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Systematic design process of a serious educational game for teaching Ohm's Law

vorgelegt von
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Zusammenfassung

In dieser Arbeit stellen wir eine Design- und Entwicklungsmethodik für effektive Lernspiele vor. Zu diesem Zweck haben wir ein Videospiel entwickelt, das Spielern Wissen über Elektromagnetismus und über die Anwendung des Ohmschen Gesetzes vermittelt. Der Designprozess basiert auf dem Mechanics Dynamics Aesthetics Framework (Hunicke et al., 2004), während wir die einzelnen Spielelemente wie Mechaniken und Spielziele mithilfe der Unifying Game Ontology (Debus, 2019) klassifiziert haben. Während des Entwicklungsprozesses wurde die Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) verwendet, um ein passendes Instruktionsdesign zu erstellen. Sie wurde dazu genutzt, um Lernaktivitäten auszuarbeiten, die dann den vorhandenen Spielelementen zugeordnet wurden. Eine klare Terminologie und Zuordnung hilft Spieldesignern und Pädagogen gleichermaßen bei der Entwicklung und Bewertung effektiver Lernspiele. Um den Erfolg unseres Spiels in Bezug auf den Wissenszuwachs zu bewerten, haben wir eine Evaluierung durchgeführt, bei der den Spielern jeweils vor und nach dem Spiel ein Fragebogen ausgehändigt wurde. Die Bewertung zeigt, dass das übergeordnete Lernziel erreicht wurde, aber einige der Lernaktivitäten noch verfeinert werden müssen.

Abstract

The goal of our work is to evolve a design and development methodology for effective serious educational games. For that matter, we designed a video game that teaches players about electromagnetism and more concretely how to apply Ohm's Law. The design process is based on the Mechanics Dynamics Aesthetics framework (Hunicke et al., 2004) while the individual game elements, such as mechanics and game goals, have been classified using the Unifying Game Ontology (Debus, 2019). During the development process, the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) was used to create a fitting instructional design. The framework was utilized to work out learning activities, which were then mapped onto the existing game elements. Having a clear terminology and mapping helps game designers and educationalists alike to develop and assess effective serious educational games. In order to assess the success of our game in regard to knowledge retention, an evaluation has been conducted where the players were handed a questionnaire before and after playing the game. The assessment shows that the learning objective has been achieved, while some learning activities still need to be refined.

Contents

1 Introduction

Electromagnetism is an important sub topic of physics covering the study of the electromagnetic force, a type of physical interaction that occurs between electrically charged particles. The electromagnetic force is carried by electromagnetic fields composed of electric and magnetic fields, and it is responsible for electromagnetic radiation such as light (Encyclopaedia Britannica, 1998c). Having an overview of the physical basics of electricity such as voltage, current and resistance, which is defined by Ohm's law, is important in order to be able to inform oneself about topics such as electric mobility or renewable energies.

For this reason, these topics are taught in school. In Bavarian high schools, for example, electromagnetism is the main topic in eleventh grade physics classes (ISB, 2004b), where students are taught topics such as electric or magnetic fields and electromagnetic induction (Anselment, 2009). However, less complex concepts, such as how electric circuits work, are introduced at even earlier grades. In Bavaria, this is done in the third or fourth grade of elementary school (ISB, 2022). Successfully imparting this knowledge is the responsibility of teachers. As trained educators, they create scientifically based instructional designs, in which they first define the content they want to teach and then create appropriate learning objectives. In order to achieve the objectives, activities are planned through which the knowledge is conveyed. Whether the learning has been successful is later tested in the form of examinations. As teaching methods or activities, the educators have many options at their disposal, such as lecturing, group projects, experiments, films or even games.

Video games, in particular, are a teaching method with a lot of potential. According to the National Education Association et al. (2012), students in the 21st century need the following skill set: (1) critical thinking and problem-solving, (2) communication, (3) collaboration, (4) creativity and innovation. These skills are also referred to as the "Four Cs". Video games have the ability to teach the Four Cs (Hewett et al., 2020). One way to do this would be a multiplayer puzzle game, for which all skills are needed. In addition, the simulation nature of video games allows physical experiments to be performed as often as desired in real time while eliminating hazards such as electrocution. Moreover, from a game design perspective, physics' concepts have always been suitable for deriving fun video game mechanics. In games such as Angry Birds (Rovio Entertainment Corporation, 2021), the law of inertia is utilized to slingshot birds into destructible structures. Another example would simply be gravity, which has to be accounted for in many jump and run games. Electromagnetism concepts and processes can also be an inspiration for different game elements: magnets or charged particles could be utilized to repel the players, or they could have to complete electric circuits in order to open a gate.

In order to make good learning material out of these video games, it is not sufficient to integrate physics concepts as mechanics in the game. Indeed, a sound instructional design process must take place. An important aspect of the science of instructional design is to define clear learning objectives, activities and assessments (Merrill et al., 1996). Therefore, the goal of this thesis is to evolve a design and development methodology for effective serious educational games. For that matter, we design a video game to teach the concepts and processes of electromagnetism, where the end goal is to learn how to apply Ohm's Law. We take a rigorous game design path where game mechanics, goals, levels and other elements are well reflected. This process is derived from the Mechanics-Dynamics-Aesthetics (MDA) framework (Hunicke et al., 2004) and the Unifying Game Ontology (Debus, 2019). Correspondingly, we utilize the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) table to clearly state the learning objectives the video game subsumes. Finally, we correlate game design elements with their counterparts in instructional design, and we assess the players' knowledge regarding Ohm's Law.

In this thesis we first present the theoretical background regarding instructional design, domain knowledge and game design in section 2. After that, we present related applications that aim at teaching electromagnetism to their players in 3. In section 4 the game design is explained in more detail, followed by an evaluation of said game in regard to learning and gameplay in section 5. At the end, a conclusion is drawn, and future work is presented.

2 Theoretical Background

The design of effective serious educational games is a complex endeavor. Indeed, it requires a good grasp of concepts in a variety of topics: (1) pedagogy and instructional design, (2) specific domain knowledge, and (3) game design. In order to explain the required theoretical background for this thesis, in section 2.1 Revised Bloom's Taxonomy is introduced as an instructional design framework. In section 2.2, an overview of the domain knowledge is given. This includes physics and electrical engineering concepts. In 2.3, both game elements and game design processes are presented in great detail. Finally, a combination of these three aspects is proposed and will create a base of the methodology section later on.

2.1 Instructional Design

In order to make learning appealing and effective, the learner is guided by a set of well-designed instructions. There are several methods and techniques to help educators design such instructions, and they are called instructional design frameworks (Moseley et al., 2005), also referred to as ID frameworks. One of the most widely used ID frameworks is Bloom's Taxonomy, which can be described as a set of three hierarchical models used to classify learning objectives. These models are also referred to as domains: (1) Cognitive, (2) Affective, and (3) Psychomotor. For each of these domains, the taxonomy provides a set of levels of complexity that the learner should go through. For the cognitive domain, Bloom's Taxonomy defines six levels of complexity: knowledge, comprehension, application, analysis, synthesis, and evaluation. These can be used to describe and classify educational learning objectives. According to Bloom (1956) (p. 120), these intellectual skills are hierarchically ordered in terms of complexity. Therefore, for example, it is necessary to have understood something before being able to apply it.

A more refined version of the original Bloom's Taxonomy, the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) was published in 2001. The major structural change is that "knowledge" has been divided into the four categories: (1) Factual, (2) Conceptual, (3) Procedural, and (4) Metacognitive, and has been contrasted with the so-called cognitive processes as a separate category. This results in a two-dimensional table in which the learning objectives can be categorized (see Fig. 2.1).

The Knowledge Dimension	The Cognitive Process Dimension					
	1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
A. Factual knowledge						
B. Conceptual knowledge		*Activity 1* Test 1A	**Objective**	*Activity 2* Test 1B	*Activity 7*	
C. Procedural knowledge			*Activity 3* Test 2	[Objective as Refocused—See Page 104] Test 1C	*Activity 6*	
D. Meta-cognitive knowledge	*Activity 4*		*Activity 5*			

Figure 2.1. Categorization of electromagnetism example utilizing revised bloom's taxonomy (Anderson & Krathwohl, 2001) (p. 103).

An example of an elaborated learning objective from Revised Bloom's Taxonomy on the topic of electromagnetism is: "Students should learn to use laws of electricity and magnetism (such as Lenz's law and Ohm's law) to solve problems." (Anderson & Krathwohl, 2001) (p. 105). As suggested by the authors in chapter 6 of the book, this learning objective can be put into the category "apply conceptual knowledge" as seen in Fig. 2.1. Besides the learning question - which is answered by creating the learning objectives - the instruction and the assessment question are of particular importance according to Moseley et al. (2005) (p. 104f). On the one hand, regarding the instruction question, there are learning activities that are intended to help learners achieve the ultimate learning objective. An example of this would be a task that helps students choose the correct physics law to be applied. The learning activities can also be classified according to Revised Bloom's Taxonomy and do not need to be put into the same category as the learning objective they are working towards. The assessment question on the other hand is answered by tests that check whether a learning activity or learning objective has led to successful learning. These tests can also be classified using the taxonomy.

To formulate the learning objectives, activities and tests, different verbs can be used, which can be assigned to the six cognitive processes of the taxonomy. When writing down the concrete formulations of the objectives and activities, they should not contain the specific names of the cognitive processes, but verbs that belong to the associated process. Some examples can be found next to each process in Fig. 2.2. A more detailed list directly from the Revised Bloom's Taxonomy can be found in the appendix (A).

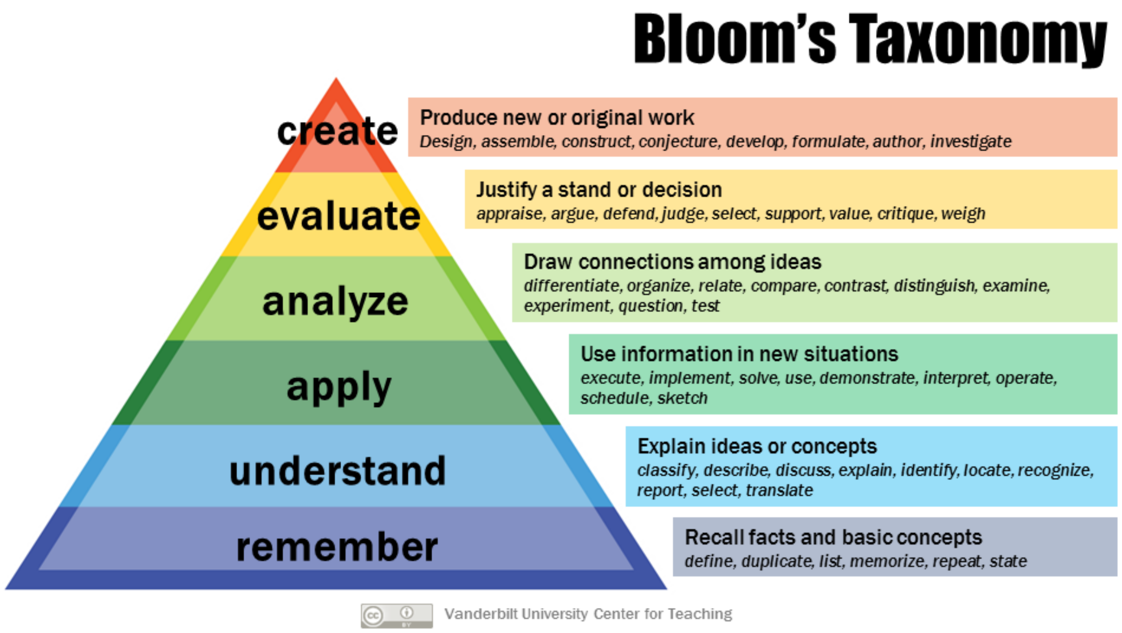


Figure 2.2. Revised Bloom's Taxonomy's cognitive processes and associated vocabulary (Armstrong, 2010).

2.2 Domain Knowledge: Ohm's Law

The concrete learning content of the game we present in this thesis consists of circuit theory, with a focus on Ohm's law. Ohm's law describes the relationship of three attributes of an electric circuit: (1) Resistance, (2) Intensity of current and (3) Voltage. "Electric current in a wire, where the charge carriers are electrons, is a measure of the quantity of charge passing any point of the wire per unit of time." (Encyclopaedia Britannica, 1998a). On the other hand, voltage - also known as potential difference, describes "the amount of work needed to move a unit charge from a reference point to a specific point against an electric field." (Encyclopaedia Britannica, 1998b). A water cycle is often used as an auxiliary mental model for electric circuits (ISB, 2004a), since the flow of water offers some similarity to the flow of electrons. A pump transports water up a mountain (see Fig. 2.3), from which it flows down again. The pump is the voltage source that generates voltage, and the difference in height of the water is the actual voltage. In this model, the current corresponds to the flow velocity of the water as it flows back down the mountain.

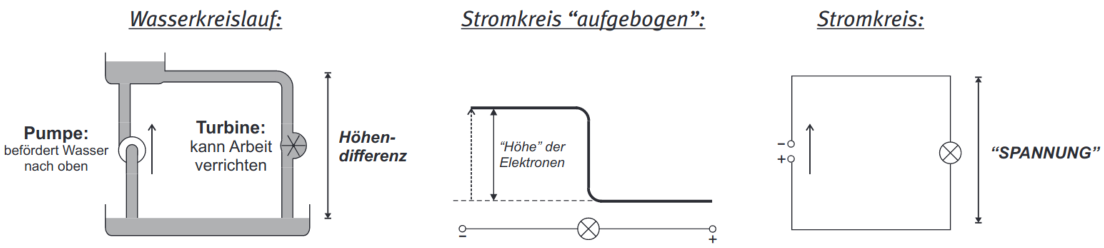


Figure 2.3. Visual representation of the flow of electricity utilizing the flow of water (ISB, 2004c).

Ohm's law defines resistance in a circuit as follows:

$$R = V/I \tag{2.1}$$

where R = resistance, V = voltage and I = the current of the circuit (Kipnis, 2009). The formula 2.1 can be transformed into the formula 2.2 for electric current and the formula 2.3 for voltage:

$$I = V/R \tag{2.2}$$

$$V = I * R \tag{2.3}$$

This describes an indirect proportionality of resistance to voltage or current intensity. In addition, this results in a direct proportionality between voltage and intensity of current. These two concepts are described by Ohm's law and are to be conveyed by the developed game. To achieve this, voltage, current and resistance must be introduced beforehand in the game. Additionally, the players must have been acquainted to the concept of a closed circuit and its components. This is explained in more detail in section 4.2 as part of the instructional design explanation of the game.

2.3 Game Elements and Game Design

One definition of the term serious game states that a serious game does not serve the sole purpose of entertainment (Alvarez, Djaouti, et al., 2011). Nevertheless, entertainment is an important aspect for serious educational games, especially for those that are intended to serve as a learning environment in their own right. The reason for this is that the engagement factor of a game determines whether the players want to engage with the game and thus with the educational material.

One framework that can be used for analyzing and designing games is the MDA framework (Hunicke et al., 2004). It contains three interdependent layers: Mechanics (M), Dynamics (D), and Aesthetics (A). The Mechanics level describes low-level elements such as the various mechanics, game goals, and intervention options through which the players can change the game state. The Mechanics level can be directly influenced and changed by the game designer. The dynamics of a game, in turn, result from the behaviors that arise when the mechanics are applied with concrete player input (Aleven et al., 2010). An example of a dynamic is time pressure. This can be created, for example, by a timer mechanic, but also by awarding bonus points to the fastest player in a multiplayer game. However, no explicit taxonomy is given for dynamics in the MDA framework. The aesthetics level describes the feelings or pleasure the players experience while playing the game. The MDA framework provides a more fine grained definition of "fun" and therefore offers eight terms to describe the aesthetics of a game: sensation, challenge, discovery, fellowship, expression, fantasy, submission, narrative (Kusuma et al., 2018). While the designer can start at the mechanics level to change the game experience, the players perceive the game at the aesthetics level. According to Aleven et al. (2010) the engagement factor of a game is determined by how successful the designers were with reaching their desired aesthetics goals, while the learning objectives and activities are mostly implemented on the mechanics and dynamics level.

To be able to look at the concrete components of a game in more detail, there are frameworks, such as the Unifying Game Ontology (UGO) (Debus, 2019). "The Unifying Game Ontology is the first classification scheme of its scope that describes game elements on the lowest level of complexity and the highest formal level" (Debus, 2019) (p. 309). The goal of the UGO is to enable researchers, practitioners, and teachers to compare the differences of smaller game elements (Debus, 2019) (p. 291). The UGO names several facets and classes such as time, space, entities, mechanics, and goals. For each of these facets, there are further classifications. The category mechanics, for example, is divided into seven further categories: activation, change of element, change of possession, choosing, creation, navigation and removal. Another category relevant to this work is goals. They can be further divided into imperative goals (e.g. "create", "find", "optimize", ...) and ultimate goals ("winning", "finishing", "prolonging"). The UGO helps to analyze game elements, such as learning activities integrated in the game, in more detail. A more detailed list of mechanics and goals can be found in section C of the appendix.

