one way to

view the visualization because the camera could not be rotated which decreased ambiguity compared to Townscaper.

The participants were asked what they would change about the visualizations to make them easier to understand. Their suggestions were previously discussed in Section 6.4.

The participants were asked if they considered the visualizations aesthetically pleasing. Eighteen participants stated that overall they considered the visualizations to be aesthetically pleasing. One participant stated that they would describe them as "eye-catching" rather than aesthetically pleasing.

Eleven participants preferred the aesthetics of Townscaper, five participants preferred the aesthetics of Stardew Valley, and two participants liked both equally. Six participants stated that they liked the visuals of Townscaper because the graphics were detailed and because the game world was 3D. Four participants stated that they disliked the pixelated art style and, therefore, disliked the visuals of Stardew Valley. One participant stated that they liked the pixelated art style. Two participants commented that they liked the Stardew Valley visuals because they were "lively" and "colorful". One participant expressed that they liked the farm-related visual theme of Stardew Valley.

The participants were asked if they considered working with the visualizations entertaining. Twelve participants answer affirmatively. Out of those participants, two stated that they enjoyed solving the tasks because they like solving puzzles, four stated that they liked the novelty aspect of the visualizations being different from regular bar charts, three participants stated that they liked the visuals of the visualizations, six participants stated that it was entertaining to use the interactive features in the games, and one participant stated that they liked that the visual theme of the visualizations matched the information it was displaying, for example, in Stardew Valley, crops in the game were used to visualize the produce in the real world. Five participants did not consider working with the visualizations entertaining. One of those participants stated that their attitude was neutral rather than negative. Four of those participants stated as the reason that they would rather use regular bar charts because it would be easier and more time-efficient.

The participants were asked where or how could the designed visualizations be useful. Twelve participants stated that they could be used for educational purposes, namely for learning about bar charts. Three participants stated that they could be used for displaying gameplay data in-game. Two participants stated that they could not think of any use case for the visualizations. One participant did not provide a specific use case, but they stated that the visualizations are suitable for children and people who are not familiar with bar charts. He reasoned that to those audiences, the visualizations could be more appealing than regular bar charts because they are playful. One participant suggested that the visualizations could be used in promotional material for the games.

The participants were asked if they considered the visualizations suitable for use in education, namely to teach children about data visualization. This question and the previous question were purposefully asked in this order to avoid influencing the participants' answers to the previous question. All twelve participants who previously suggested using the visualization for educational purposes answered affirmatively. Out of the remaining seven participants, five answered affirmatively. One participant stated that the visualizations could be used for educational purposes but only in elementary school. They reasoned that for elementary school children, it would be entertaining, but older audiences might consider it childish. One participant stated that the visualizations could be used for educational purposes if the children could create the visualizations themselves. They reasoned that just interpreting the visualizations would not be sufficiently entertaining, and it would not hold the children's attention.

Thirteen participants stated that the playfulness of the visualizations would be beneficial when used in education. They suggested that the visualizations could appeal to the children more than regular bar charts and, therefore, would hold their attention for longer. Two participants emphasized that the visualizations are best suited for elementary school children because older children might consider them childish or uninteresting. Four participants stated that the visualizations could be used to demonstrate the differences between grouped and stacked bar charts, and to teach which is more suitable for which purpose. Five participants stated that it is paramount that the children can create visualizations themselves and not only interpret

existing ones. They reasoned that the creative process would facilitate learning better than interpreting visualizations and that it would be more enjoyable for the children. Two participants emphasized that to use the visualizations for educational purposes, they have to be nearly flawlessly designed to avoid confusing or frustrating the children. One participant stated that the visualizations could be used to introduce the concept of bar charts but that they would not be useful for audiences already familiar with regular bar charts.

6.6 Observations

This section describes observations about the participants' behavior during the tasks.

In Stardew Valley, overall, nine participants across all tasks harvested crops for the purpose of learning the names of the crops. In tasks P1Q1 and P1Q2, eleven and nine participants, respectively, invented the names of the crops and made no attempts to determine their names in-game. Across all tasks, five participants walked over the crops, which made them shake. The participants used it to count the crops more easily. Two participants harvested items from crops to count the crops more easily because they visually change or disappear after being harvested.

