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Kiili, Kristian

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Using a multi-step research approach to inform the development of a graph literacy game

Kristian Kiili, Antero Lindstedt, Manuel Ninaus, Tua Nylén

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Abstract

Critical reading - the ability to critically evaluate information - has become a crucial skill in our modern information society and the rise of fake news. Games might be able to help to address this rather new field of education. Therefore, we first conducted a literature analysis on the use of games that aim at supporting critical reading and media literacy. We found that most of the used games improved participants' critical reading skills, were mostly targeted at adults, and the games focused on written information and fake news, but omitted graph literacy. Next, we ran an empirical study to investigate adolescents' competencies in critically reading and interpreting graphs. In a storified setting, adolescents acted as fact checkers and were supposed to interpret graphs and identify misleading graphs. Our results revealed that adolescents struggled in both the identification of misleading graphs as well as the interpretation of graphs. Consequently, based on our literature review and empirical results, we developed a game to support graph reading. The design of the game is presented.

Keywords

Game-based learning, Graph literacy, Misleading graphs, Critical reading

1 Introduction

One of the main challenges of our times is the wide spread of misinformation and disinformation on the Internet [1]. The exposure to false information, in conjunction with poor critical reading skills, may endanger citizens' possibilities to form evidence-informed decisions on important issues. Recently, we have witnessed an example of the global spread of COVID-19-related misinformation that can have important consequences for how a disease ultimately affects the population [2]. Take a moment to imagine how the information flow around the pandemic might appear to young readers. The statements of experts, laypersons, and eminent leaders may provide conflicting information. Further, the conflicting information is shared in different social media channels. Who should I trust? What should I believe? What do the graphs illustrating the spread of the disease and the death curves around the globe mean? The central question here is whether our education system has prepared all students with sufficient critical reading skills to help them analyze, evaluate, and interpret the conflicting and misleading information they encounter. Previous research suggests that this is probably not the case [3, 4, 5], and there are worrying signs of the polarization of critical reading skills [3, 6]. Thus, there is a need to produce learning materials that support the development of critical reading skills, particularly among those individuals who struggle most.

This paper focuses on graph literacy. Graph literacy refers to the ability to read and understand graphs [7]. Graphs are used to display numerical data in graphical format and they present information in a two-dimensional space. Successful graph reading requires three competences, or going through three steps, which have been defined as 1) reading the data, 2) reading between the data and 3) reading beyond the data [8]. In short, the step of reading the data refers to the ability to extract data by visually inspecting the elements drawn in the graph, the step of reading between the data refers to the ability to infer the mathematical relationship between the variables of the graph, and the step of reading beyond the data refers to the ability to make a numerical forecast based on the graph's underlying trend [8].

Ciccione and Dehaene [8] have pointed out that although graphs have become ubiquitous in our life, the scientific investigation of graph reading is in its early phase. Thus, it is not surprising that studies that focus on critical reading of misleading graphs are rare. The concept of a misleading graph, refers to a graph that is based on valid data, but the appearance of the graph has been manipulated to distort the message of the graph. Emerging research in this field has shown that individuals with low graph literacy tend to neglect information in the axes labels and scales of graphs, and tend to rely more on spatial-to-conceptual mappings grounded in their real-world experience [9]. For example, individuals may assume that higher bars mean higher values also in graphs where the y-scale is reversed. Thus, spatial features that conflict with general conventions can be used to mislead graph readers. This is a common trend for example in social media. Unfortunately, graph literacy research has almost solely focused on reading well-formed graphs and very little is known about adolescents' abilities to evaluate and interpret misleading graphs.

We start bridging this gap and begin to characterize, in some detail, the perception of misleading graphs among adolescents, and we will utilize this knowledge to develop a game that aims to support critical reading of graphs. In order to be able to design a graph reading game for adolescents we first conducted a literature review to explore to what extent games have been used to support critical reading skills, particularly critical reading of graphs. Second, we conducted an experimental study to evaluate students' abilities to both identify and interpret misleading graphs. These research activities provided us a starting point to design the Chart Trace game. Before describing the details of Chart Trace, we report the results of the literature review and the graph reading study.