2.4 Combining Learning And Game Elements

One of the biggest challenges of serious game design is that the learning and gaming aspects have to be combined appropriately (Arnab et al., 2015). It should be noted that game designers and educators often use different terminology and look at the subject from different angles (Gunter et al., 2006). Arnab et al. (2015) argue that "high-level pedagogical intents can be translated and implemented through low-level game mechanics". Based on this, they introduce the term Serious Game Mechanic (SGM), which is defined "as the design decision that concretely realizes the transition of a learning practice/goal into a mechanical element of gameplay for the sole purpose of play and fun". Through the Learning Mechanics and Game Mechanics (LM-GM) framework created by Arnab et al. (2015), learning elements can be mapped to game elements and vice versa. Through the framework, SGMs can be identified and analyzed. It is intended to help game designers and educationalists to analyze serious educational games and to find SGMs across different games. The topology of gameplay rules underlying the LM-GM framework describes two types of rules: low level rules that allow the players to change the state of the world and higher level rules that describe the goals of a game. Arnab et al. (2015) claim "that learning must [...] be defined at a higher level, through goals, rules and other components that have a pedagogical value". The game and learning mechanics elaborated in the LM-GM framework can be viewed in 2.4. The core components are in the center and extend along the vertical axis. Listed horizontally are functional mechanics that belong to the corresponding core mechanics.

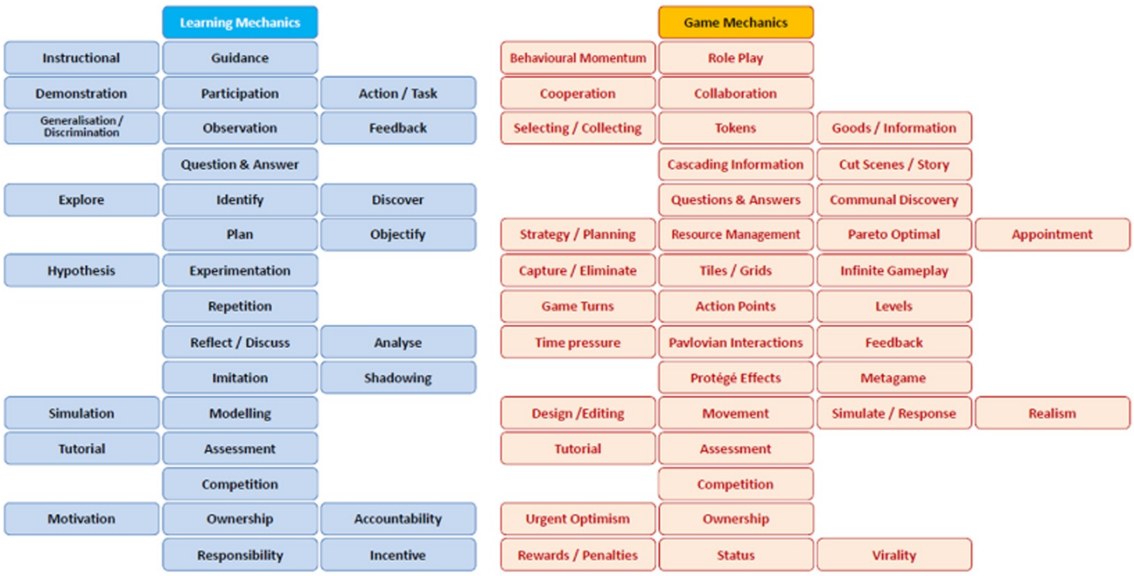


Figure 2.4. Learning and game mechanics as proposed by the LM-GM framework (Arnab et al., 2015).

Another framework dealing with the design of serious educational games was presented by Aleven et al. (2010). It is based on three main components. The first one is about creating learning objectives. Within this component, the required prior knowledge, the knowledge to be taught, and possible knowledge transfer are determined. The required objectives, activities and tests are defined using the Revised Bloom's Taxonomy as described in section 2.1. The framework's second component consists of analyzing or planning the game using the MDA framework, as presented in section 2.3. The third part considers the use of Research-based Instructional Design Principles. "[Those] promote thinking about whether the game supports learning in ways that are consistent with empirical research on instruction and robust learning." (Aleven et al., 2010). An example of Jim Gee's 36 principles of game-based learning is that you can practice many times in the game without getting bored with the content (Gee, 2007). Aleven et al. (2010) claims that the focus of the framework is to support thinking about serious educational games. Thus, designing a game can be approached from both the educational and the gaming aspects.

For the design of the video game that has been created in the scope of this thesis, aspects of both frameworks were incorporated. Using Revised Bloom's Taxonomy, learning objectives, activities, and tests were specified and mapped to game elements as described in the Unifying Game Ontology. This mapping is comparable to serious game mechanics from the LM-GM framework. Furthermore, the game design of the project is based on the MDA approach.

3 Related Work

Ohm's law is an important and fundamental law of physics (Alexander, 1938). Consequently, there are already some applications that deal with the teaching of Ohm's Law, but also with the teaching of physical concepts in general. In order to get an overview of what already exists in terms of video games on Ohm's Law, the first section of this chapter presents six different digital applications that deal with said topic. The majority of these are video games. They are analyzed based on Revised Bloom's Taxonomy and the Unifying Game Ontology, and related examples of learning activities, learning objectives, game elements, and game goals are elaborated. A large part of the related work was tested personally.

The two main aspects to consider when designing a serious educational game are integrating the desired learning content and creating an engaging game (Aleven et al., 2010). However, since not every game claims to be an effective serious educational game, the second part of this chapter classifies and evaluates the applications based on two criteria: successful knowledge transfer and engagement factor. This is recorded in a serious game classification scheme.

3.1 Analysis Of Related Games And Applications

3.1.1 Simple Club App

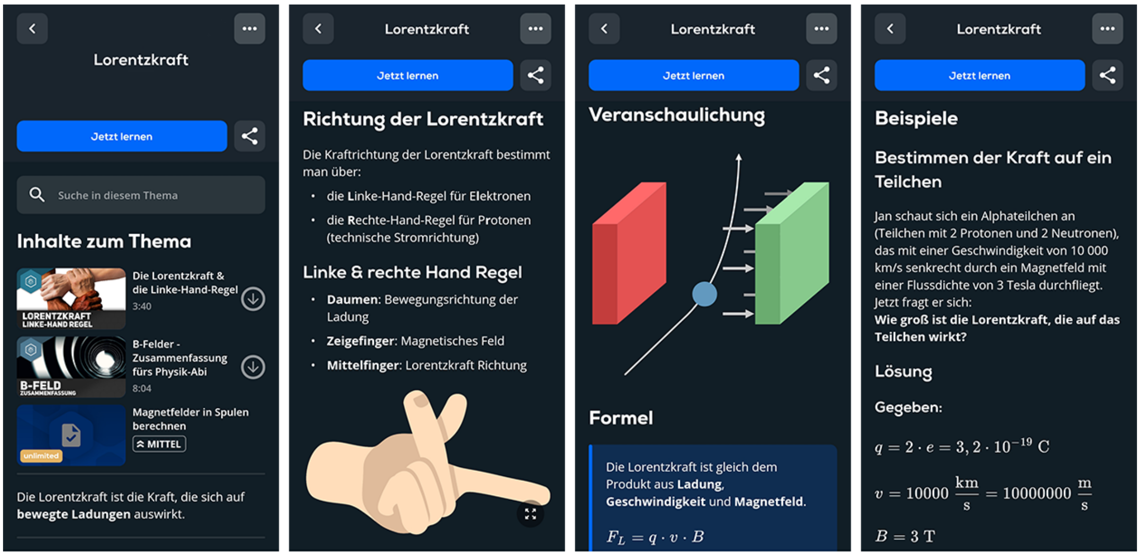


Figure 3.1. Screenshots from the simpleclub app (simpleclub GmbH, 2016).

The simple club app contains teaching materials for various school subjects and university courses. One of these is physics, for which there are specific chapters on electromagnetism. An exemplary learning objective is the Lorentz force, for which there are learning activities such as reading descriptive texts, watching videos and experimenting with interactive animations. The visualizations and explanations of the concepts are used to remember and understand the formulas and concepts of the Lorentz force (see Fig. 3.6). The paid premium version also offers exam-like tasks, learning plans and statistics on learning progress. These serve the assessment of the learning progress. However, the premium version could not be tested within the scope of this work. The learning content is developed in collaboration with universities such as the Karlsruher Institute of Technology. The simple club app is the only application presented in related work that is not a video game, and accordingly has fewer gamified elements and game mechanics. However, the exercises include proximate goals such as "solve" or "find", for example, when solving a problem using the formula of the Lorentz force.

Figure 3.2. Gameplay screenshot of Physikus (HEUREKA-Klett Softwareverlag GmbH, 2003).

3.1.2 Physikus

Physikus (HEUREKA-Klett Softwareverlag GmbH, 2003) is a 3D point and click adventure game in which the player must solve puzzles to save the world. The learning content consists of four physics topics: Optics, mechanics, acoustics, and electricity. There are learning objectives for each of the subfields. An objective from the electricity part is learning and applying Ohm's Law. In Physicus the player can click near the border of their screen to move between static scenes in which there are objects to inspect. Scene switching is a "navigation" mechanic, according to the UGO. An example object from the game is the suitcase shown in Fig. 3.2 on the left, which contains a circuit. The circuit can be activated ("activation" mechanic) by pressing the red button after inserting a second resistor to close the circuit ("creation" mechanic). The resistor's value can be increased and decreased using the arrows ("change of element" mechanic). To solve the puzzle, the correct wattage must be reached, which can be found on a piece of paper elsewhere in the world. This involves, for instance, the imperative goal "Find". However, the player does not learn the required knowledge through activities in the world, but has to read texts like the one on the right in Fig. 3.2 to acquire the knowledge. The applying and practicing of knowledge is therefore gamified, but the learning part is implemented more classically through reading. However, the texts are supported by animations of the concepts. Thus, the learning activities in the theoretical part are similar to those in the simple club app. Though, there are additional activities in the gamified part. One example is the insertion of the second resistor. The player learns that they can only activate the circuit when it is closed. This activity counts as understanding conceptual knowledge.

3.1.3 Supercharged!

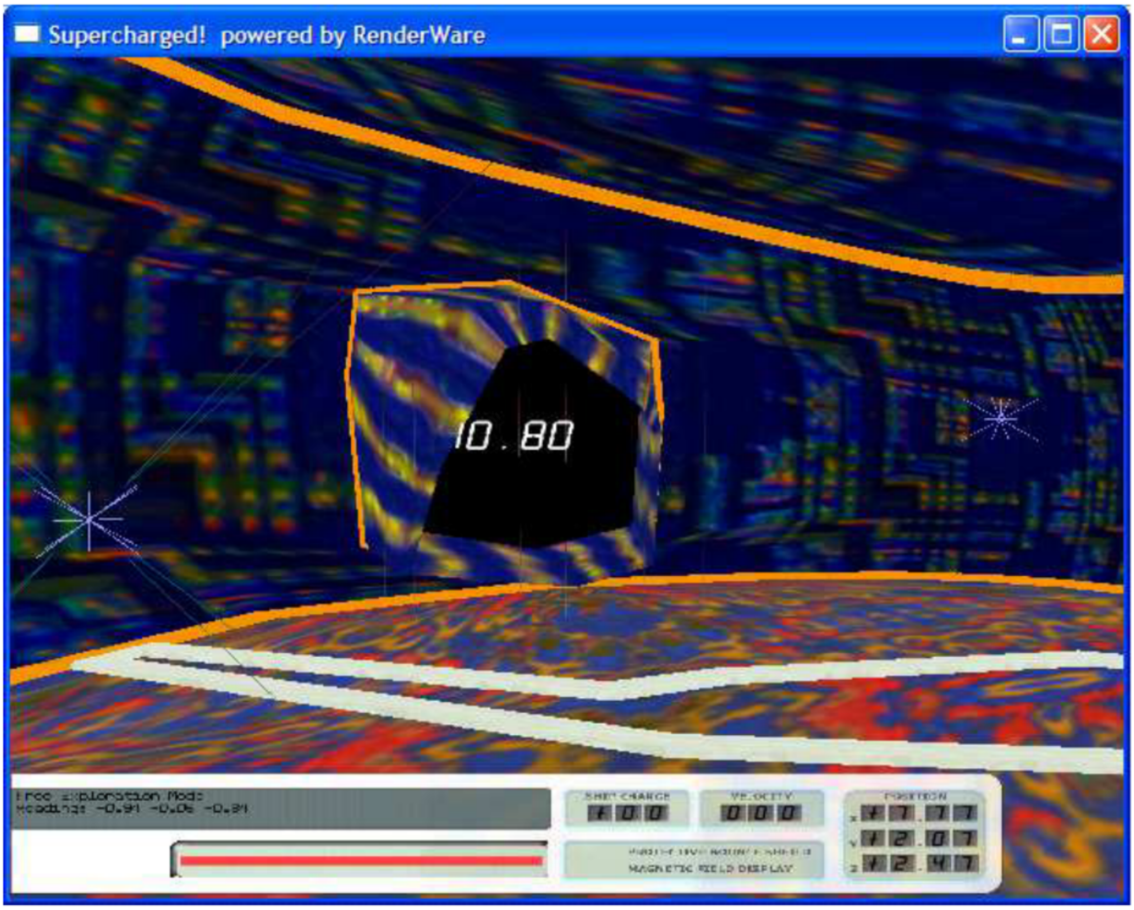


Figure 3.3. Gameplay screenshot of Supercharged! (Squire et al., 2004).

The computer game Supercharged! (Squire et al., 2004) is a 3D simulation game developed as a learning activity for schools in collaboration with MIT physicist John Belcher. Players control a spaceship that must be moved through a maze using charged elements. The game is divided into two phases: a planning phase and a game phase. In the planning phase, charge points can be set from which the ship can either be repelled or attracted. The player can charge the ship negatively or positively and has a limited amount of fuel with which to move without the electrostatic forces. The game has complex "navigation" mechanics that consist of arranging and placing loaded objects, but also maneuvering the ship. In addition, building the maze is a "creation" mechanic. Objectives are for example "choosing" the right objects or "optimizing" the path. The labyrinth itself consists of elements from the subject area of electromagnetism, such as charged surfaces or electric currents. One learning object is to understand physical phenomena such as the electrostatic forces that prevail between charged objects. The game was created as part of a research project and could not be tested because no binaries were available. It is a serious educational game, where the learning activities are directly integrated into the game. This is also the case with the game developed in the practical part. An example of a learning activity in Supercharged! is the placement of the loaded objects. The player has to remember that equal charges repel and unequal charges attract in order to influence the path of the ship correctly. The activity belongs to the category "remember conceptual knowledge".

3.1.4 Wired

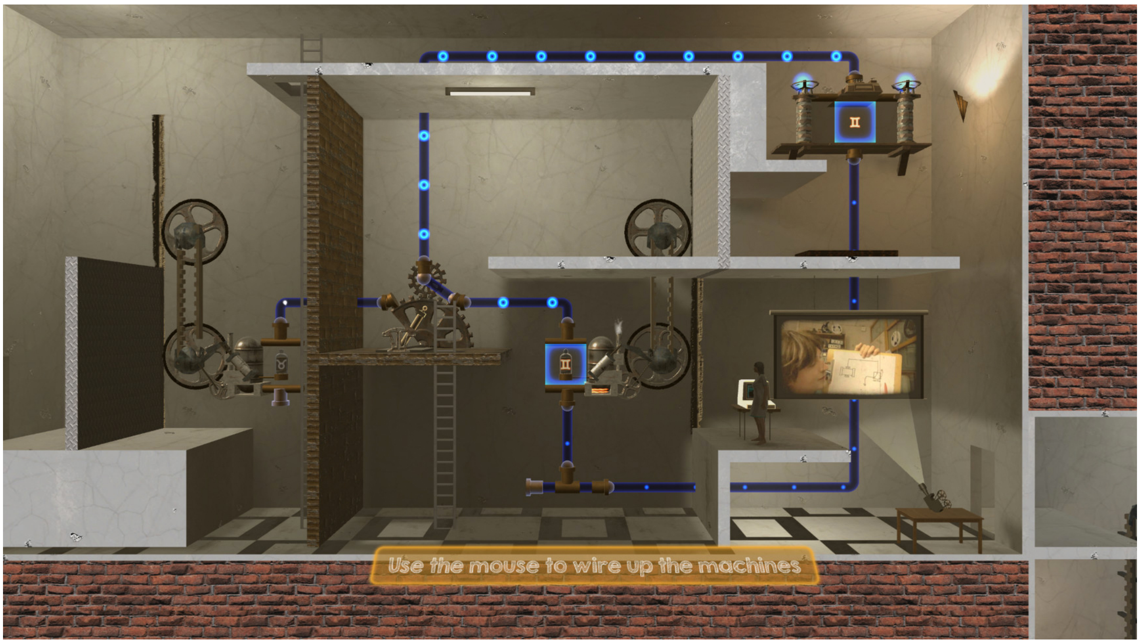


Figure 3.4. Wired on Steam (University of Cambridge Engineering Department, 2018).