In Townscaper, fourteen participants used the highlighting feature in task P2Q4, four participants used it in task P1Q4, one participant used it in task P1Q3, and one participant used it in task P2Q5. In all those instances, the participants used the feature to easily count the building blocks.

7 Discussion

This chapter discusses the results of the user study and proposes potential solutions to the discovered issues described in Section 6.4. Based on the user study results, this chapter also provides answers to the research questions, which were described in Chapter 5.

Despite the discovered issues described in Section 6.4, the results suggest that the tasks were easy to solve. In Part 2, three tasks were solved correctly by all participants, and from the remaining three tasks, each had at most three participants who answered incorrectly. This sentiment was confirmed by the participants' feedback in Section 6.5, and the Likert scale ratings in Section 6.3.

Tasks in Part 2 required the participants to perform the *retrieve value*, *find extremum*, and *filter* types of tasks based on the analytic task taxonomy [29]. Tasks P2Q1 and P2Q4 were based on the *retrieve value* type, P2Q2 and P2Q5 were based on the *find extremum* type, and P2Q3 and P2Q6 were a combination of the *filter* and *find extremum* types. The most incorrect answers, five in total, were recorded for the pair of P2Q1 and P2Q4. However, it seems unlikely that retrieving values was the cause of the incorrect answers because the *find extremum* task type contains the *retrieve value* task as its subtask[29], and there were fewer incorrect answers for tasks of that type. Namely in tasks P2Q3, P2Q5, and P2Q6, all participants answered correctly. The possible contributing factors to the incorrect answers could be that participants were less familiar with single variable bar charts because they were not present in tasks in Part 1, and that the visualizations in tasks P2Q1 and P2Q4 contained columns with values equal to zero, which made it challenging for the participants to determine what each column represents[1].

As described in Subsection 6.1.1, there were two cases of participants not interpreting the visualization in task P1Q2 as intended. One of those participants reported that they were inexperienced with video games and that they did not know Stardew Valley. The other participant reported that they played games regularly and that they knew Stardew Valley. These cases demonstrate that familiarity with the games might not provide a significant advantage when interpret-

1. The issue is discussed in relation to task P2Q4 in Section 6.4

ing the visualizations. To prevent misinterpretation of the designed visualizations, it is recommended to display them alongside a brief guide on how to interpret them.

7.1 Solutions to discovered issues

As described in Section 6.4, participants suggested that adding labels to the visualizations would be beneficial. The games contain no features that would facilitate a solution to this problem. In Stardew Valley, the player can craft and place a *Wood Sign* object, which displays an in-game item on it. However, it is limited to displaying in-game items and cannot display alphanumeric symbols. Therefore, using the *Wood Sign* to display labels would still require additional information to be communicated outside of the game, which offers little improvement over the current state. Creating an overlay program that displays user created labels could potentially solve this issue. However, the camera in neither game is static, therefore, the positions of the labels would have to adjust automatically, and in Townscaper, they would have to account for the 3D movement and perpective. Therefore, this approach would require solving complex labeling problems. Oeltze-Jafra and Preim [31] presented a survey of labeling techniques that are used in medical visualizations that could potentially be utilized in this solution.

For grouped bar charts, the participants suggested leaving gaps in place of columns, which have value equal to zero. In the current design of grouped bar charts, as described in Section 4.1, such columns are omitted completely and no gaps are placed. Adding the gaps would require modifying the separator between groups because in the current design, groups are separated by gaps. Increasing the number of gaps in a group separator would not be sufficient in cases when there are many adjacent zero-value columns because the adjacent gaps representing zero-value columns might be mistakenly interpreted as a separator between groups. One possible solution is to select one color and declare columns of that color to be the separators between groups. This information would have to be communicated to the viewer outside of the game because the separator columns would be indistinguishable

from regular columns. This solution would decrease the number of available colors for the visualization by one.

In tasks P2Q1, participants noted that if a column with its value equal to zero was at the beginning or at the end, the visualization provides no information to determine in which of those two locations the column actually is. The solution to this issue could be to either add a representation of the horizontal axis or, alternatively, to add a marker at the bottom of each column. See an example visualization with tilled soil as markers in Figure 7.1. The marker could be, for example, tilled soil, stone pavement, or any in-game object. One participant suggested solving the issue by extending the tilled soil in each column to the height level of the highest column present in the visualization. See an example in Figure 7.1.