2 Previous Research on Critical Reading Games

With our literature review we aimed at identifying the current state-of-the-art of learning games to support critical reading, with the following search query on Scopus (scopus.com): **TITLE-ABS-KEY [**("epistemic games" OR "mobile games" OR gamification OR gamified OR "game-based" OR "game based" OR "serious game" OR "learning game" OR "educational game" OR "video game" OR "board game" OR dgbl OR gbl OR "educational video game" OR "educational video game" OR "video game" OR "educational simulation" OR "learning simulation") **AND** ("fake news" OR "disinformation" OR "misinformation" OR "trustworthiness" OR "credibility" OR "misleading" OR "news literacy" OR "media literacy" OR "news literacies" OR "media literacies" OR "media education")**]** and searched for original research articles that were published in

English. The search returned altogether 234 papers from which we identified only 10 papers (see Table 1) that fit our inclusion criteria. Our criteria were 1) that the game described by the paper was targeted for training critical reading and 2) that the paper provided empirical results.

Table 1. Summary of reviewed papers

Ref.	Approach	Game	Digital	Sample	Outcome
[12]	Learn to identify fake news by generating fake news	FakeYou	yes	adults	N/A
[13]	Finding logical fallacies in arguments; foster critical thinking	Global Digital Citizens (gamified)	yes	adults	positive
[14]	Learn to identify fake news (information verification skills)	MAthE the Game	yes	adults	positive
[15]	Development of news literacy games; learning by participatory game design	Fakeopoly; The Lying Geese	no	children	positive
[16]	Learn to identify fake news by generating fake news	Bad News	yes	adults	positive
[17]	Learn to identify fake news (information verification skills)	UNISON	no	adults	positive
[18]	Learn to identify fake news by generating fake news (Bad News); identify fake news (Fakefinder)	Bad News; Fakefinder	yes	adults	mixed
[19]	Learn to identify fake news by generating fake news	Fake news game	yes	adults	positive
[20]	Learn to identify fake news	Bad News	yes	adults	mixed
[21]	Learn to identify fake news	Trustme!	yes	adults	positive

Most of the 10 papers had been published within the last three years. This already shows two things: (i) there is a recent increasing research interest into this rather young field of research due to its increasing relevance in our information society [cf. 10] and (ii) compared to other - more traditional - learning domains (e.g. STEM) the use of games is still rare [cf. 11] within this field of study. The latter, however, might be a result of the former: given the general efficacy of game-based learning, it seems likely that more critical reading games will be developed in the future.

Most of the games identified through the literature search emulated fake news and/or social media posts (90% of papers). Most games approached critical reading by either letting participants analyse blog posts, social media posts, or other online material (i.e. players acted as fake news detectors; 50%) or spread them or generate new ones (participants acted as fake news spreaders/generators; 40%). Further, the majority of studies reported positive outcomes related to critical reading skills after playing the game (70%). For instance, [16] showed that participants who had been practicing by playing Bad News (participants had the role of a fake news producer) rated real fake news significantly less reliable than a control group of participants who had been playing Tetris instead. All games primarily utilized written information, which was sometimes accompanied by photographs or images. None of the games or studies specifically addressed graphs or graph reading. Moreover, with the exception of one study [15], only adults participated in the respective studies. Therefore, we could not identify any clear guidelines on how to map graph reading onto game mechanics and how to take the characteristics of our target group into account in a graph reading game.

3 Graph Reading Study

3.1 Method

Participants

Thirty-six students from 3 classes participated in the study. The participants were 7th-9th graders (mean age = 14.6 years, SD = 0.96 years; 15 boys, 16 girls, 5 did not report their gender). The permission to conduct the study was received from the school principal and the teachers. Caretakers of the students were informed about the study. Students who did not provide consent to use their data as well as students without caretakers permission were excluded from the analyses.