The PC game Wired (University of Cambridge Engineering Department, 2018) is a platformer game published by the University of Cambridge Engineering Department. The player has to move through the rooms of a former school by connecting given circuit elements with cables in the right way, thus opening the door and "reaching" the next section. To build a circuit, the player operates terminals that can be used to connect nodes with cables by clicking on them. Placing circuit elements can be a "change of element" mechanic or a "creation" mechanic, depending on whether the circuit is created from scratch or modified. In addition, other components such as switches can be operated via the terminals. One learning objective within the game is to learn how to build circuits, thus "applying conceptual knowledge" about circuit theory. To solve the puzzles, the player must understand how electrons flow through a circuit in order to connect the correct nodes and prevent short circuits, for example. This knowledge must then be "understood" before one can solve the circuit puzzles. You also need to be able to "remember" and identify different circuit elements to include other components such as voltage sources and switches. During the game, videos are shown again and again between the puzzles, which either explain mechanics or physical concepts or give the player an understanding of the background story.

3.1.5 Power Grid Tycoon

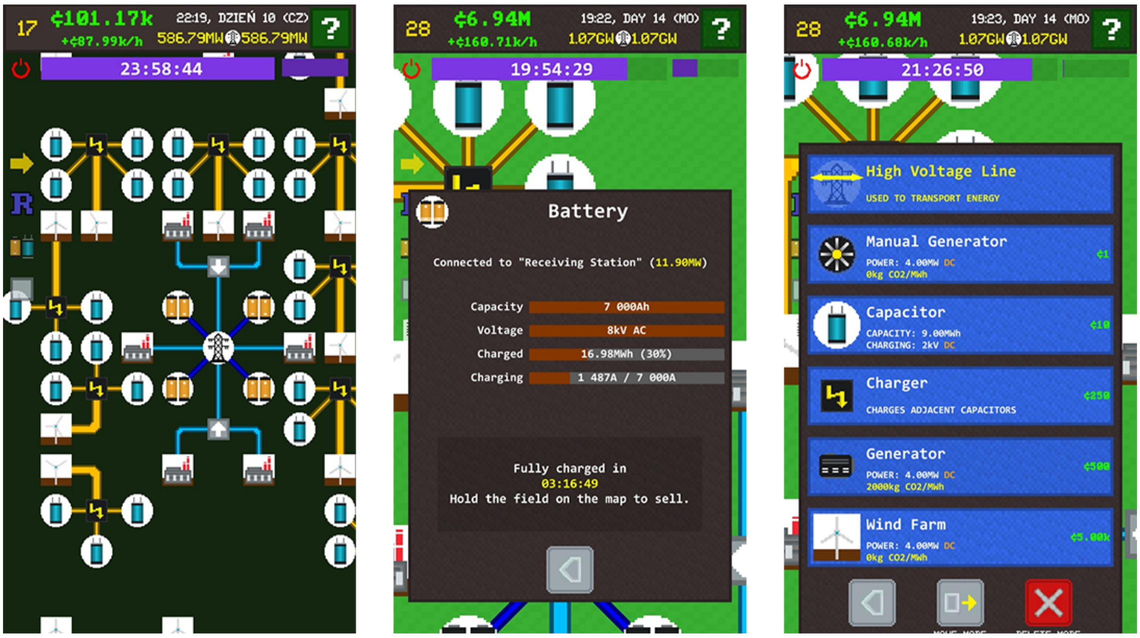


Figure 3.5. Screenshot of Power Grid Tycoon from the google app store (iade, 2021).

Power Grid Tycoon (iade, 2021) is a strategy idle game. The player builds a network of power generators and produces electricity. They will receive ingame currency for selling this electricity ("creation" mechanic). Through mini-games, the player also has the opportunity to earn money. He can use this money in the form of a classic "change of element" mechanic to improve the components in his power network and, for example, to produce or store more electricity. Capacitors, for instance, can be replaced by batteries, or generators can be replaced by wind turbines and later by coal-fired power plants. The main goals of the game are to "create" a power network and to "obtain" as much money as possible to "optimize" the system. Power Grid Tycoon is not an educational game. Nevertheless, while playing the game, you get to know the different components in a power grid better. This learning objective belongs to the category "remembering factual knowledge". Further objectives could be extracted from elements like the CO2 emissions produced by the power plants, which must not be exceeded in order to achieve certain goals or the distinction between direct and alternating current. A learning activity in the game is the placement of the network components, where one repeats their names regularly. The activity is also assigned to the category "remembering factual knowledge".

3.1.6 ElecHead

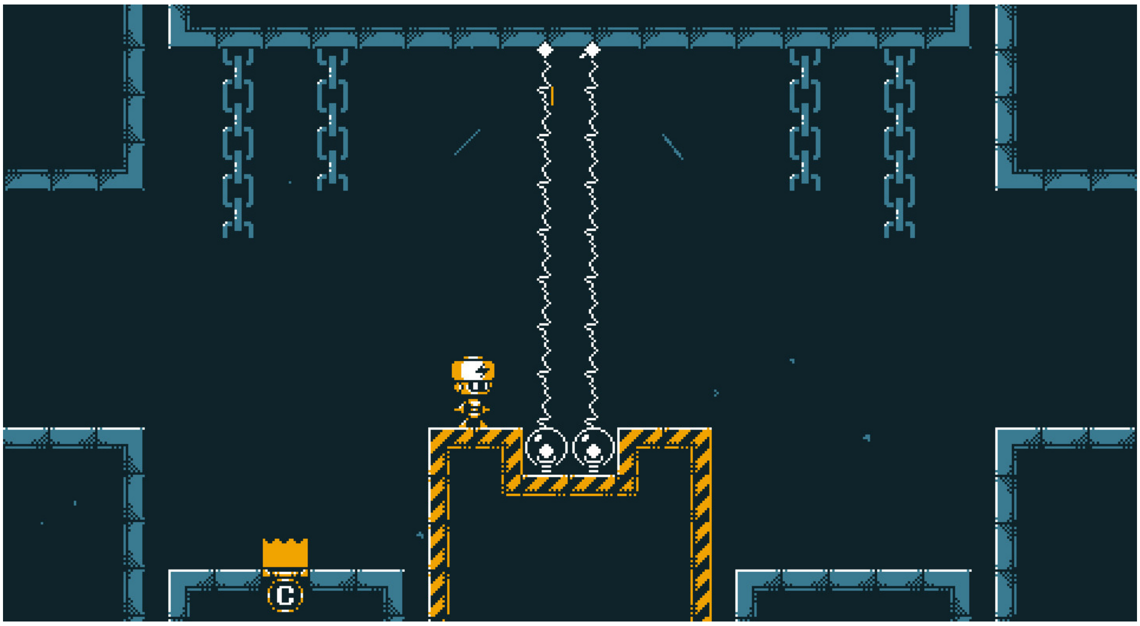


Figure 3.6. ElecHead on Steam (NamaTakahashi, 2021).

ElecHead (NamaTakahashi, 2021) is a puzzle platformer released in 2021 by NamaTakahashi. Here, the player plays a robot that can charge surfaces and thereby, for example, make connected platforms move or materialize. With this mechanic, puzzles must be solved in order to progress in the world. The main goals of ElecHead are to "reach" the next rooms while "solving" puzzles. The main focus in regard to mechanics is to "activate" platforms or other objects through electricity and to "move" and "jump". The game was not designed as a serious educational game, making it harder to find proper learning objectives. However, ElecHead makes use of electromagnetic concepts in the design of the basic mechanics. For example, the conductivity of objects is used to activate objects connected to the conductors. One could formulate a learning objective around this topic. Since the concepts are not implemented realistically, the player cannot apply the knowledge learned in the game to the real world. The player does not need any special prior knowledge to play the game. Even though it is not a serious game, it can still arouse an interest in electromagnetism due to the thematic reference, for example if the player wants to comprehend to what extent the mechanics correspond to reality. The puzzles, which use the basic mechanics in a variety of creative ways, make for an entertaining and enjoyable game. Even the tutorials have to be unlocked by using the main mechanics and are thus well integrated into the game flow, which never leads to a break in immersion.

3.2 Classification In Regard To Learning And Engagement

In Fig. 3.7 you can see the classification of the presented applications in terms of their successful knowledge transfer and engagement factor, i.e. how much fun the player has playing the game. An effective serious educational game should have as high a value as possible in both categories, and thus be found in the upper right area of the scheme.

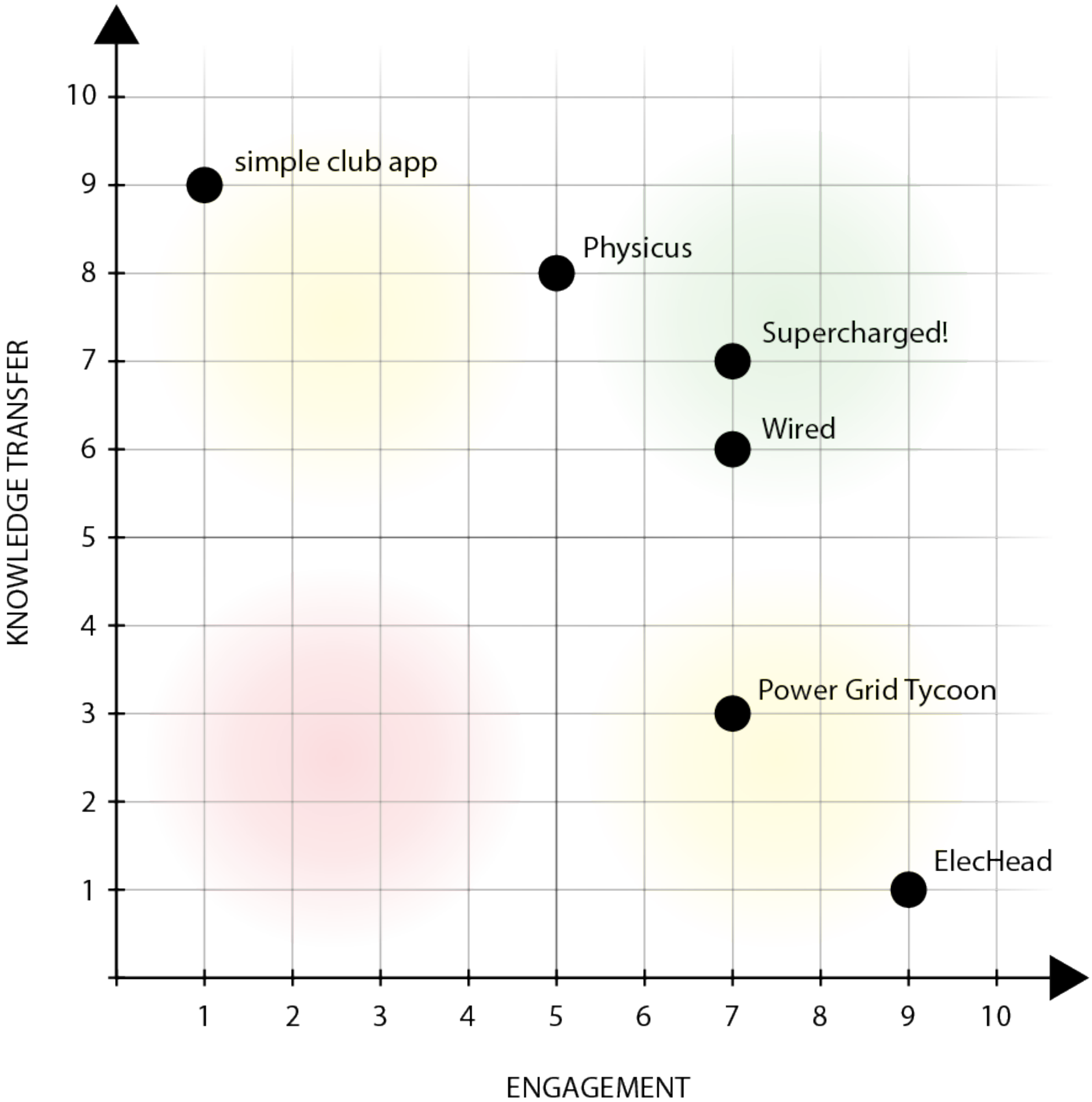


Figure 3.7. Serious educational game classification scheme in regard to successful knowledge transfer and engagement factor.

4 Electrified: A Serious Educational Game To Teach Ohm's Law

The game that was created as part of this thesis is called Electrified. Since the topic is electromagnetism, it includes information about electrical engineering and circuit theory as well as the fundamentals of the topic. Since it was created as a serious educational game, it must have a high engagement factor and communicate the learning goals effectively. Moreover, knowledge retention tests have been designed to assess the learning. More about this in chapter 5. The game should serve as an independent learning environment and not as an accompanying learning activity for e.g. school lessons. This means that the game itself contains various learning activities. Electrified was developed with a focus on the gaming aspect, but every design decision was made considering the instructional design and its interplay with the gaming aspect. In the following section, the basic concept of the game is explained. First, the game mechanics and the game design is examined in more detail in regard to the MDA framework and the Unifying Game Ontology. In section 4.1.3 the goals of the game are explained in further detail. Section 4.2 describes the instructional design, such as the learning items, objectives and activities of the game. The last section describes how the gaming and learning aspects are connected to each other. It also explains how and where they were concretely implemented within the game.

4.1 Game Design

4.1.1 Concept

Electrified is a cooperative puzzle platformer based on the theme of electromagnetism. By solving puzzles, the two players can progress through the levels while learning more about the topic of electromagnetism. Players are able to change their character's charge between a negative, neutral and positive state. Just like in the

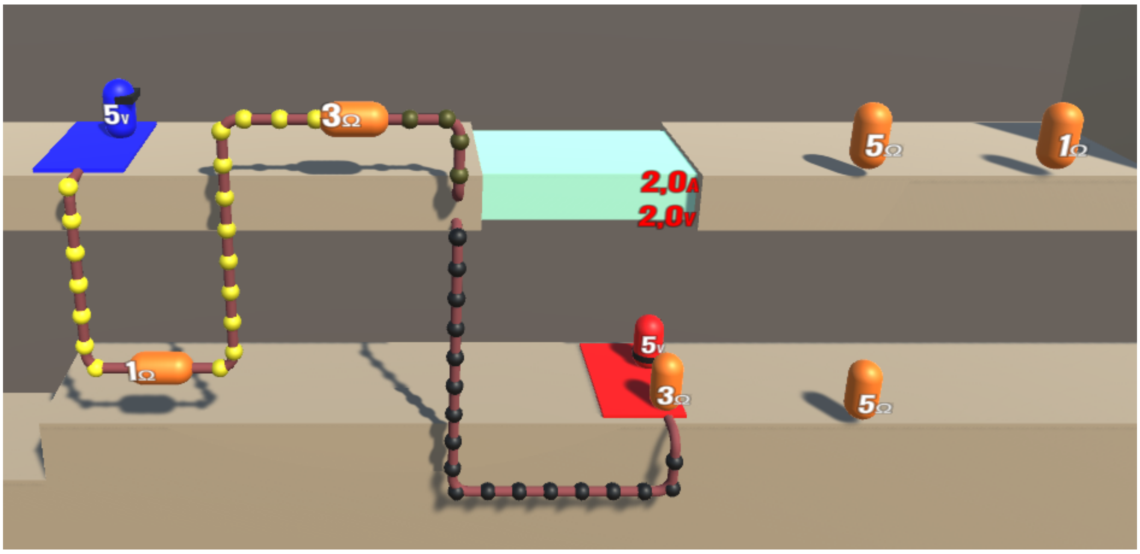


Figure 4.1. Screenshot from the game Electrified.

real world, charges of the same type repel each other and opposing charges attract one another. This allows players to be affected by charged objects scattered throughout the world. Consequently, it is possible to use static charges like a trampoline to overcome high obstacles. These forces also act between the two characters, allowing for additional cooperative elements and more interactions between players. In addition, when the characters are charged, they can act as voltage sources in a circuit. Players can do this by standing on contact plates connected to circuits, and depending on how they are charged, they will act as voltage sources of either 5V or -5V. Using the different circuit elements, puzzles can be solved by opening doors, most of the time, necessary for progression. The complexity of the riddles increases by introducing more complex components and concepts (e.g., use of parallel circuits instead of exclusively series circuits). Moreover, it is possible to construct different circuits by replacing individual circuit elements. The player can obtain a solid physical understanding of Ohm's law and the importance of different circuit elements piece by piece through the learning and game elements described. At the same time, the game helps to approach the basics of electricity in a model-like way, and it helps to build up an intuition for the flow of electrons in different circuits. In the following subsections, we will delve deeper into the game design process, starting with the core mechanics and which dynamics and aesthetics emerge from them. Furthermore, the goals that can be found within the game are outlined and the instructional design will be explained.