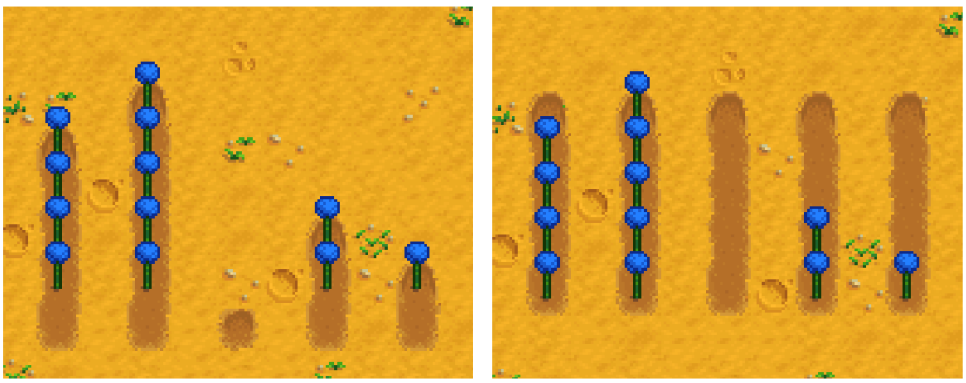

Figure 7.1: On the left, there is an example of a visualization in Stardew Valley that contains tilled soil that marks the bottom of each column. On the right, there is an example of a visualization with the extended tilled soil in each column.

To solve the issue of overlapping sprites in Stardew Valley, visualizations could only use crops that have nearly square-shaped sprites. This solution would limit the number of unique crops that are available to use in the visualizations.

To allow the visualizations in Stardew Valley to be viewed for an unlimited period of time, it would be necessary to prevent the in-game night-time from commencing. Preventing night-time with the current

approach is not possible. However, this issue can be solved with the modding approach.

Solutions to the discovered issues that were proposed by the participants are described in Section 6.4.

7.2 Answers to the research questions

Following are answers to the proposed research questions based on the results of the user study described in Chapter 6.

> Are the visualizations usable?

The results in Chapter 6 suggest that participants overall had no issues solving the tasks and interpreting the visualizations. Thirteen participants solved all tasks in Part 2 correctly. Four tasks in Part 2 (namely P2Q2, P2Q3, P2Q5, P2Q6) received Likert scale ratings, where the majority of participants selected the *Strongly agree* option. See Table 6.4. Those ratings further show that the participants perceived the tasks as easy and that they were confident about their solutions. Despite the issues with the visualizations described in Section 6.4, seventeen participants stated that the visualizations were easy to interpret. In tasks in Part 1, the majority of participants were able to interpret the visualization as intended with only the task instructions and no additional guidance. This suggests that the intended interpretation is intuitive. The results suggest that the visualizations are usable.

> What are the most commonly encountered issues when using the visualizations?

All discovered issues of the visualizations are described in Section 6.4. The four most commonly encountered issues (reported by seven or some participants) were: determining which side of the visualization is the front because of the ability to rotate the camera in Townscaper, determining which months correspond to which columns in task P2Q4[2], the visual elements of columns in Townscaper not being uni-

2. See the instructions in the task sheet in Appendix F, and a still image of the visualization in Figure 5.2.

form[3], and the sprites of some crops, namely blueberry, wheat, and amaranth, overlapping in Stardew Valley. Solutions to these issues proposed by the participants are described in Section 6.4, and additional solutions are proposed in Section 7.1. No solution was proposed to the visual elements of Townscaper not being uniform because the variability of visual elements is a feature of the game and cannot be disabled.

> Could these or similar visualizations be used for education purposes, specifically to teach elementary school students about data visualization?

All participants stated that the visualizations could be used for educational purposes. However, two participants stated that they could only be used under specific circumstances, namely only in elementary school, and only if the children could create the visualizations themselves. Overall, two participants reasoned that the visualizations are best suited for elementary school children, and five participants stated that the children have to be able to create visualizations themselves. See all suggestions made by the participants in Section 6.5.

The results suggest that the visualizations could be used for educational purposes. However, it is recommended to implement the solutions to the discovered issues, as described in Section 6.4 and Section 7.1, and conduct a further study to evaluate these modifications and their impact on the user experience.