Materials and Procedure

Two different types of graph literacy tasks were constructed: tasks of evaluating the misleadingness of graphs and tasks of interpreting information in the graphs. Half of the used graphs were line graphs and half were bar graphs. Each graph contained eight data points, a title, and the corresponding labels for both axes. All graphs presented quantitative information of phenomena familiar from the geography school subject (e.g. population growth, annual rainfall). In order to decrease the influence of geographical topic knowledge on the outcome, certain labels and titles were masked (e.g. title: countries and areas were replaced with general terms such as “one area” or “one country”; data labels: countries and areas were replaced with alphabets starting from A.).

Evaluation Tasks:

32 evaluation tasks were included in the study. Half of the graphs were well-formed and half contained spatial conflicts designed to mislead the readers. Four types of spatial conflicts were used: 1) the y-axis did not start from zero, 2) the range of the y-axis was too large, 3) the x-axis was reversed and 4) the x-axis was uneven (for example the years shown on the x-axis did not increase or decrease linearly). Figure 1 shows an example of a misleading bar graph in which the y-axis does not start from zero. In evaluation tasks, participants were asked to respond to the following statement on a 6-point response scale (1 completely disagree – 6 completely agree): “The graph is misleading”. In order to simulate fast reading behavior on the Internet, students had only 20 s to respond to each task.

Interpretation Tasks:

All four graphs included in the interpretation part were designed to mislead students. The interpretation tasks measured students’ ability to read between the data: students had to find relationships in the data represented by the graphs including spatial conflicts. For example, they had to examine differences in bar heights and the trends illustrated by line graphs (Fig. 2). Interpretations were measured using a multiple-choice item for each graph. The choices included (i) the correct choice; (ii) an incorrect choice aligned with the spatial manipulation (i.e. designed to be an obvious choice if the reader does not pay attention to y- or x-axis scales and labels); and (iii) two other incorrect choices. Students could score one point for each task. Interpretation tasks did not have a time limit.

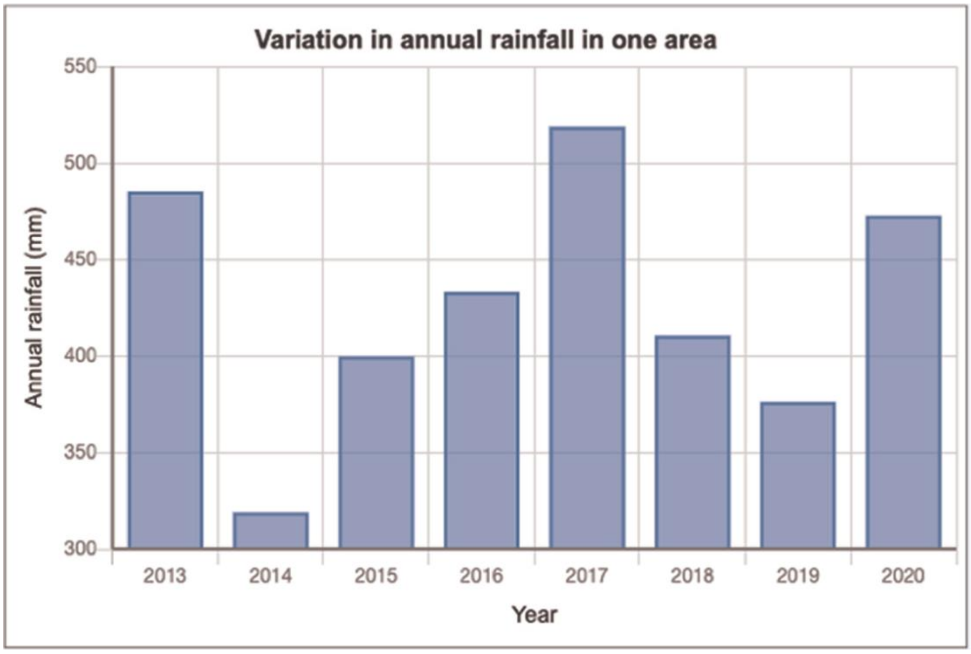

Fig. 1. Example of an evaluation task: the y-axis of the graph does not start from zero

Procedure:

The study was conducted in a web-based environment during regular school hours and a teacher administered the activities. First, students filled in the demographics questionnaire. The rest of the activities were storified. The used story was inspired by the results of the literature review (i.e. act as fake news detectors). Accordingly, in the beginning students were informed that they will act as fact checker trainees in a media company and their task is to ensure that misleading graphs do not end up in production. Students got some basic information about misleading graphs before the actual tasks. After that students completed the 32 evaluation tasks following the four interpretation tasks. Finally, a few days after completing the study, the teacher gave a debriefing session in which students got feedback about their performance (based on log files) and some of the tasks were discussed in detail.