4.1.2 Core Mechanics

We designed a series of games mechanics that emphasize natural physical phenomena regarding electromagnetism: Charge Switching, Charge repelling/attracting, Character repelling/attracting, Circuit Activation, Circuit Building.

Charge repelling/attracting

We conducted early oral play tests, where the development team was asked to rate the mechanics of the game in regard to them being fun. Those tests determined that interacting with static charges was fun for the testers. Those elements are placed in the world and are either positively or negatively charged. Giving a player's character the same charge as a static charge allows them to be repelled by it. The mechanic is used to overcome obstacles that cannot be overcome by just jumping. This is a "navigation" mechanic that can be categorized as "accelerating" or "jumping" (Debus, 2019).

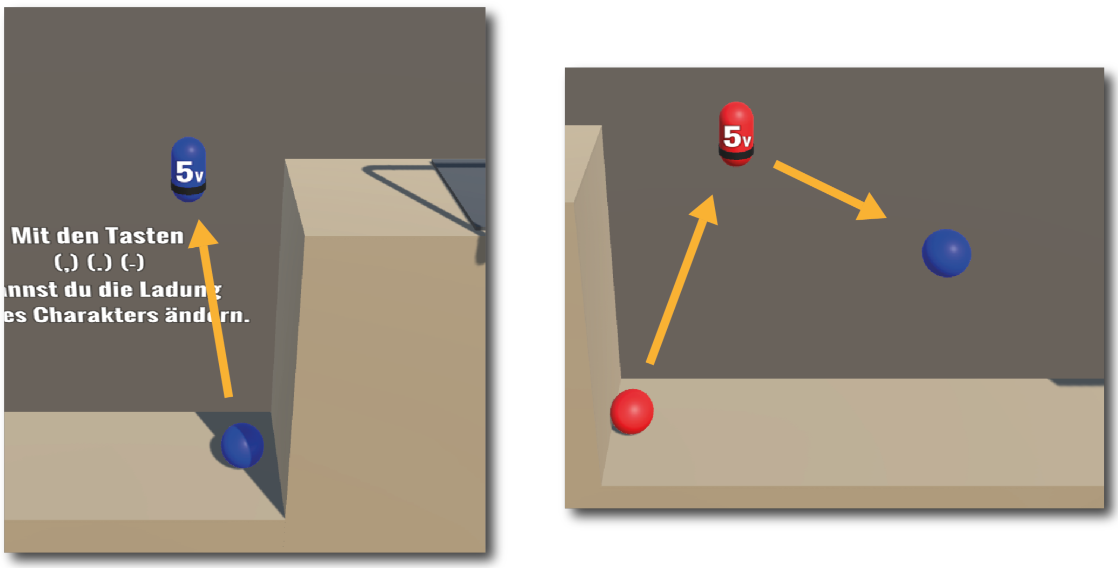


Figure 4.2. A player using static charges in Electrified to overcome obstacles.

Charge Switching

It quickly became apparent that the ability to change the charge of one's character was necessary for the characters' navigation: it gives the characters the possibility to detach from a strongly charged element. In addition, this mechanic provides players with more flexibility. Indeed, it is possible for the player to stand on a static charge in a neutral state, take on its charge, and thus give themselves a strong push or repelling force. In addition, it can be used to build more complex jump-and-run elements, where the player must change charges at the right time during a jump to successfully complete the element.

The dynamics that emerge from the repelling/attracting and charge changing mechanics offer a wide range of possibilities for navigation and result in a fun jump-and-run experience for the player. By utilizing jump-and-run elements one can create the aesthetic of "challenge" as described by Hunicke et al. (2004). Changing a character's charge can be categorized as a "change of element" mechanic according to Debus (2019): the character "transforms" into a voltage source with either a positive or negative charge.

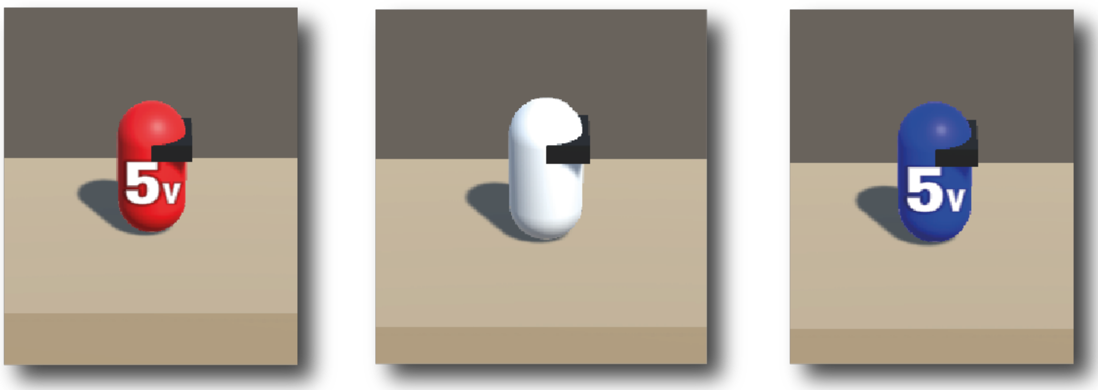


Figure 4.3. The three states a character can reach in Electrified by switching charge.

Character repelling/attracting

The fact that the players didn't repel or attract each other until now was criticized by the testers as unrealistic. Indeed, charged elements would usually attract or repel each other. Thus, the implemented electrostatic forces were also applied to the two characters, which allows for cooperative jump-and-run elements such as players standing on top of one another, pushing and boosting each other to an otherwise unreachable platform. In the context of the Unifying Game Ontology, this mechanic can be classified analogously to the charge repelling/attracting mechanic.

Due to the similarity to the repelling/attracting mechanic already introduced, the forces between players allow for even more complex and diverse jump-and-run elements. The other player can now function as a dynamic charge that can change its type midair. Through that, even more challenging obstacles can be built, however this mechanic with its resulting dynamics also leads to an aesthetic of fellowship. The two players now can cooperate during jump-and-run sequences to reach their goal.

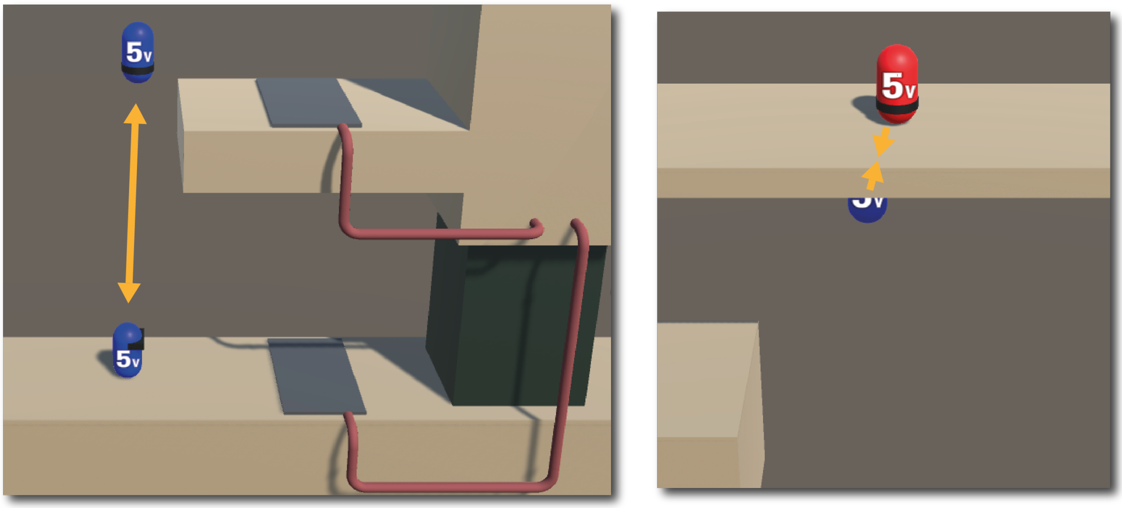


Figure 4.4. Two characters repelling/attracting each other to overcome obstacles.

Circuit Powering

When charged, the characters resemble the positive and negative poles of a battery. This gave rise to the idea of incorporating circuits as puzzle elements that can be activated in cooperation - one player as the positive pole and one as the negative pole. For the implementation of electric circuits in Electrified we used a well-known simulation library called the spice engine (Delport et al., 2019). This library does not offer the splitting of a voltage source into its terminals, natively. For this reason, the characters were not modeled as single terminals, but as whole voltage sources that can be set active by standing on a contact plate and switching their charge to either positive or negative. According to the UGO this is an "activation" mechanic.

Each player being a voltage source on their own has the advantage that a single player can activate a circuit and open a door, without needing the help of the other player. In addition, it is thus possible to increase the voltage in a circuit by having the second player stand on another contact plate and act as a second voltage source. In Fig. 4.5 you can see how one player has assumed a positive charge and thus creates an electric potential of five volts, while the other player is negatively charged and causes an electric potential of minus five volts. This creates a voltage of ten volts on the door, and it opens. With the circuit powering mechanic and its resulting dynamics, there can be created a new kind of cognitive challenge. The players have to analyze the circuits and find a solution. Since in many circuits both players need to act as a voltage source for the riddle to be solved, there also arises the aesthetic of fellowship, since both players depend on each other to progress. An entirely new aesthetic described by Hunicke et al. (2004) that is introduced through the circuits is "sensation". The players can observe the flow of electrons in different circuits and under different circumstances.

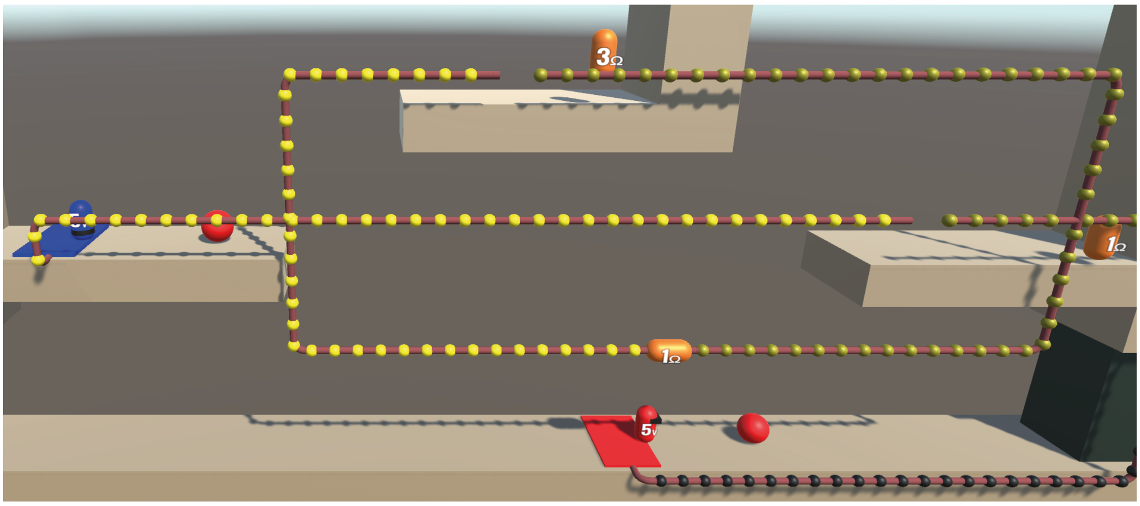


Figure 4.5. Two characters serving as voltage sources to open a door.

Circuit Building

In addition, in Electrified it is possible to change circuits by inserting and removing components. Characters can each carry a component, such as a resistor, and insert it into gaps in the circuit. For example, a resistor can be removed and replaced with a piece of wire so that the overall resistance in the circuit is reduced, and a coil burns out, clearing the way to the next section. This mechanic has been added so that players have another way to interact with circuits and are able to change the current or resistance within a circuit apart from being able to manipulate the voltage. This mechanic can be assigned to two categories of the UGO, depending on the current state of the circuit. One can classify the placement of elements as a "creation" mechanic when closing a previously disconnected circuit. However, you can also assign the mechanic to the "change of element" category, since you can also transform circuits with it, for example, when you create a parallel circuit by connecting two loose cable ends.

This mechanic allows the player to try out new components and their effect on the whole circuit. It creates a small testing laboratory for the players inside the game. This dynamic leads to an aesthetic of "sensation", too, which is described as "[a] sense of pleasure as the result of trying something new" (Kusuma et al., 2018).

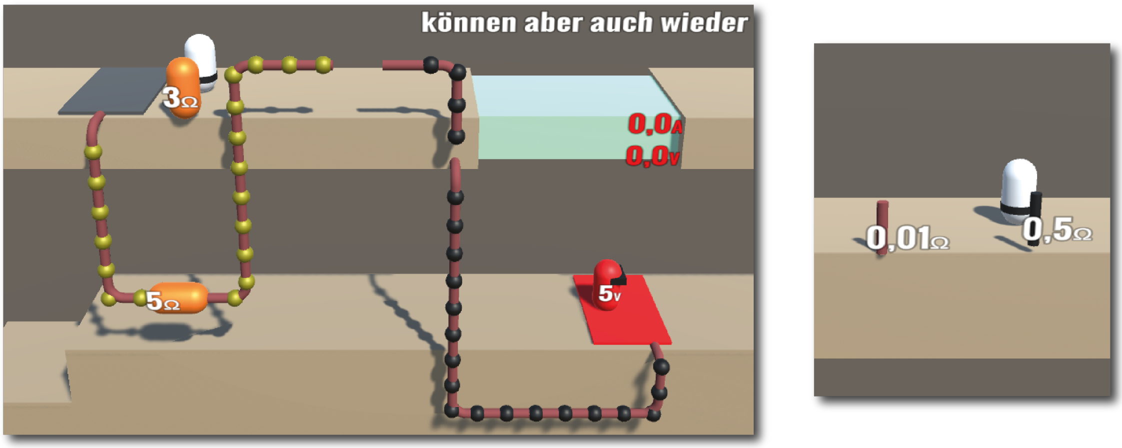


Figure 4.6. Players with different components that can be inserted into empty circuit slots.

4.1.3 Game Goals

With the Unifying Game Ontology, not only can you categorize mechanics, but also identify the goals and elements of a game. The ontology offers a variety of terms to describe the goals. The main goals in Electrified are to "reach" the next section and to "solve" riddles. These are imperative goals according to Debus (2019). The ultimate goal of Electrified is "finishing" by reaching the last room.

Jump-and-run elements are common at the beginning of the game, with the goal of "reaching" the other side of a gap or landing on a contact plate to open a door (see Fig. 4.4). In later puzzles, for example, one goal is to "choose" the right resistor to successfully "configure" a circuit and make a motor work (see Fig. 4.6). In Fig. 4.10 on the right side one can see a riddle where the player has to "optimize" a circuit by replacing a resistor with a wire, which has less resistance, in order to progress in the level. Later on, the player has to "find" a component to insert into an empty slot within a circuit in order to create a closed circuit. Those are the different types of goals that can be found within the riddles in Electrified.

4.2 Instructional Design

Various learning activities are implemented in the game. They are represented by game elements and are intended to help the player achieve the learning objective. After successfully completing the game, the player should be able to solve circuit problems using Ohm's law. The focus is on conceptual problems and not on concrete formulas. The game aims to visualize the concepts within an electric circuit and thereby support the formation of correct mental models and avoid misconceptions. The target group of the game are persons who have already dealt with the topic of electric circuits - for example in school - but do not deal with the subject on a regular basis. Thus, terms such as current, voltage and resistance should not be completely foreign to the player and the game should serve to repeat and deepen the knowledge. This is necessary because the learning objective of the game is to apply Ohm's law, and building up all the basic factual knowledge (Anderson & Krathwohl, 2001) (e.g., terminology, symbols, details of elements, etc) is beyond the scope of this bachelor thesis. Nonetheless, the basics will be refreshed within the game, such as voltage, current, and resistance.

Electrified consists of a level divided into four different sub-levels (see Fig. 4.13, Fig. 4.14, Fig. 4.15, Fig. 4.16). The first part teaches players the basic movement mechanics so that they can learn to control their characters and later use these skills to solve puzzles. For the cooperative jump-and-run elements, it is important that both players master certain basic skills regarding jump-and-run mechanics. Therefore, the two players are separated at the beginning in order to practice individually. At the end of one sub-level (training sub-level), the players are introduced to the next one through 3D visualizations of the important concepts in the next sub-levels. The faster player can already inspect them while his teammate follows. The introduction to the second sub-section consists of 3D visualizations of the concepts of voltage and current, as can be seen in Fig. 4.7. In the third sub-level, voltage is the primary theme, so most of the learning activities there are centered around it. However, since current and voltage both increase or decrease when one of them changes, due to their direct proportionality, it is important to also visualize current at this point to make the distinction between the two concepts clear. The sub-level on voltage is followed by the sub-levels (3 and 4) on resistance and current. A visualization of the main concept is presented at the beginning of each new sub-level. Throughout the following sections, the learning activities found in the different sub-levels of the level are explained, and how they were implemented can be seen. At the end of 4.2 there is a table according to which the learning activities and the learning objective are concretely classified using Revised Bloom's Taxonomy.