7.2.1 Study limitations

The target audience for the visualizations is children. However, the study was conducted with adults because conducting a study with children poses a significant challenge from an ethical perspective, and because it would be inadvisable to conduct a study with children before confirming that the designed visualizations are usable, and before evaluating potential flaws in the design.

3. These elements include the varied roof types, roofs distorting the visual height comparison, varied building block shapes, doors appearing instead of windows, and the window-covered block.

Another limitation is that the sample does not contain an equal representation of men and women. Furthermore, the majority of participants study or work in IT, all participants are young – less than 40 years old, and the majority of participants stated that they have a positive attitude towards video games and play them regularly. Therefore, the sample does not accurately represent the general population.

7.2.2 Future work

The results of the user study confirmed that the visualizations are usable, but many issues were discovered. This thesis proposed potential solutions to the issues. A further study is required to determine if these solutions are viable and would benefit the design of the visualizations. When the design is sufficiently refined, a user study could be conducted with children to evaluate how they interact with the visualizations. As the participants proposed, it is recommended to allow the children to create visualizations rather than interpret existing visualizations because it is an interactive creative process that is more likely to be enjoyable for the children.

The observations in Section 6.6 suggest that the participants did not frequently harvest the crops in Stardew Valley to learn their names. The participants tested the controls of the game before the tasks, and they were informed that they could harvest the crops. Therefore, they were aware of the option to use the feature and have decided not to utilize it. The potential reasons could be, for example, that the participants were focused on solving the tasks and forgot about the feature or that they did not consider the feature beneficial. To learn more about the participants' perception of the feature, a future study could include tasks which would require the participants to use the harvesting feature to solve the tasks.

8 Conclusion

This thesis aimed to propose designs of visualizations in existing games and evaluate those designs. The evaluation was conducted to answer the following research questions regarding the visualizations:

- Are the visualizations usable?
- What are the most commonly encountered issues when using the visualizations?
- Could these or similar visualizations be used for education purposes, specifically to teach elementary school students about data visualization?

An analysis was conducted to determine which games are the most suitable platforms for displaying visualizations. Townscaper and Stardew Valley were selected in the analysis. Designs of single variable bar charts, grouped bar charts, and stacked bar charts were proposed for both games. A design of a 3D bar chart was proposed for Townscaper. Tools were implemented to simplify the creation of visualizations based on the proposed designs.

A user study was conducted with nineteen participants to evaluate the designed visualizations. The study included interviews and tasks regarding the designed visualizations. The visualizations included in the study were single variable bar charts, grouped bar charts, and stacked bar charts in both Townscaper and Stardew Valley. The 3D bar charts were omitted because they cannot be created in Stardew Valley; and therefore, could not be compared between the games.

The study determined that the visualizations are usable. Overall, participants considered the tasks to be easy, and the visualizations to be understandable. The most frequently encountered issues were determining the front side of the visualizations in Townscaper because the camera could be rotated, determining which categories on the horizontal axis correspond to which columns in a single variable bar chart when some values are equal to zero[1], the visual elements of

1. This refers to taks P2Q4. See the instructions in the task sheet in Appendix F, and a still image of the visualization in Figure 5.2.

Townscaper, such as roofs and building block shapes, not being uniform, and the sprites of crops in Stardew Valley overlapping, namely the sprites of blueberry, wheat, and amaranth.

Using the designed visualizations for educational purposes was determined to be feasible. All participants stated that the visualizations could be suitable for teaching children about data visualization, namely about bar charts.

For future work, it is recommended to implement and evaluate the solutions to the discovered issues proposed by this thesis. Subsequently, a study could be conducted to evaluate the visualizations with children.