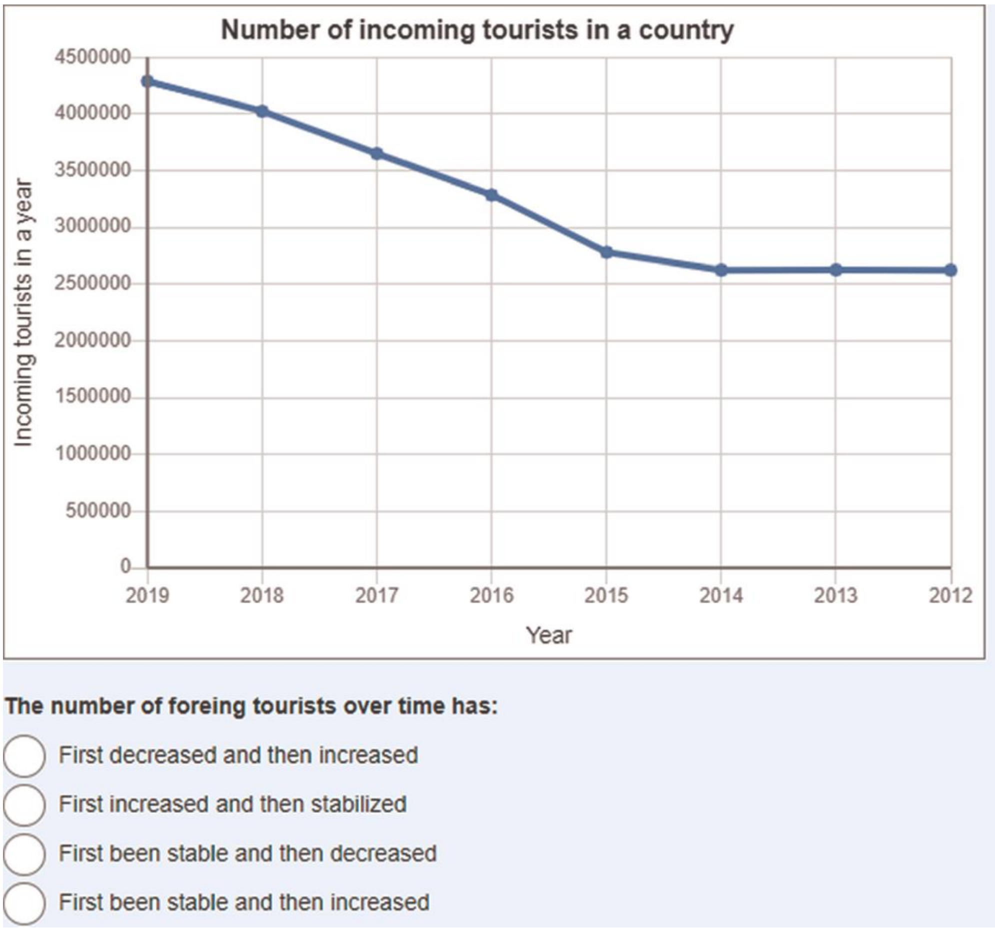

Fig. 2. Example of an interpretation task: the x-axis is reversed

3.2 Results

A paired-samples t-test was run to investigate students' abilities to evaluate the trustworthiness of the graphs (evaluation tasks). The analyses indicated that the students ability to identify well-formed graphs (M = .56, SD = .14) did not differ from their ability to identify misleading graphs (M = .55, SD = .13), t(35) = 0.352, p = .727, d = 0.05. Their overall performance was only slightly above chance indicating huge challenges to evaluate the trustworthiness of graphs. On the other hand, it is also possible that the tasks confused students and they based their evaluations on irrelevant details of the graphs (e.g., they may have considered how suitable bar and line graphs were for presenting the used data set or judged the graphs based on the credibility of the used data set). When considering only misleading graphs, students' performance in tasks including y-axis manipulations was higher (M = .61, SD = .19) than in tasks including x-axis manipulations (M = .45, SD = .27), t(35) = 2.786, p = .009, d = .46. This might indicate that students paid more attention to the y-axis of the graph than on the x-axis.