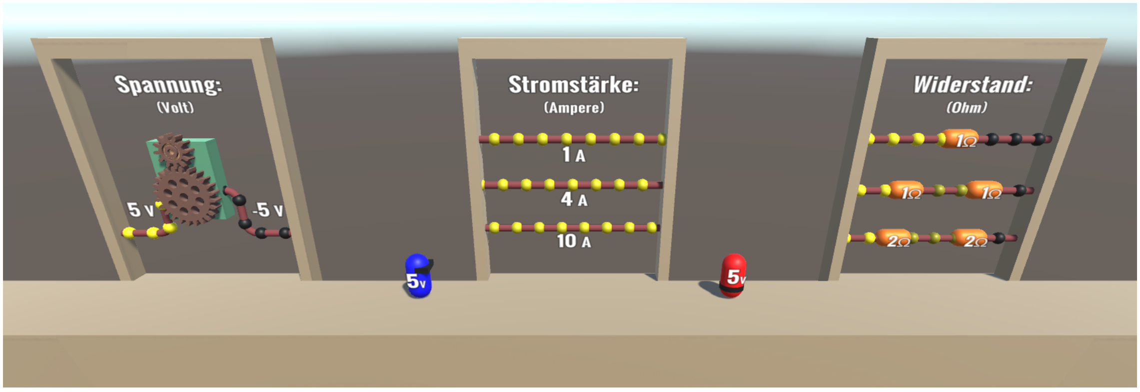


Figure 4.7. 3D visualizations of the three main circuit concepts: voltage, current and resistance.

Learning objective: Solve circuit problems with Ohm's Law (Apply Conceptual Knowledge)

After playing the game, a player should be able to solve conceptual problems regarding electric circuits with the help of Ohm's Law. They should be able to apply the law to familiar, but also to unfamiliar tasks. These include problems such as adding a resistor to a circuit so that a lamp does not burn out, or adding more voltage to a circuit to activate a motor.

Activity 0: Recalling of units (Remember Factual Knowledge)

The first activity helps the player with recalling the units of voltage, current and resistance. For this, the units are introduced via visualizations as in Fig. 4.8 and assigned to the concepts. After that, the units are used regularly and displayed on objects. For example, doors display the applied voltage and current in volts and amperes, and each resistor has a label with the number of ohms.

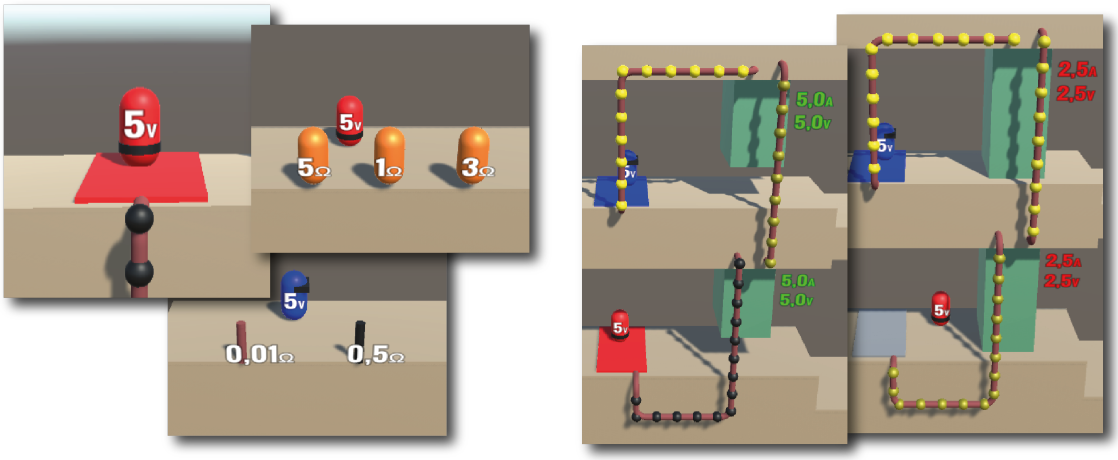


Figure 4.8. Usage of units within the game Electrified.

Activity 1: Understanding of voltage, current and resistance (Understand Conceptual Knowledge)

The second activity helps the player with understanding the concrete concepts behind voltage, current and resistance. For this purpose, 3D visualizations of the three concepts are distributed throughout the game (see Fig. 4.7). These elements can be inspected, and they illustrate through animations what is behind the concepts. The visualizations are distributed throughout the level. At the beginning of each sub-level there are the animations that fit the theme of the sub-level and at the end there is a summary where all three concepts are repeated once again.

Activity 2: Manipulating voltage in a circuit (Understand Conceptual Knowledge)

The goal of this activity is to teach about the cause-and-effect of voltage change in a circuit so that the player can explain it. In the twelve circuits within Electrified, there are always either one or two contact plates on which the players can stand. There they can serve as voltage sources. If no contact plate is active in a circuit, no current flows. As soon the first charged player stands on a contact plate, they will see that the electrons start to move. If a voltage of five volts is sufficient for the door component to open, this will happen. If the input power is not enough, the second charged character must move to another contact plate, and the players can observe that the electrons are now moving faster than before. This shows the direct proportionality of voltage and current to the players. This activity is found in every sub-level that contains a circuit. However, the direct proportionality is best seen in the voltage sub-level, where circuits with one and two contact plates specifically alternate and thus oppose each other, highlighting the effect of different voltage values (see Fig. 4.9).

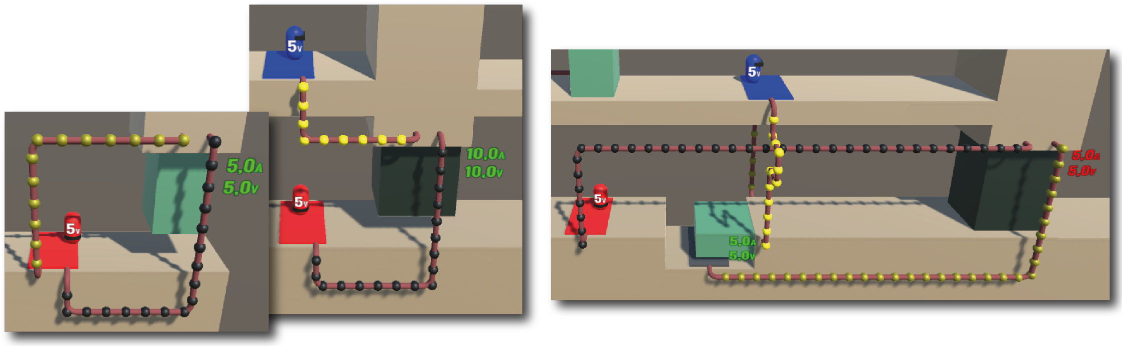


Figure 4.9. Circuits requiring one or two voltage sources to open the attached door.

Activity 3: Inserting resistors into a circuit (Understand Conceptual Knowledge)

The goal of this activity to teach the cause-and-effect of resistance change in a circuit so that the player can explain it. In the resistance sub-level of the game, resistors are introduced. They come in different forms and strengths. The player is able to insert resistors into the gaps in a circuit and take them out again. For example, in the puzzle in Fig. 4.10, there is a circuit with two gaps and each player has one resistor each with the values one, three and five ohms. By trying them out, players can now see that the higher the resistance, the lower the current, and vice versa. In this way, the player learns the indirect proportionality between resistance and intensity of current. This activity can still be found in other circuits where the player can swap resistors. In one example, the player must replace a classic resistor with a piece of wire to burn out a coil, which then clears the way.

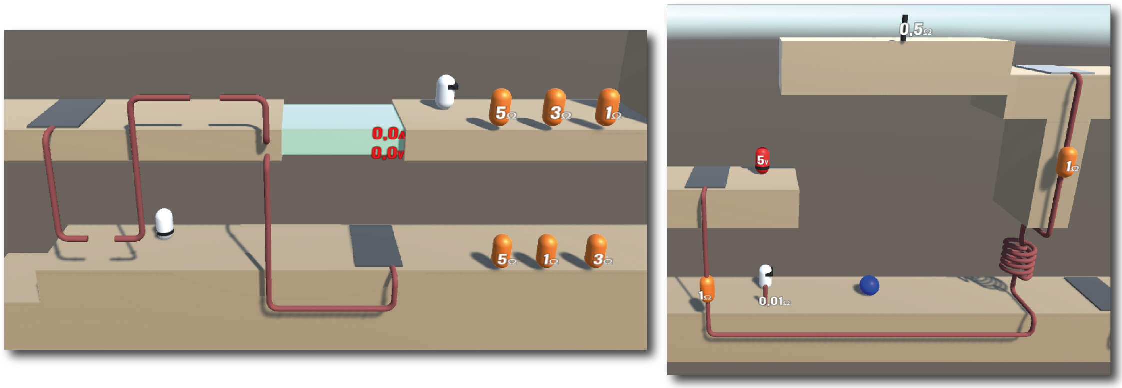


Figure 4.10. Riddles in Electrified where resistors have to be inserted to progress to the next stage.

Activity 4: Differentiating between conductors (Analyze Conceptual Knowledge)

Another activity introduced in the resistance section helps to differentiate between different types of conductors. As mentioned earlier, resistors come in different forms because every material has some electrical resistance. In Electrified, for example, there are the classic resistors as used in electrical engineering, but you can also, for example, use cables that have a much lower resistance, which is why they are also used as conductors. So in the puzzle with the coil, the classical resistance is removed and replaced by a conductor. Because of this, enough current flows so that the coil can burn out and clear the way (see Fig. 4.10). This activity belongs to the category "analyze conceptual knowledge" and, according to the hierarchy of Revised Bloom's Taxonomy, is ranked higher than the learning objective's category, which belongs to "apply". In this activity, however, the conceptual knowledge is considered to be the resistance in an electric circuit and not Ohm's law, which is why this activity does not violate the teaching framework's hierarchy regarding the learning objective.

Activity 5: Explain current flow in parallel circuits (Understand Conceptual Knowledge)

In the last sub-level of the game, which deals with current, parallel circuits are introduced. Through these, it can be observed that different intensities of current can occur even within the same circuit. In the last circuit, for example, there is a parallel section where three cables run in parallel, two of which are interrupted (see Fig. 4.11). If one activates the circuit, the current flows through the connected piece, but has the same current intensity at each point. If one now connects the other two cables by inserting resistors in the gaps, the player can observe how the current strength in the parallel sections is lower than in the cables before and after the parallel piece. The player can now explain that input current divides onto the parallel wires, and thus they can explain the behavior of current in parallel circuits in comparison to the behavior in series circuits.

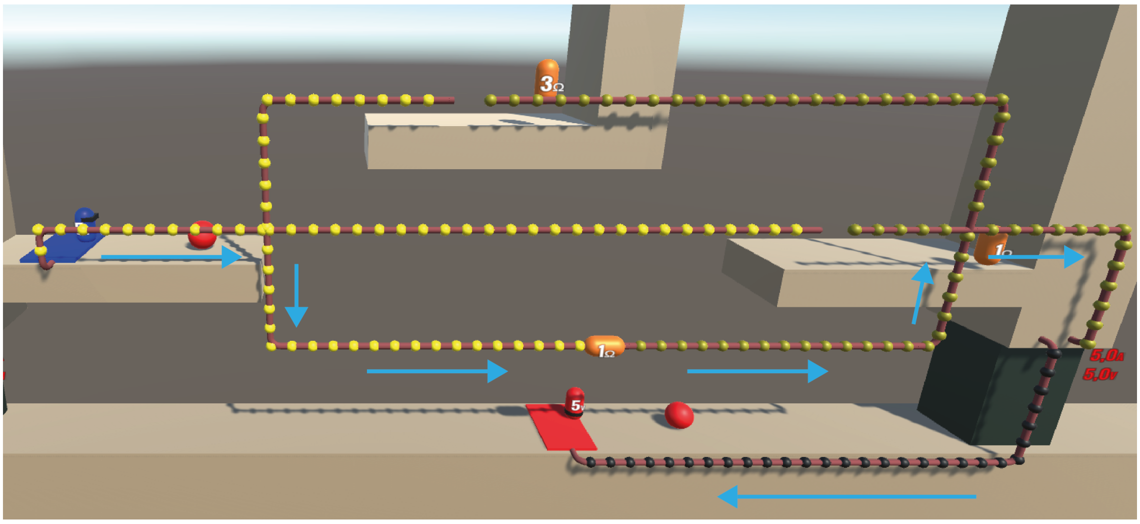


Figure 4.11. Parallel circuit riddle in Electrified.

Activity 6: Attributing lack of current to gap in circuit (Analyze Conceptual Knowledge)

Another learning activity from the current sub-level aims to show that a player can attribute a lack of electric current in a circuit to a missing component and the resulting gap. This activity can already be found in the resistance sub-level, since there are no resistors in the first circuit and therefore no current flows (see Fig. 4.10), but the focus of the activity is in the sub-level concerning current. For example, one puzzle's only aim is to create a connection between two cables in order to open a door. Also, in the puzzle described in the previous section, gaps have to be closed to establish a current flow in certain parts of the wire (see Fig. 4.11).

The presented learning activities were extracted from the existing game. For example, the possibility of influencing the voltage in a circuit arose from the fact that there are two players, each of whom can change their charge and act as a voltage

	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual Knowledge	Activity 0					
Conceptual Knowledge		Activity 1 Activity 2 Activity 3 Activity 5	Objective	Activity 4 Activity 6		
Procedural Knowledge						
Meta-Cognitive Knowledge						

Figure 4.12. Classification of the presented learning objective and activities in regard to Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001).

source. In places where it was deemed useful, the existing mechanics were adapted to generate further learning activities from them or to improve existing ones. For example, not only classical resistors were made available for installation, but also cables and other conductors. It was tried to find suitable learning activities that work towards the learning objective. Nevertheless, the instructional design described here serves only as an example to illustrate the design process of a serious educational game. Consequently, the examples shown in Fig. 4.12 merely serve as a way to teach Ohm's law, but can be modified or extended as needed. Whether it is a successful instructional design is checked by the assessment in 5.

4.3 Learning Elements Representation In Game Elements

To be able to revise the evaluated learning activities in a meaningful way, it must be clearly defined in which game elements they are represented. For this purpose, an overview of the entire level design is given (see Fig. 4.13, Fig. 4.14, Fig. 4.15, Fig. 4.16) and the previously presented learning and game elements are mapped onto each other.

The learning activity regarding recalling of units spans the entire level. It starts with the 3D visualizations at the beginning of each sub-level, which concretely explain the effects of each concept and assign the according units. In addition, the resistors show their value and consequently their unit and also at each door you can find their current and voltage that is present at any given time. Also, a player's character shows five volts when it is not neutrally charged. Therefore, you can connect this activity in Electrified with change of element and activation mechanics, because when you use these mechanics, the values of the circuits are updated and therefore the focus is automatically on their units as well. The goals most associated with the activity are "configure" and "optimize", since the value labels allow a concrete assessment of how a change has affected the circuit.

The understanding of voltage, current and resistance is a broad learning activity and accordingly widely distributed across the level. Similar to activity 0, there are the 3D visualizations at the beginning of each sub-level that show the effects of voltage, current and resistance. You can also explore the aforementioned concepts on each of the twelve circuits in Electrified by, for example, transforming your character into an additional voltage source through charge switching and activating the circuit, or by increasing the voltage and consequently the amperage. Another possibility to cause a change in the circuit's behavior is to add additional resistance. One can thus try out different resistors and observe their effect. Consequently, when configuring and optimizing the circuits, players can examine the concepts and their effects and thus better understand them.

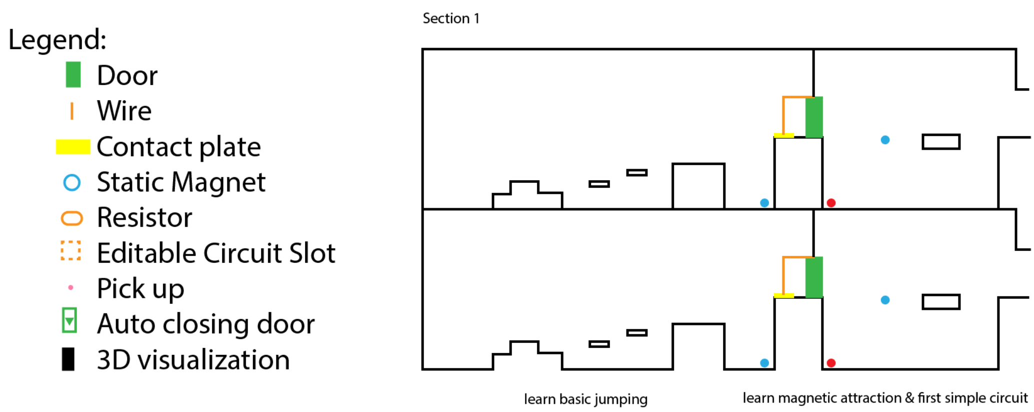


Figure 4.13. Detailed design of sub-level 1 (training) of Electrified.