Bibliography

1. DJAOUTI, Damien; ALVAREZ, Julian; JESSEL, Jean-Pierre; RAMPNOUX, Olivier. Origins of Serious Games. In: 2011, pp. 25–43. ISBN 978-1-4471-2160-2. Available from DOI: 10.1007/978-1-4471-2161-9_3.
2. KUHN, Jeff. Minecraft: education edition. *Calico journal*. 2018, vol. 35, no. 2, pp. 214–223.
3. ZAMMITTO, Veronica. VISUALIZATION TECHNIQUES IN VIDEO GAMES. In: 2008. Available from DOI: 10.14236/ewic/EVA2008.30.
4. UNWIN, Antony. Why is data visualization important? what is important in data visualization? *Harvard Data Science Review*. 2020, vol. 2, no. 1, p. 1.
5. BOY, Jeremy; RENSINK, Ronald A.; BERTINI, Enrico; FEKETE, Jean-Daniel. A Principled Way of Assessing Visualization Literacy. *IEEE Transactions on Visualization and Computer Graphics*. 2014, vol. 20, no. 12, pp. 1963–1972. Available from DOI: 10.1109/TVCG.2014.2346984.
6. TAL, Aner; WANSINK, Brian. Blinded with science: Trivial graphs and formulas increase ad persuasiveness and belief in product efficacy. *Public Understanding of Science*. 2016, vol. 25, no. 1, pp. 117–125. Available from DOI: 10.1177/0963662514549688. PMID: 25319823.
7. SIMKOVA, Monika. Using of Computer Games in Supporting Education. *Procedia - Social and Behavioral Sciences*. 2014, vol. 141, pp. 1224–1227. ISSN 1877-0428. Available from DOI: https://doi.org/10.1016/j.sbspro.2014.05.210. 4th World Conference on Learning Teaching and Educational Leadership (WCLTA-2013).
8. HAWORTH, Robert; SEDIG, Kamran. The importance of design for educational games. *Education in a technological world*. 2011, pp. 518–522.

9. NOEMÍ, Peña-Miguel; MÁXIMO, Sedano Hoyuelos. Educational Games for Learning. *Universal Journal of Educational Research*. 2014, vol. 2, pp. 230–238. Available from DOI: 10.13189/ujer.2014.020305.

10. YU, Zhonggen. A Meta-Analysis of Use of Serious Games in Education over a Decade. *International Journal of Computer Games Technology*. 2019, vol. 2019, pp. 1–8. Available from DOI: 10.1155/2019/4797032.

11. GÄBLER, Johannes; WINKLER, Christoph; LENGYEL, Nóra; AIGNER, Wolfgang; STOIBER, Christina; WALLNER, Günter; KRIGLSTEIN, Simone. Diagram Safari: A Visualization Literacy Game for Young Children. In: *Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*. Barcelona, Spain: Association for Computing Machinery, 2019, pp. 389–396. CHI PLAY '19 Extended Abstracts. ISBN 9781450368711. Available from DOI: 10.1145/3341215.3356283.

12. HUYNH, Elaine; NYHOUT, Angela; GANEA, Patricia; CHEVALIER, Fanny. *Designing Narrative-Focused Role-Playing Games for Visualization Literacy in Young Children*. 2020. Available from arXiv: 2008.13749 [cs.HC].

13. ADAR, Eytan; LEE-ROBBINS, Elsie. *Roboviz: A Game-Centered Project for Information Visualization Education*. 2022. Available from arXiv: 2208.04403 [cs.HC].

14. AMABILI, Lorenzo; GUPTA, Kuhu; RAIDOU, Renata. A Taxonomy-Driven Model for Designing Educational Games in Visualization. *Proceedings of the IEEE*. 2021, vol. PP, pp. 1–1. Available from DOI: 10.1109/MCG.2021.3115446.

15. DIAKOPOULOS, Nicholas; KIVRAN-SWAINE, Funda; NAAMAN, Mor. Playable Data: Characterizing the Design Space of Game-y Infographics. In: 2011, pp. 1717–1726. Available from DOI: 10.1145/1978942.1979193.

16. CARDOSO, Bruno; COHN, Neil; TRUYEN, Frederik; BROSENS, Koenraad. Explore Data, Enjoy Yourself - KUbism, A Playful Approach to Data Exploration. In: ARDITO, Carmelo; LANZILOTTI, Rosa; MALIZIA, Alessio; PETRIE, Helen; PICCINNO, Antonio;

DESOLDA, Giuseppe; INKPEN, Kori (eds.). *Human-Computer Interaction – INTERACT 2021*. Cham: Springer International Publishing, 2021, pp. 43–64. ISBN 978-3-030-85613-7.

17. WALLNER, Günter; KRIGLSTEIN, Simone. PLATO: A visual analytics system for gameplay data. *Computers & Graphics*. 2014, vol. Volume 38, pp. 341–356. Available from DOI: 10.1016/j.cag.2013.11.010.