Overall, these findings reveal that students struggled in judging the misleadingness of the graphs. Thus, it was not surprising that students' performance in graph interpretation tasks was poor (M = 1.17, SD = 1; max score 4). Importantly, 74% of the all incorrect answers were the ones aligned with the spatial manipulations (i.e. designed to be an obvious choice if the reader does not pay attention to axis scales and labels). Unfortunately, we did not include any tasks that would have required interpretation of well-designed graphs. Thus, we cannot say for sure whether the misleading features of the graphs or the lack of general ability to read well-designed graphs led to poor performance. However, the results suggest that to some extend students knew how to read graphs as the majority of incorrect answers were aligned with the used manipulations.

Although the sample size was small, the results suggest that there is a need to produce learning materials that support reading of graphs, critical reading in particular. This conclusion is further supported by previous findings indicating that international 8th graders tend to struggle in graph reading [22]. These results and the identified lack of graph reading games demonstrate the need to develop games for graph reading.

4 Design of the Chart Trace Game

In this section we describe the first iteration of the Chart Trace game. The game is targeted for adolescents and aims to support the development of graph reading skills, particularly critical evaluation of the graphs. With respect to the graph reading framework, the game focuses on the steps of reading the data and reading between the data [8]. Based on our graph reading study we decided to map game mechanics to graph interpretation tasks and include both well-formed and misleading graphs in the game. We used performance results of the study in balancing the difficulty level of the game.

To facilitate the development work, we used the Number Trace game [23] as a starting point for the Chart Trace game. In Chart Trace, the player controls a dog character on a walkable platform located in the forest and tries to collect bones shown on the platform. Moving in the forest consumes energy and the challenge is to collect the bones with minimum energy consumption. Roughness of the terrain in different parts of the platform varies and moving in rougher terrain consumes more energy. The amount of energy required to get to different locations on the platform is presented with a graph (see Fig. 3). In other words, the energy consumption presented in graphs is mapped to the game world (roughness of the platform) and to moving on the platform (energy consumption). Consequently, as the player has only a limited amount of energy, the ability to interpret the graphs is an essential part of the gameplay and continuous graph reading is needed to make right decisions and succeed in the game.

In practice, the graphs include seven data points that are labeled with letters (A, B, C, D, E, F). In the case of bar graphs, the platform is divided evenly into six sections marked with the same letters starting from A (example in Fig. 3). For line graphs, the platform is divided evenly into five sections. In bar graph tasks the data points (bars) indicate how much energy is spent by walking through the whole section (Fig. 3). By figuring out how much energy is required to cross each section, the student must decide the best route to the bone. Since the dog always starts from the leftmost position on the platform, the player effectively has two options: walk towards right until the bone is reached, or use the teleport skill (arrow button on top of the screen) to instantly move (without losing any energy) to the rightmost position on the platform and then walk towards left to the bone. For example, Fig. 3 shows a task that includes a misleading graph. If the player does not notice that the x-axis is reversed, he might assume that it would take less energy to walk to the bone through sections A to C as the first bars in the graph are shorter. However, as the x-axis is reversed, the best solution is to teleport the dog to the right side of the platform and walk through sections F to D to the bone (total sum of energy consumption 9 compared to 21). Line graphs work similarly as bar graphs except that the energy consumption of each section is defined as an average of section's start and end point values. In practice, the energy consumption between two consecutive data points is linear.