The learning activity of manipulating voltage in a circuit is mainly encoded in two elements. In sub-level 1 there is a door that the players can open individually. At the beginning of sub-level 2 they reach a door which they cannot open alone, but where they have to rely on their teammate as a second voltage source. In the middle part of sub-level 2 there is a whole room dedicated to the learning activity (see Fig. 4.14). In this room, players must each activate circuits on their own to unlock the second contact plate for the main circuit. By alternating circuits that can be operated alone with those that require a second player, a contrast is created that illustrates the effects of the voltage increase. The game goals of the elements involved are solving puzzles and reaching the next room.

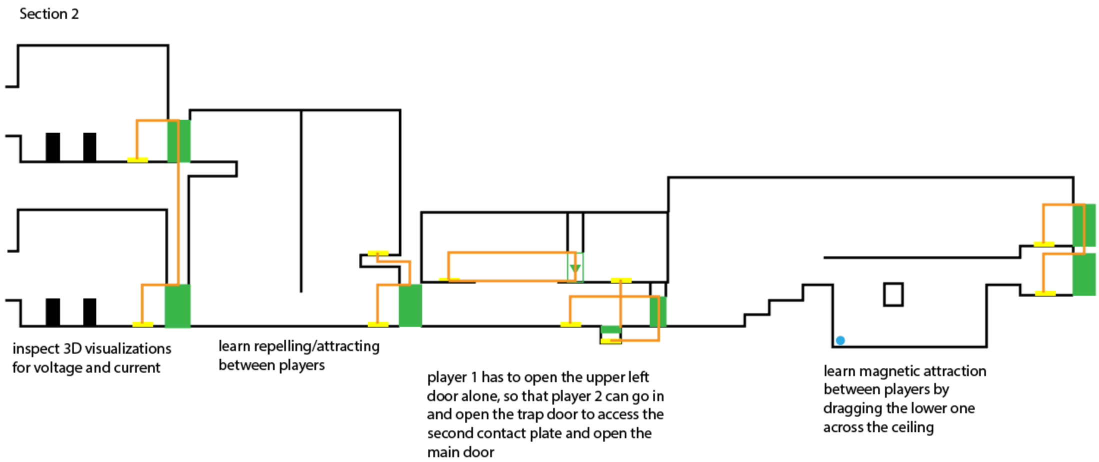


Figure 4.14. Detailed design of sub-level 2 (voltage) of Electrified.

Inserting resistors into a circuit is the main theme of section 3. Here, for the first puzzle, players must select the two correct resistors from a possible six and insert them into the circuit, so that creating a large enough flow of electrons is possible, once the circuit is activated (see Fig. 4.15). In the second room, the existing circuit must be configured so that the resistance is low enough to cause the coil to burn out. This can be achieved by inserting a lower resistor.

Another learning activity found in sub-level 3 teaches the player to differentiate between conductors. In the coil puzzle described earlier, players must remove the previously installed ohmic resistor and then select a wire to insert into the resulting gap. When activating the circuit, you will know that you have chosen the right one when the coil starts heating up. If it doesn't, players must further configure and optimize the circuit.

There are two parallel circuits in Electrified. These are located in sub-level 4 of the game. However, parallelism is only relevant for solving the puzzle in the last room. The player has to install resistors to create a connection between two parallel pieces of wire and thus reduce the total resistance of the circuit (see Fig. 4.16, last room). This game element is intended to help the player explain the flow of current in a

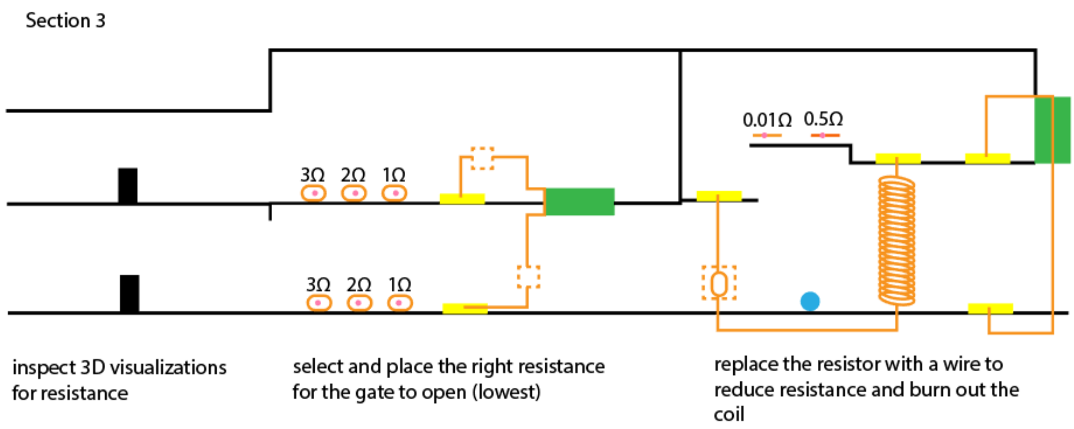


Figure 4.15. Detailed design of sub-level 3 (resistance) of Electrified.

parallel circuit. The main mechanics here are the insertion of components and the associated creation of connections of the loose wire ends. Activating the circuit is also essential, so that current flows and the connection can be recognized. Charge switching also plays a certain role, as this influences the direction of flow. To solve the puzzle, the circuit must be optimized so that a lower total resistance prevails.

Attributing a lack of current to a gap in the circuit is a learning activity that is present in the first riddle of sub-level 3 and sub-level 4 of the game. When players activate the circuit via the contact plates, they notice that no current flows. To solve the problem, they have to insert a circuit component into the gap so that a flow of electrons can occur. Thus, the learning activity consists mainly of configuring circuits.

In summary, the most important mechanics for learning activities are activating circuits and changing them. Additionally, charge switching and thus transforming the player into a voltage source is of particular importance. However, the movement mechanics do not add any educational value, but they increase the engagement factor of the game. The goals pursued by the game elements that are relevant for learning are mostly of the type "configure", "optimize" and "choose" as defined in the UGO (Debus, 2019).

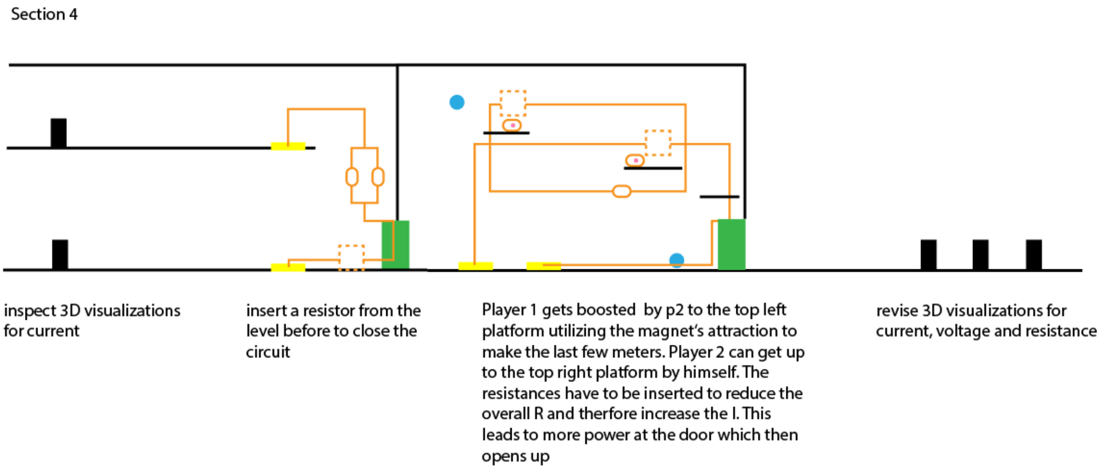


Figure 4.16. Detailed design of sub-level 4 (current) of Electrified.

5 Evaluation About Knowledge Retention

5.1 Test Design

For the purpose of testing the knowledge transfer of the players, a questionnaire was designed, which included questions about the gameplay as well as questions about domain knowledge. It is intended to test the knowledge transfer on the one hand, but also the engagement factor of the game, as presented in section 3.2. A qualitative study was conducted with 17 participants. The participants were between 20 and 54, while the median age was 23. The majority of participants were male (70%), 24% female and 6% of other gender. About half of the testing sessions were conducted under supervision of the game developer. Since the point of the game Electrified is to teach concepts and not to solve concrete calculations, the questions also reflect this. The tests, which will be explored in more detail in the next paragraphs, were created to match the learning activities defined in 4.2 and consequently fall into the same categories of Revised Bloom's Taxonomy (see Fig. 5.1). Each test consists of multiple questions. The survey was designed to first assess the players' prior knowledge by asking them the test questions. Then, testers played and completed the game Electrified, and then answered the same learning questions again. This allows for direct comparison of learning progress based on the individual tests. The tests are as follows:

Test 0: This is to test whether the player can remember the units that were presented in the game, such as volt, ampere and ohm. To do this, the player is asked to assign the correct units to voltage, current and resistance.

Test 1: Test 1 asks if the player knows what concepts are behind voltage, current, and resistance. To do this, the respondent is asked to simply answer questions about how the three concepts work, such as which points in a circuit have the same voltage, how the flow of electrons behaves, or how installing resistors affects the electrons.

	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual Knowledge	Activity 0 Test 0					
Conceptual Knowledge		Activity 1 Test 1 Activity 2 Test 2 Activity 3 Test 3 Activity 5 Test 5	Objective Test Obj	Activity 4 Test 4 Activity 6 Test 6		
Procedural Knowledge						
Meta-Cognitive Knowledge						

Figure 5.1. Classification of the presented learning objective, activities and tests in regard to Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001).

Test 2: This test asks how current and resistance behave when the voltage in an electric circuit changes. The focus is on whether the player understood the direct proportionality between voltage and current.

Test 3: The goal of this test is to see if the player has understood the indirect proportionality between resistance and current and that installing a resistor will affect the current of the entire circuit, assuming it is a series circuit.

Test 4: This is to test the depth of the player's understanding of resistors or conductors. It is tested whether the respondent has understood that resistors can consist of different materials and that even conductors such as cables have a certain basic resistance. The player should be able to distinguish between conductors and resistors.

Test 5: Test 5 deals with the deeper understanding of current. By introducing parallel circuits in activity 5, the player learns that current can also differ within a circuit and exactly how it behaves. To test this, questions are asked about different parallel circuits where the player must determine, for example, which points in the circuit have the same intensity of current.

Test 6: The sixth test is about circuits in general and how current behaves within them when the circuit has a gap, for example. Thus, it is to be tested whether the player can attribute the absence of current flow to the gaps in the circuit. To do this, the player must determine from a selection of circuits in which current flows and in which it does not.

Test Obj: Finally, this test checks whether the player has reached the learning objective, i.e. whether he or she can apply Ohm's law. For this purpose, more general questions about circuits are asked, for example, what can be done to prevent a lamp in a circuit from burning out.

5.2 Playtesting Questionnaire

There are three categories of questions in the questionnaire: (1) questions about the participant, (2) questions about domain knowledge, and (3) questions about the game play and its engagement factor. The questions regarding domain knowledge are asked once before playing the game and once afterwards in order to assess the learning progress. These questions can be classified as tests in the context of the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001) - as described in the previous section - and thus answer the assessment question of said framework. The following section introduces the different categories the question are divided into. The complete questionnaire can be found in the appendix under D.

Questions about the participant: At the beginning of the survey, some questions about the person participating are asked in order to better assess the respondent group and to better classify their answers. These include questions about age, gender and, for example, how the person estimates his or her prior knowledge on the subject of electric circuits and electromagnetism.

Questions about the game elements: After playing the game, players should rate how engaging they found Electrified in general and how much they enjoyed the individual mechanics. This will help quantify the fun factor of the game.

Questions about domain knowledge: These questions are intended to test how much knowledge the player already had about circuits and Ohm's law at the beginning of the game, and how much he has learned after successfully completing Electrified. For this purpose, he is asked the questions once before and once after the game. The questions are grouped based on the learning activities so that there are at least two questions for each activity. These groupings are referred to as Test 0 to Test 6 in the previous text.

5.3 Results

This section presents the results of the survey. First the general results are summarized, then the individual tests for each learning activity are analyzed, and it is shown how successful the activities were in conveying the desired knowledge. Finally, feedback on the gameplay and mechanics is outlined.

The survey shows that, on average, players were able to answer more questions after they played the game, than they did before. For example, the number of questions answered correctly was 15.5 out of 24 initially and 17.2 out of 24 on the second part of the questionnaire. Overall, twelve players were able to answer more questions on the second part of the questionnaire than before, three participants had the same number of correct answers, and two participants were able to answer fewer questions after playing (see Fig. 5.2). The largest improvement was six more questions that could be answered, while the largest step backwards was minus three answers.

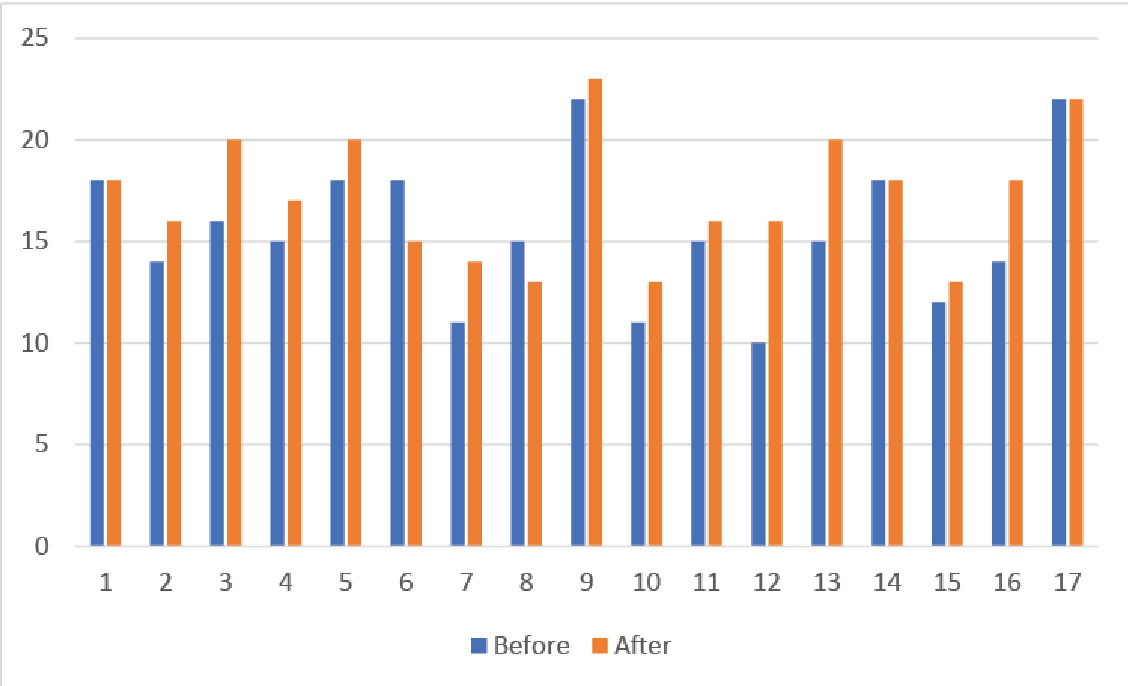


Figure 5.2. Amount of correct answers of the 17 participants before and after playing the game.

Participants were asked to self-assess their prior knowledge of the topic of electric circuits and Ohm's law, with one representing little prior knowledge and five representing great prior knowledge. The participants who rated themselves with three out of five recorded an average improvement of 2.25 questions and were thus the group that improved the most. The group of individuals who rated their prior knowledge as particularly low included the greatest absolute changes, but also included one individual who worsened. The participant who rated their prior knowledge as five out of five was able to answer the same number of questions in both runs.

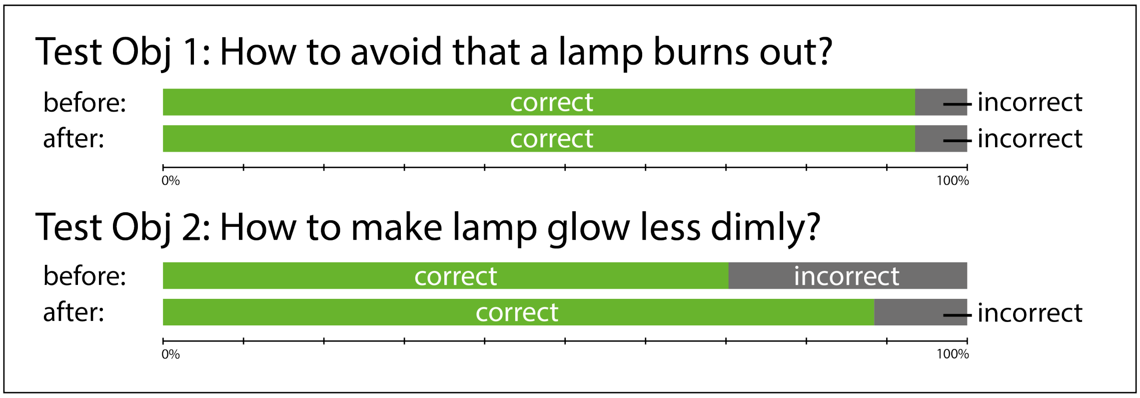


Figure 5.3. Answers regarding the learning objective's test before and after playing the game.