18. KUAN, Yen-Ting; WANG, Yu-Shuen; CHUANG, Jung-Hong. Visualizing Real-Time Strategy Games: The Example of StarCraft II. In: *2017 IEEE Conference on Visual Analytics Science and Technology (VAST)*. 2017, pp. 71–80. Available from DOI: 10.1109/VAST.2017.8585594.

19. LI, Wei; FUNK, Mathias; LI, Quan; BROMBACHER, A.C. Visualizing event sequence game data to understand player's skill growth through behavior complexity. *Journal of Visualization*. 2019. Available from DOI: 10.1007/s12650-019-00566-5.

20. NAIDOO, Jef; CAMPBELL, Kim. Extended abstract: Best practices for data visualization. In: *2016 IEEE International Professional Communication Conference (IPCC)*. 2016, pp. 1–3. Available from DOI: 10.1109/IPCC.2016.7740509.

21. AHDELL, Rolf; ANDRESEN, Guttorm. Games and simulations in workplace eLearning. *Master of Science Thesis*. 2001.

22. *Creating Dataviz Using the Video Game 'Townscaper'* [online]. Medium, 2022 [visited on 2023-04-15]. Available from: https://debugger.medium.com/creating-dataviz-using-the-video-game-townscaper-8d7038e0815e.

23. *Wordle2Townscaper* [online]. [visited on 2023-04-15]. Available from: https://github.com/tarmo888/Wordle2Townscaper.

24. TESSLER, Chen; GIVONY, Shahar; ZAHAVY, Tom; MANKOWITZ, Daniel; MANNOR, Shie. A Deep Hierarchical Approach to Lifelong Learning in Minecraft. In: 2016.

25. PARKER, Rachel; THOMSEN, Bo; BERRY, Amy. Learning Through Play at School – A Framework for Policy and Practice. *Frontiers in Education*. 2022, vol. 7. Available from DOI: 10.3389/feduc.2022.751801.

26. LEWIS, Clayton; RIEMAN, John. Task-centered user interface design. *A practical introduction*. 1993.

27. CARPENDALE, Sheelagh. Evaluating Information Visualizations. In: 1970, pp. 19–45. ISBN 978-3-540-70955-8. Available from DOI: 10.1007/978-3-540-70956-5_2.

28. SAKET, Bahador; ENDERT, Alex; DEMIRALP, Çağatay. Task-Based Effectiveness of Basic Visualizations. *IEEE Transactions on Visualization and Computer Graphics*. 2019, vol. 25, no. 7, pp. 2505–2512. Available from DOI: 10.1109/TVCG.2018.2829750.

29. AMAR, R.; EAGAN, J.; STASKO, John. Low-Level Components of Analytic Activity in Information Visualization. In: 2005, vol. 15, pp. 111–117. ISBN 0-7803-9464-X. Available from DOI: 10.1109/INFVIS.2005.1532136.

30. DUNCAN, Ian K.; TINGSHENG, Shi; PERRAULT, Simon T.; GASTNER, Michael T. Task-Based Effectiveness of Interactive Contiguous Area Cartograms. *IEEE Transactions on Visualization and Computer Graphics*. 2021, vol. 27, no. 3, pp. 2136–2152. Available from DOI: 10.1109/TVCG.2020.3041745.

31. OELTZE-JAFRA, Steffen; PREIM, Bernhard. Survey of Labeling Techniques in Medical Visualizations. In: 2014.

32. *Bar Chart* [online]. [visited on 2023-04-15]. Available from: https://www.twinkl.cz/teaching-wiki/bar-chart.

A Contents of the thesis archive

The archive of this thesis, in the Masaryk University Information System, contains the following:

- The *Towncharts* folder, which contains the tool for creating visualizations in Townscaper.
- The *Stardew Charts* folder, which contains the tool for creating visualizations in Stardew Valley.
- The *Tasks* folder, which contains the save files required to recreate the tasks in Stardew Valley, and a text file containing the encoded towns required to recreate the tasks in Townscaper. To recreate the Stardew Valley tasks, place the save files into the `StardewValley/Saves` folder[1] while the game is not running. Then run the game and load the save file. Each save file is named after its corresponding task. To recreate the Townscaper tasks, copy an encoded town text string to the clipboard, run the game, and in the menu, click the *Load from Clipboard* button. In the event that the town cannot be loaded, ensure that the encoded town text string was copied without a space at the end.
- The *Task sheets* folder, which contains the task sheets for all tasks in both Czech and English.