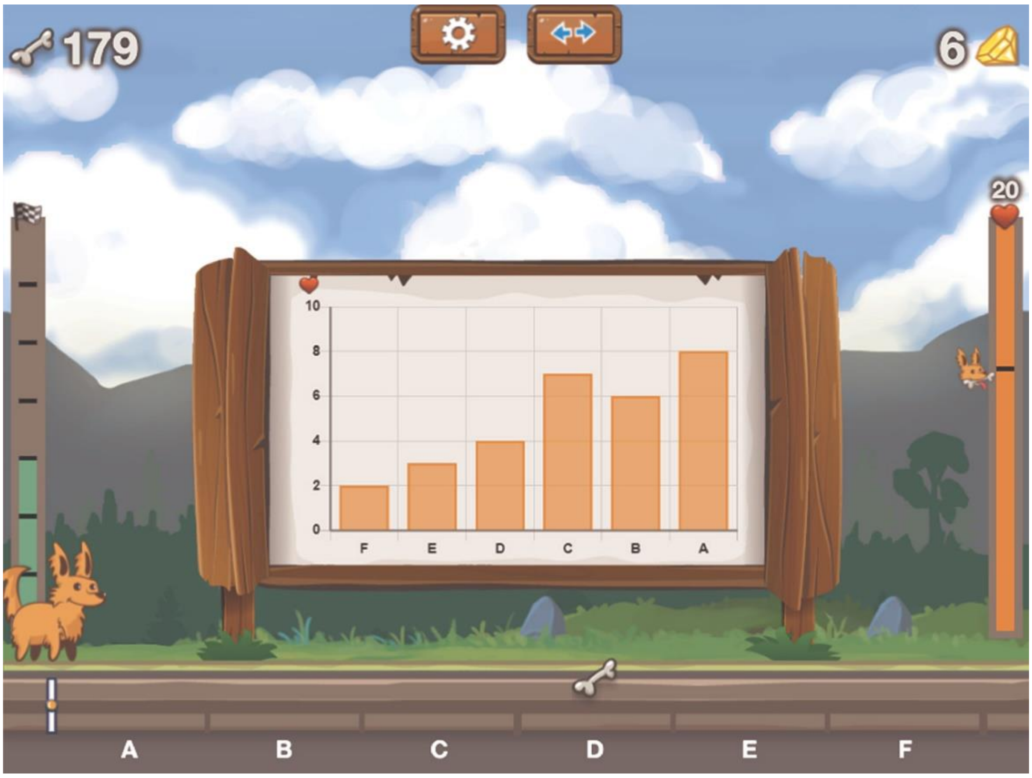

Fig. 3. Bar graph task with a reversed y-axis.

We implemented several mechanics to make the decision making more complex. Figure 4 shows an example of a task in which the bar graph shows the energy consumption for both walking and jumping on the platform. Based on the graph the player has to decide whether he activates the jumping shoes or tries to reach the bone by walking. That is, to correctly solve a task, players have to infer that they need to calculate the sum of the sections' energy values needed to reach the bone from left and right and for both jumping and walking to be able to make the needed comparisons. If needed the decision space can be further extended by providing special skills to the player. In the example task, there is a special skill available that allows the player to reset the energy consumption of one segment to zero. The activation of special skills requires diamonds that the player has a certain amount in each level. Thus, also the manipulation of available diamonds can be used in determining the difficulty level of the game. The game also includes scaffolding features that can be activated to help players to realize the misleading elements of the graphs.

One game level consists of 6–10 tasks (graphs) and the player has certain amount of energy points in each task. Half of the tasks are balanced in the way that if the player does not select the right route to collect the bone, the player will run out of energy. In each level the player can gain 1–3 stars depending on their playing performance (economical energy consumption). This creates clear goals for the player and focuses the player's attention on energy consumption, i.e. to the graphs describing the consumption. As the graphs are mapped to energy consumption, the energy bar provides continuous feedback for the player. This approach allows players to experience the data that the graphs display. In general, the aim of the game is to create perceivable cognitive conflicts when players interpret graphs incorrectly hopefully leading to reflective thinking on their graph reading behavior and strategies.