For tests 0 (Recalling of units), 1 (Understanding of voltage, current and resistance), 2 (Manipulating voltage in a circuit) and 4 (Differentiating between conductors), it was observed that the tests received more correct answers on the second part than before. In tests 0, 2, and 4, there was an improvement in the associated questions between 6% and 18% (see Fig. 5.4). Test 1 also showed improvement in all sub-questions, except for the last of the five questions, where neither learning progress nor regression was evident (see Fig. 5.5). The exact results of the questions can be seen in the appendix under D. The test on the learning objective (Solve circuit problems with Ohm's Law) was similar. A clear improvement can be seen for the second question, as it received around 20% more correct answers in the second questionnaire part than in the first run (see Fig. 5.3). However, neither a deterioration nor an improvement could be seen for the first question. In summary, survey participants improved on tests 0, 1, 2, 4, and the test regarding the learning objective.

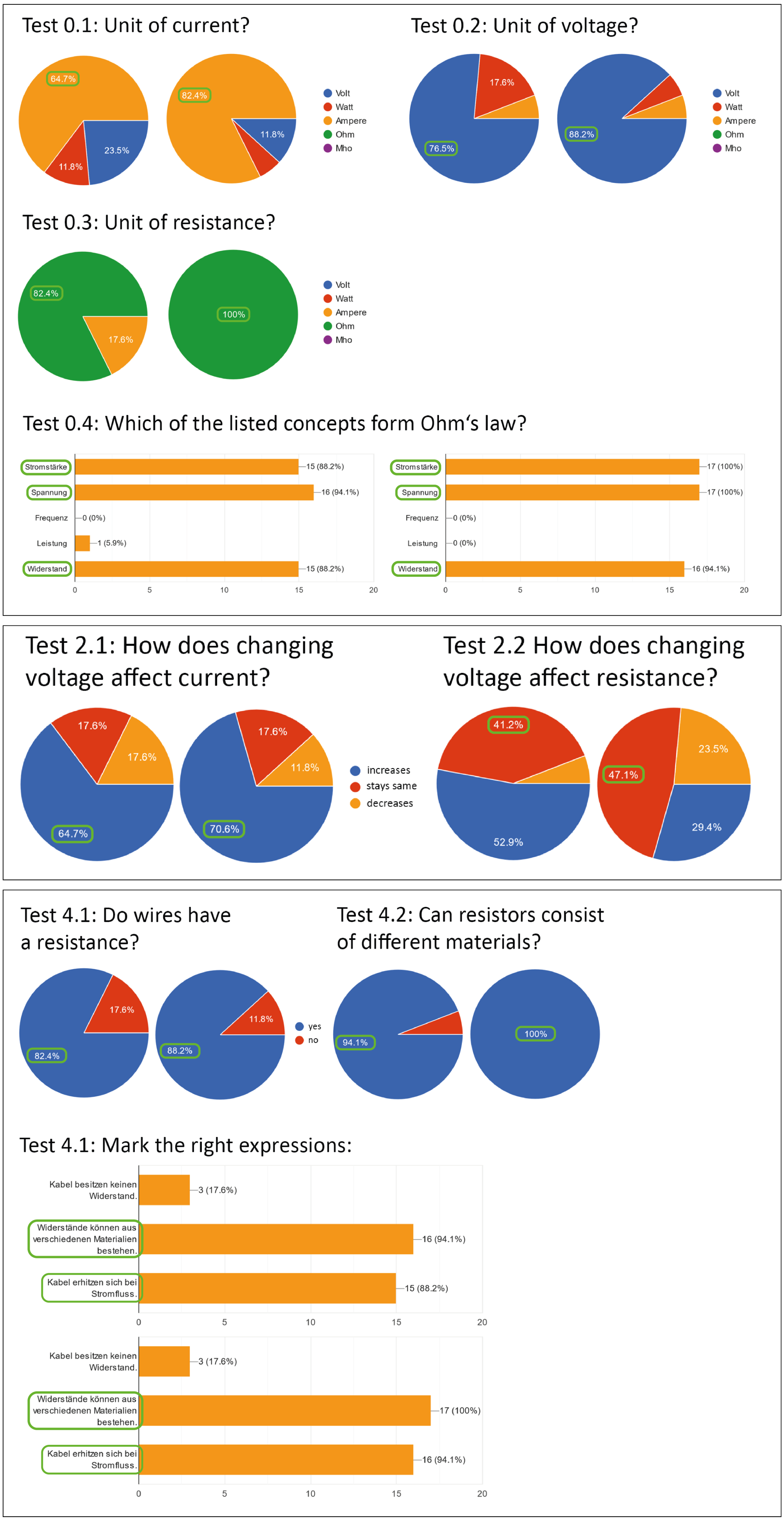


Figure 5.4. Answers regarding tests 0, 2 and 4 before and after playing the game.

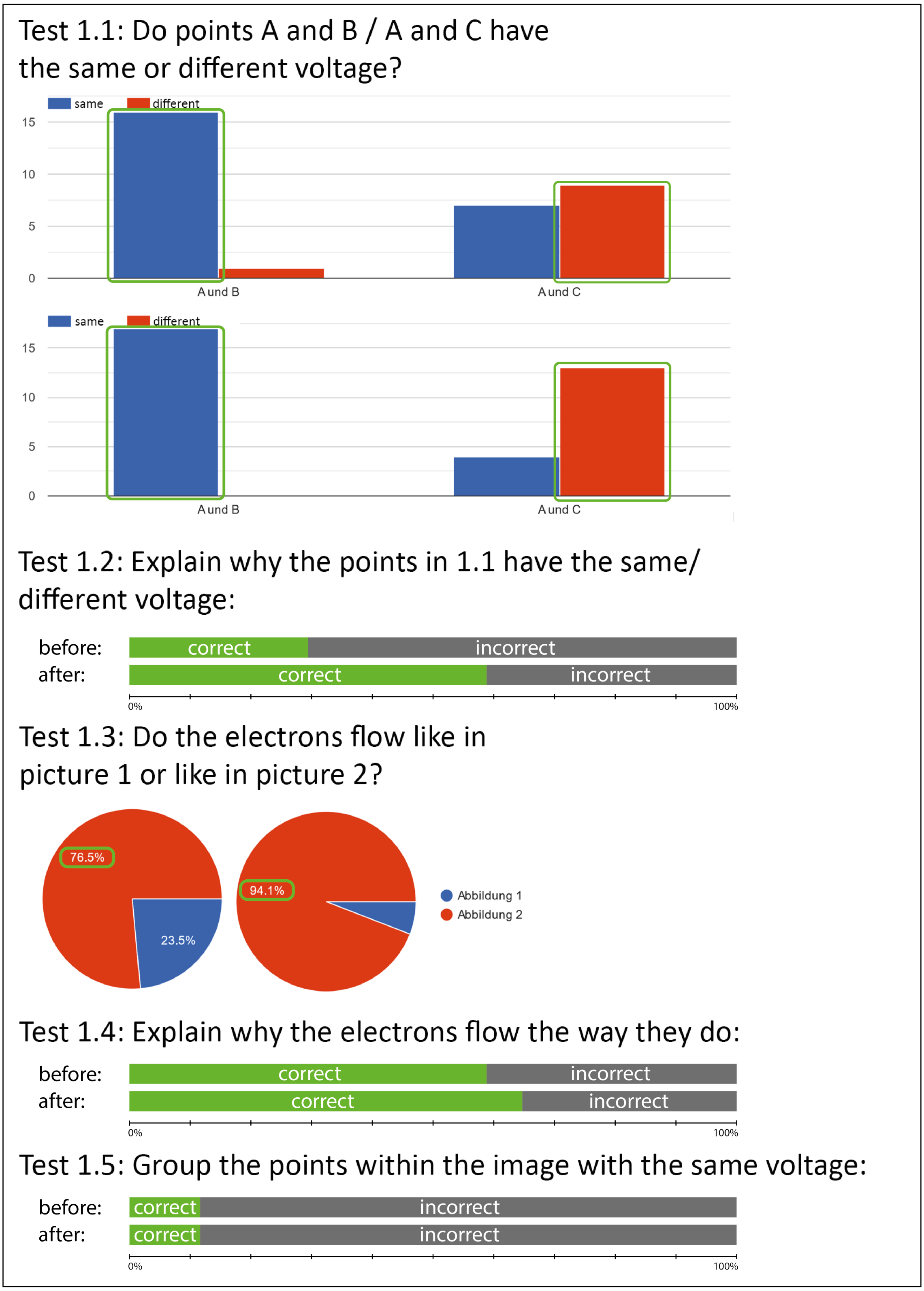


Figure 5.5. Answers regarding test 1 before and after playing the game.

The test on learning activity 5 (Explain current flow in parallel circuits) showed no learning progress among the testers. The test contains two questions, where the second question received the same number of correct answers before and after playing. The first question consists of two parts. While the second part received one more correct answer, the first part received one more incorrect answer (see Fig. 5.6). Consequently, there was neither progress nor regression in test 5.

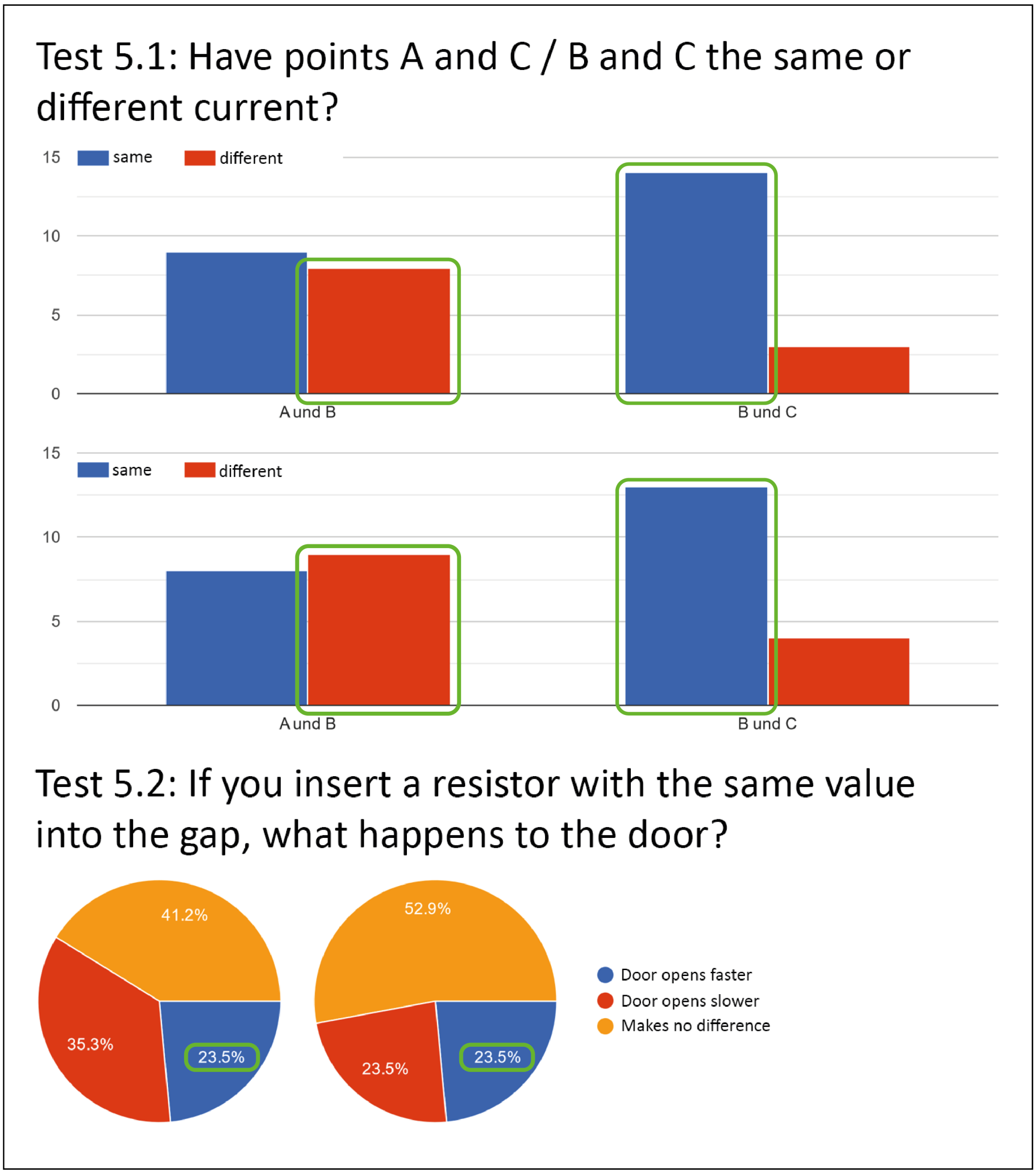


Figure 5.6. Answers regarding test 5 before and after playing the game.

Tests 3 (Inserting resistors into a circuit) and 6 (Attributing lack of current to gap in circuit), on the other hand, actually showed a regression in terms of correct answers. In the test on learning activity 3, there were exactly the same number of correct answers before and after playing regarding the first sub-question, while in sub-question two there were only 23.5%, instead of the previous 35.3%, of correct answers. In test 6, the first question was neutral in terms of the participants' learning progress and in question two the number of correct answers dropped by 17.6% (see Fig. 5.7).

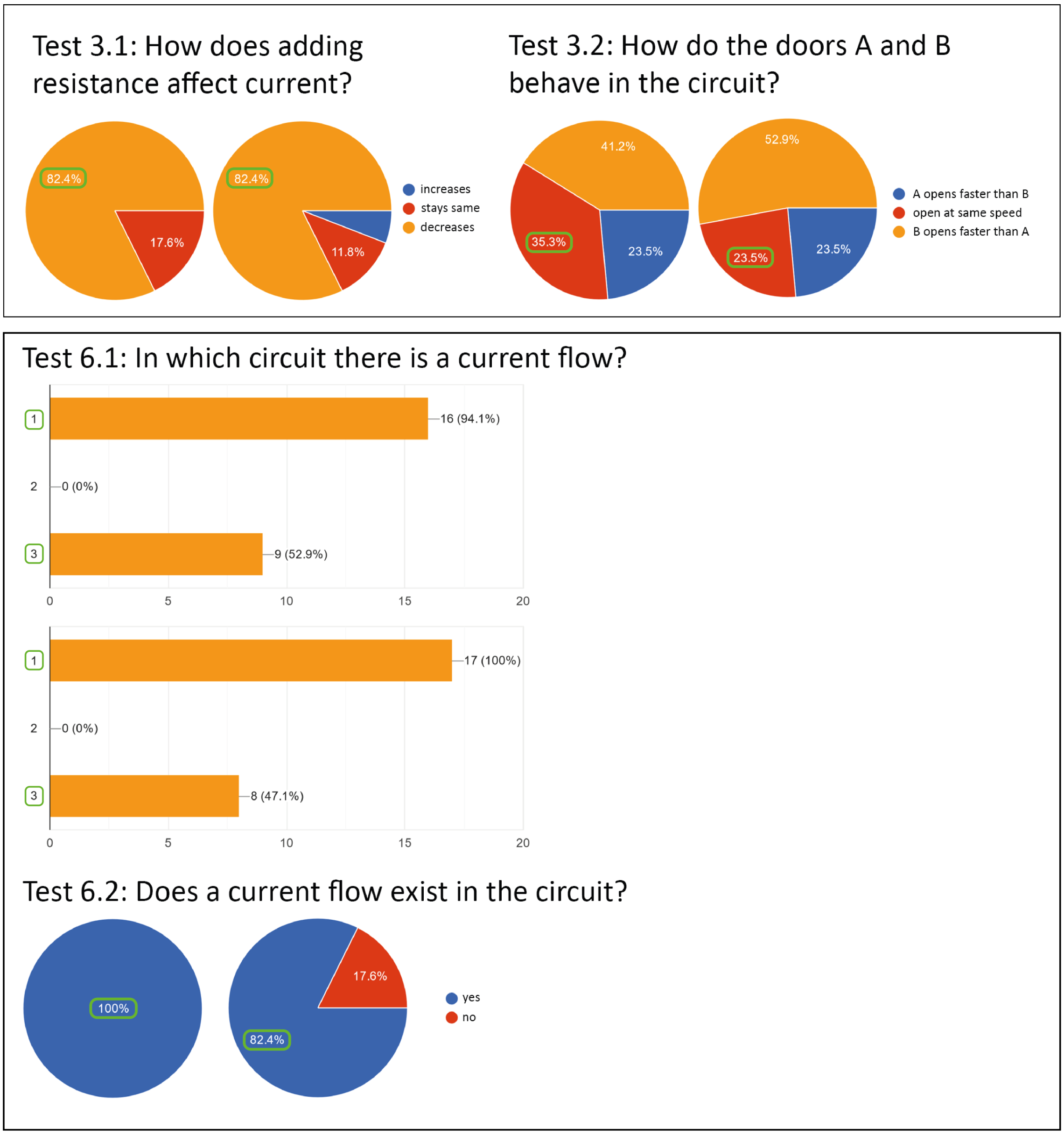


Figure 5.7. Answers regarding tests 3 and 6 before and after playing the game.