1. For instructions how to locate the folder, go to `https://stardewvalleywiki.com/Saves` (Accessed: 12 May 2023).

B Informed consent form

Informed Consent for Research Participation and with Processing of Personal Data

About this study

Project title: *Playful visualization: Evaluating data visualization in video games*
Author: Tereza Šťastná
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Department: Department of Visual Computing, Faculty of Informatics, Masaryk University
Project duration: March 2023 - June 2023

The goal of the project

This interview is a part of a user study included in a diploma thesis, *Playful visualization: Evaluating data visualization in video games*. The goal of the thesis is to investigate how games can be used to visualize data in a playful way. The aim of the user study is to gather feedback on the visualizations.

Your Involvement In the Study

You will be asked about personal information, namely your:

- gender (answer is not required),
- age,
- occupation and education,
- color vision deficiencies (answer is not required),
- personal experience with video games and data visualizations.

You will be asked to complete several tasks involving data visualizations in video games and to give your opinion on the visualizations.

What data is collected

I will collect the following data:

- audio and video recording of the interview,
- your answers to all questions and tasks during the interview.

With your consent, I will record the interview on audio and video, and I will take notes to document your comments.

What will happen with your data

All collected information will be stored under a pseudonym that will be assigned to you before the interview begins.

The recordings will be transcribed into text form and subsequently deleted. The recordings will be deleted no later than on 15th of May 2023.

When referencing information from the interview in the thesis, I will not provide any details that would allow any third party to identify you.

This form will be stored separately from all collected data.

How long will your personal information be stored

Your personal information will be stored only for the duration of the project.

Collected data in anonymous form may be used in further research projects.

Information necessary to comply with the General Data Protection Regulation (EU 2016/679, GDPR)

Your personal data will be processed with consent provided by you for the purpose of research in the field of data visualization.

Personal data controller: Tereza Šťastná, Faculty of Informatics, Botanická 68a, 602 00 Brno, 456525@mail.muni.cz, +420 731 312 356.

Contact for the Personal Data Protection Office of Masaryk University: poverenec@muni.cz.

Your rights regarding processing of your personal data:

- You have the right to request from the controller the access to and rectification or erasure of personal data or restriction of processing concerning your personal data.
- You have the right to lodge a complaint with a supervisory authority (Úřad pro ochranu osobních údajů - The Office for personal data protection, www.uoou.cz).
- You have the right to withdraw this consent to the processing of personal data at any time without any risk of sanction or disadvantage by contacting the personal data controller. The lawfulness of processing based on consent before its withdrawal is not affected.

Participation is voluntary

Your participation is voluntary and you may take a break or leave the interview at any time without giving a reason. You may also withdraw from the study after the interview, in which case, the recordings and all other data relating to your interview will be deleted immediately. You may withdraw until 24th of April 2023.

Consent for Research Participation and Processing of Personal Data

Based on information described in this document:

- I consent to participate in *Playful visualization: Evaluating data visualization in video games* research project.
- I consent to processing of my personal information for research purposes as described in this document.

Date: _____

Name of participant: _____

Signature: _____

Name of interviewer: Tereza Šťastná

Signature: _____

C Personal information questionnaire

Personal Information Questionnaire

How old are you?

What is your gender?

- ○ Female
- ○ Male
- ○ Other
- ○ Prefer not to say

Do you have color vision deficiency?

- ○ Yes
- ○ No
- ○ Prefer not to say

If you answered Yes, can you specify which type?

What is your current occupation?