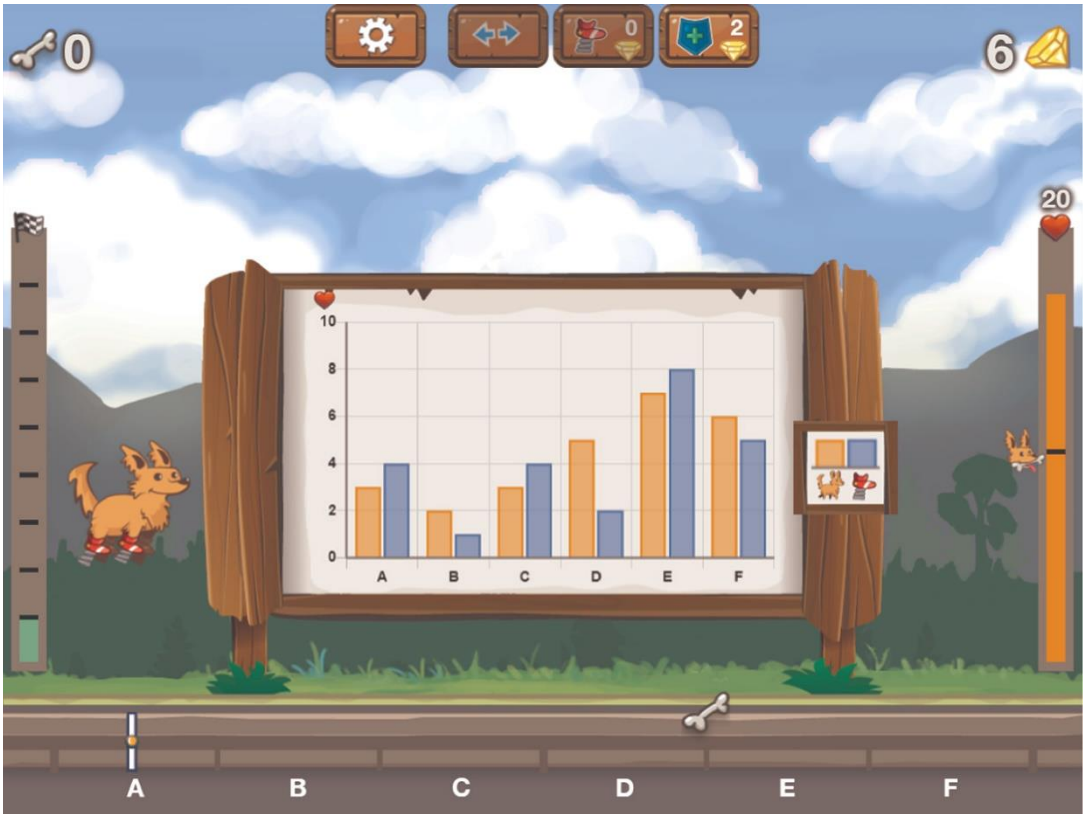

Fig. 4. Bar graph task that includes two movement ways and on-demand energy reset skill

5 Conclusions

The aim of the presented work was to report the first iteration of the evidence-based development of a game that addresses critical reading of graphs. We followed a multi-step approach. First, by analysing the literature on the use of games to foster critical reading skills, we found that research has focused on adult populations and none of the articles examined games that address graph reading but most applied a storified approach by putting players in the shoes of a fake news detector or creator. Although we could not identify any game mechanics used to support graph reading, the results indicated that game-based approaches have been successfully used to support critical reading of written information. Next, we ran an empirical study on graph reading with adolescents using a similar storified approach (i.e. act as fact checker in a media company) that was successfully used in several of reviewed articles. Our results indicated that adolescents lacked the necessary competences to adequately read and interpret graphs, particularly misleading graphs. Accordingly, in a final step, we designed and developed a game for adolescents which aims to foster graph reading competencies including identification of misleading graphs. As our empirical study revealed that graph interpretation tasks provide clearer information about graph reading abilities than credibility evaluation tasks, we used graph interpretation as a main learning mechanic of the game. Next, we will run small-scale studies to evaluate the quality of the game design and to define a blueprint for the next iteration of the Chart Trace game. It is possible that several iterations are needed before it is reasonable to evaluate the effectiveness of the game at a large scale in classrooms.

Notes

Acknowledgments

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