- ☐ Employed Full-Time
- ☐ Employed Part-Time
- ☐ Student
- ☐ Unemployed
- ☐ Prefer not to say

D Questions about video games and data visualizations

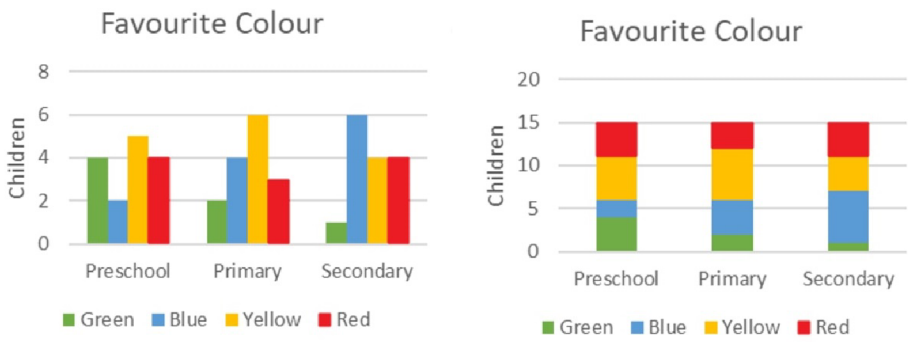

Figure D.1: Two example bar charts (Image source: Bar Chart [32]) used in the interview to verify that the participants can interpret bar charts at this level of complexity correctly. During the interview, this visualization was diplayed on a laptop screen.

- What field do you study or work in?
- What is the highest degree or level of education you have completed?
- Do you like video games?
- How often do you play video games?
- What kind of video games do you play, if any?
- Do you know a game called Stardew Valley?
  - If the answer is yes: Have you played it?
- Do you know a game called Townscaper?
  - If the answer is yes: Have you played it?

- Do you regularly encounter data visualizations?
  - If the answer is yes: What kind of visualizations are they and how often do you encounter them?
- Are you familiar with bar charts?
  - If the answer is yes: How confident are you in your ability to understand them?
- See the example bar charts in Figure D.1. How would you interpret it?

E Task sheets: Part 1

P1Q1

This visualization represents the production of crops on a farm in 2019, 2020, 2021, and 2022. Please draw a bar chart that represents the same data. Explain your process.

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P1Q2

This visualization represents the production of crops on a farm in 2012, 2013, and 2014. Please draw a bar chart that represents the same data. Explain your process.

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P1Q3

This visualization represents the color distribution of newly constructed buildings in a village from 2003 to 2007. Please draw a bar chart that represents the same data. Explain your process.

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P1Q4

This visualization represents the color distribution of newly constructed buildings in a village from 2019 to 2022. Please draw a bar chart that represents the same data. Explain your process.

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

F Task sheets: Part 2

P2Q1

This visualization represents the amount of blue jazz flowers grown on a farm from April to August. What amount was grown in July?

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P2Q2

This visualization represents the amount of crops grown on a farm from April to October. In which month was the third highest amount of crops grown?

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P2Q3

This visualization represents the amount of crops grown on a farm in 2006, 2007, and 2008. In which year was the lowest amount of pumpkins grown?

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P2Q4

This visualization represents how many green buildings were constructed in a city in each month of 2010. How many green buildings were constructed in April?

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P2Q5

This visualization represents the color distribution of buildings completed in a small town in each quarter of 2011. Which quarter has the second highest amount of completed buildings?

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

P2Q6

This visualization represents the color distribution of buildings completed in a town in each quarter of 2012. In which quarter was the highest amount of light blue buildings completed?

The task was easy to complete.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

I am confident that I solved the task correctly.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
○	○	○	○	○	○	○

G Feedback questions

- How would you rate the overall difficulty of the tasks?
- Do you feel like your understanding of the visualizations has improved over time?
- Did you find the visualizations easy or difficult to understand?
- Were there any elements that made the visualizations more difficult to understand?
  - If the answer is yes: What were those elements?
- Were the visualizations in one game easier to understand than in the other game?
  - If the answer is yes: In which game and why?
  - If the answer is yes: Did your preference vary depending on the graph type?
- What would you change about the visualizations to make them easier to understand?
  - What issue does the suggested change solve?
- Did you find the visualizations aesthetically pleasing?
- Were the visualizations in one game better aesthetically than in the other game?
  - If the answer is yes: In which game and why?
- Did you find working with the visualizations entertaining?
- Would you like to work with similar visualizations again in the future?
- Where or how do you think similar visualizations could be useful?

- Do you think teachers could use these or similar visualizations to teach children about data visualization?
  - If the answer is yes: Would it have any benefits compared to using regular graphs?
- Do you have any additional comments or feedback?