The evaluation on gameplay revealed that the game received an average rating of 4.2 out of 5 points, with 1 being "not much fun" and 5 being "a lot of fun". 16 of the 17 evaluations were in the 4 to 5 point range, while one participant awarded only one point. Participants who gave 5 points were able to answer an average of 2.7 more questions on the second part of the questionnaire, while those who gave 4 points only had an average of 1.3. The participant who gave a 1 out of 5 was still able to answer 2 more questions after playing. The highest scoring mechanic was pushing off charged elements with 4.5 points. Activating circuits and manipulating their elements received 4 and 3.9 points out of 5, respectively (see Fig. 5.8).

In the written feedback, the cooperative aspect, the movement and repelling / attracting mechanics, respectively, and the puzzle tasks were especially praised. Each of these elements was mentioned at least six times. In addition, the gradually increasing level of difficulty was highlighted as positive and that the game did not feel like an educational game. In the context of cooperation, it was also mentioned that you can hinder each other by pushing each other off, which was perceived as a fun and competitive mechanic. According to the written feedback, even though the movement was perceived as fun, it still needs improvement. The controls were said to be too sensitive for precise jumps, and the characters get stuck on walls too easily. Another point that was mentioned several times was that the concepts could be better communicated, for example via clickable explanation buttons. In addition, it was not clear to some players whether the charges moving through the wires were electrons or imaginary protons, and which color was associated with the positive pole and which with the negative pole. Also, it was not made clear that the static charges could be of different strengths. One participant also criticized that the player with more prior knowledge has an advantage in solving the puzzle, and the player with less prior knowledge thus has difficulties in understanding the solutions. Missing visuals like music or skins for the players were also criticized, and two participants wished for a more detailed tutorial.

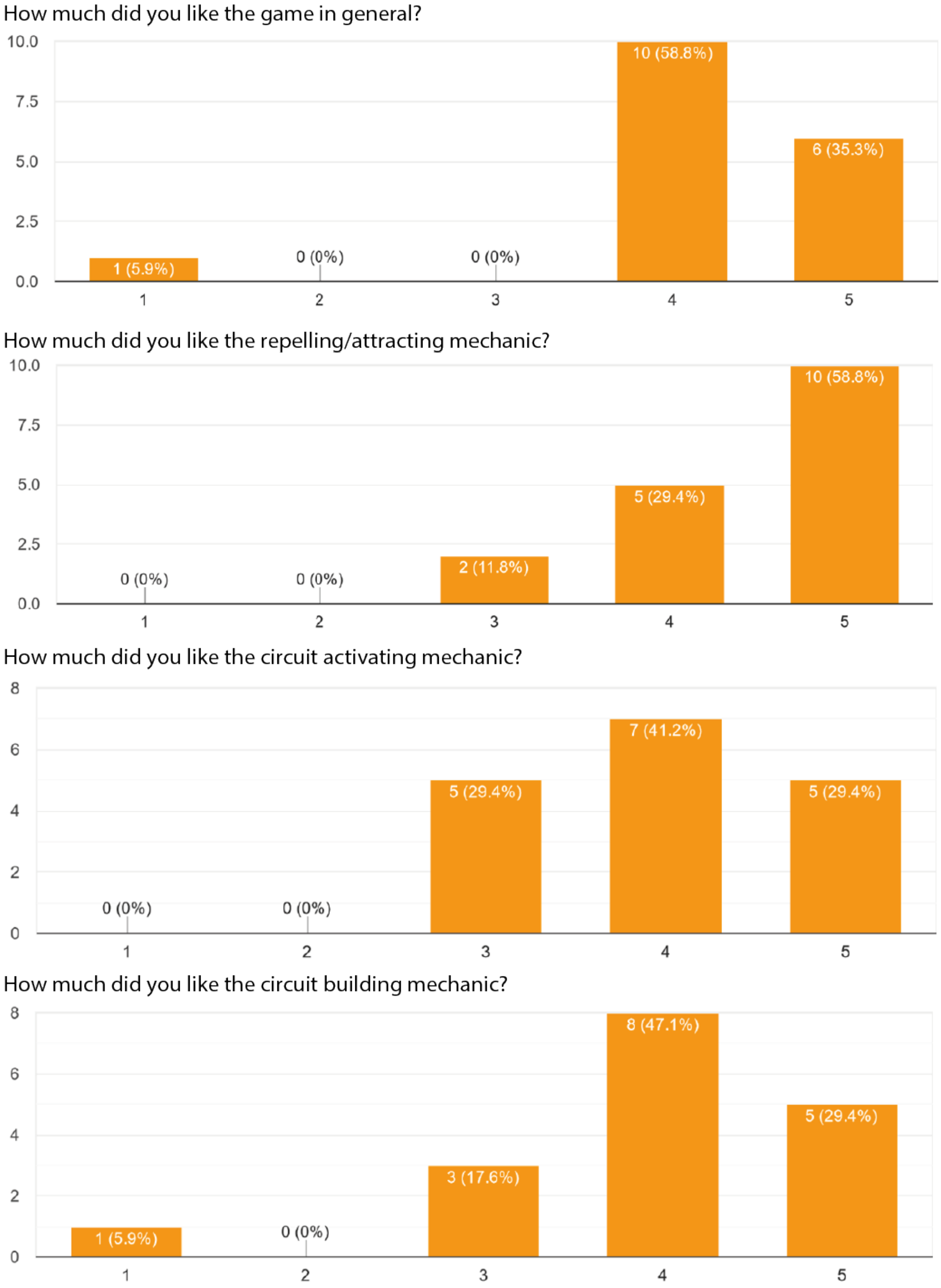


Figure 5.8. Answers regarding the gameplay.

5.4 Discussion

The majority of participants could answer more questions after playing Electrified than before. This suggests that these players have learned something new. The three participants who were able to answer the same number of questions in both tests already had an above-average number of questions correct in the first run (18, 18, 22 out of 24). The testers who improved had an average score of 14.4 correct questions before playing Electrified. They had more potential to improve, and they used it. One can conclude that the learning effect is more effective for testers with less prior knowledge. For one of the two participants who worsened, one major criticism was that the game was too difficult. So it may be that players who have to focus too much on the mechanics perceive the concepts less well.

The learning activities on reacalling of units and understanding the concepts of voltage, current and resistance were apparently successful, as the players improved significantly in the associated tests (see Fig. 5.4 and Fig. 5.5). This could be due to the fact that there were concrete explanations for these two learning activities in the game. At the beginning of each section in the game, animated 3D visualizations exist in the background that visualize the effect of voltage, current and resistance and name the corresponding unit (see Fig. 4.7). Even though most players looked at these elements only briefly, there is little room for interpretation in the visualizations on how exactly the concepts are effecting their environment and also the units are concretely assigned to their associated concepts. These elements are not very interactive or gamified, respectively, but explicitly showing how they work obviously helps players understand them. However, the text questions in Test 1 also show that the players recognize, for example, that the voltage in a motor drops, but they cannot explain exactly why this is the case.

Learning activity 2, which dealt with voltage changes in the electric circuit, was apparently also successful in conveying knowledge (see Fig. 5.4). One reason for this could have been the puzzle at the end of the jump-and-run tutorial, where the player cannot open the door in front of him alone. In the tutorial sub-level, the players are separated and consequently can open all the doors alone. At the end of it, however, they come together and before this is the case, they have to open a door together. During playtesting, one player was often faster than the other and reached this common door first. Since he was used to being able to open any door by activating the circuit and suddenly this was no longer the case, the player was forced to stop and think about why the door would not open. Often the players would then wonder aloud what to do next, prompting a discussion between them about said puzzle. Thus, the players actively engaged in solving the problem. Another reason for the success of learning activity 2 could be that the change in speed of the electrons was the most notable change after a second player stood on a contact plate.

Learning activity 4, in which the player learns to differentiate between different types of conductors, was successful in terms of learning progress, too (see Fig. 5.4). This activity was implemented mainly via the coil puzzle, where players had to replace an ohmic resistor with a piece of wire in order to burn out a coil. Again, most players did not understand the puzzle right away and were forced to think of a way to solve it. Once players realized they needed to remove the ohmic resistor, they now had to choose between a cable with very low resistance and a cable with slightly more resistance, which they then installed in the resulting gap. Since the pieces of cable were on a raised platform, it was more efficient to think ahead about which of the pieces they needed to get than to just try it out. Forcing them to think about the puzzles was probably a key factor in the success of the learning activity.

Test 5 shows that players do not improve in explaining the current flow in parallel circuits (see Fig. 5.6). One possible explanation is that there are too few puzzles in the game that deal with it. There are two parallel circuits in Electrified, and only in the second circuit is the parallel flow of electrons relevant to solving the puzzle. During playtesting, it was also shown that the players did not have to spend a long time thinking about said puzzles, but directly realized that they had to connect the cable pieces by inserting resistors. As a result, no further attention was paid to the circuits and their peculiarities in terms of current flow. Consequently, in Electified there must be more puzzles about this learning activity or the existing ones must be revised so that the player is forced to pay closer attention to the flow of electrons.

In learning activity 3, which is about inserting resistors into an electric circuit, there was even a deterioration in the ability of answering questions correctly (see Fig. 5.7). A slight worsening occurred in sub-question two of test 3, where the player is asked to judge whether the door in front of a resistor opens faster than the one behind a resistor. The problem with this question could be that the illustrated circuit was not implemented in the same form in the game, which makes the question a transfer task and thus more cognitively demanding. In addition, it is not relevant to the game to pay attention to the opening speed of the doors, which is probably why many players did not do this. The question arises, however, whether the decrease of correct answers occurred by chance or whether it was due to a misconception conveyed by Electrified. For example, it could be that players thought that the voltage drop after a resistor would cause the second door to receive less input power. This would at least explain why more testers indicated after playing that the door in front of the resistor opened faster than the one behind it. To verify this, one would need to revise the question and learning activity in a second iteration of the instructional design.

Attributing lack of current to a gap in a circuit was not achieved either according to the results of Test 6, but similar to activity 3, a regression was recorded (see Fig. 5.7). Since inserting components was an important part of many puzzles, it cannot be argued, as in Test 5, that there were too few use cases. The circuits depicted in the tasks were also found in the game.

After playing Electrified, more players were able to solve problems about electric circuits using Ohm's Law (see Fig. 5.3). They were able to solve problems on circuits that they were not directly confronted with in the game. The first sub-question from the learning objective's test was what to do about a light bulb burning out. This had already been answered correctly by many participants before, with the most common answer being to add a resistor to the circuit. A strong improvement was seen in the second sub-question, where players were asked what could be done to make a light bulb not just glow dimly. Apparently, the players were more familiar with the concept of reducing the current or voltage through resistors than they were with increasing the input power to a light bulb by increasing the voltage and thus the intensity of current. However, after the participants tested the game, there was a greater variety in correct responses. It is possible that playing Electrified opened up more different perspectives for participants on how to view the relationships in circuits. The learning objective was achieved for many players, even though not all individual learning activities were successfully completed. By improving the deficient activities in a further iteration of the instructional design, perhaps an even greater learning effect could be achieved.

From the fact that the players who rated the game with 5 out of 5 points achieved a significantly greater learning progress than the participants who awarded 4 points, it can be concluded that a higher engagement factor leads to a better learning progress. However, it may also be that solving puzzles and the resulting knowledge gain was fun for the player, since also the participant who awarded only 1 out of 5 points in regards to engagement factor was able to answer more questions than before playing the game.

6 Conclusion And Future Work

In the context of this work, a methodology was presented that serves as a guideline for the design and development process of serious educational games. Thereby, the creation and analysis of such games shall be facilitated for educationalists as well as for game designers by concretely connecting the two topics. The MDA framework (Hunicke et al., 2004) serves as the basis for the game design, while the individual game elements such as mechanics and goals are classified by using the Unifying Game Ontology (Debus, 2019). The instructional design is created utilizing the Revised Bloom's Taxonomy from Anderson and Krathwohl (2001). Learning activities defined in the instructional design are explicitly mapped onto the game mechanics and game goals to determine at what points in the game learning content is communicated. It is therefore precisely defined where the player learns each bit of knowledge. This makes it possible to use knowledge retention tests to check which learning activities successfully impart knowledge and which still need to be improved. By clearly mapping the activities to game elements, one knows which parts of the game need to be adjusted in order to optimize the learning process. As an application example of the methodology described above, a game called Electrified was developed in the context of this thesis. This game is considered to be a proof-of-concept of said methodology and aims at teaching the players how to apply Ohm's law. An evaluation showed that four of the seven defined learning activities were successful and three activities did not achieve the desired effect. These must be revised in the context of a further development iteration. In the case of the learning objective, which consisted of solving problems within electric circuits using Ohm's law, learning progress was observed despite the failed learning activities.

In the future, further development iterations for the game Electrified would be interesting, in which both the instructional design and the game mechanics will be further assessed and enhanced to improve the learning process. In addition, the proposed methodology could be applied to the development of other games, which could for example, try to achieve learning objectives within higher cognitive process categories. One could also analyze which mechanics and goals are combined with which cognitive processes and how often certain mappings appear.

Bibliography

Aleven, V., Myers, E., Easterday, M., & Ogan, A. (2010). Toward a framework for the analysis and design of educational games. *2010 Third IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning*, 69–76 (cit. on pp. 7–11).

Alexander, L. (1938). The teaching of ohm's law. *American Journal of Physics*, *6*(2), 68–70 (cit. on p. 11).

Alvarez, J., Djaouti, D. et al. (2011). An introduction to serious game definitions and concepts. *Serious Games & Simulation for Risks Management*, *11*(1), 11–15 (cit. on p. 7).

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of bloom's taxonomy of educational objectives.* Longman New York. (Cit. on pp. iii sq., 2 sqq., 28, 34, 40 sq., 55).

Anselment, P. (2009). *Impulse physik 11.* Ernst Klett Verlag GmbH, Stuttgart. (Cit. on p. 1).

Armstrong, P. (2010). *Bloom's Taxonomy.* Retrieved April 21, 2022, from https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/. (Cit. on p. 5)

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., De Freitas, S., Louchart, S., Suttie, N., Berta, R., & De Gloria, A. (2015). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology*, *46*(2), 391–411 (cit. on pp. 8 sq.).

Bloom, B. S. (1956). *Taxonomy of educational objectives: The classification of educational goals.* (Vol. 1). David McKay Company New York. (Cit. on p. 3).

Debus, M. S. (2019). Unifying game ontology: A facetted classification of game elements. (cit. on pp. iii sq., 2, 8, 23 sq., 27, 37, 55).

Delport, J. A., Jackman, K., Le Roux, P., & Fourie, C. J. (2019). Josim—superconductor spice simulator. *IEEE Transactions on Applied Superconductivity*, *29*(5), 1–5 (cit. on p. 25).

Encyclopaedia Britannica. (1998a). *electric current*. Retrieved April 21, 2022, from https://www.britannica.com/science/electric-current. (Cit. on p. 6)

Encyclopaedia Britannica. (1998b). *electric potential*. Retrieved April 21, 2022, from https://www.britannica.com/science/electric-potential. (Cit. on p. 6)

Encyclopaedia Britannica. (1998c). *electromagnetism*. Retrieved May 9, 2022, from https://www.britannica.com/science/electric-current. (Cit. on p. 1)

Gee, J. P. (2007). *Good video games+ good learning: Collected essays on video games, learning, and literacy*. Peter Lang. (Cit. on p. 10).

Gunter, G., Kenny, R. F., & Vick, E. H. (2006). A case for a formal design paradigm for serious games. *The Journal of the International Digital Media and Arts Association*, *3*(1), 93–105 (cit. on p. 8).

HEUREKA-Klett Softwareverlag GmbH. (2003). Physikus [PC CD-ROM]. (Cit. on p. 13).

Hewett, K. J., Zeng, G., & Pletcher, B. C. (2020). The acquisition of 21st-century skills through video games: Minecraft design process models and their web of class roles. *Simulation & Gaming*, *51*(3), 336–364 (cit. on p. 1).

Hunicke, R., LeBlanc, M., & Zubek, R. (2004). Mda: A formal approach to game design and game research. *Proceedings of the AAAI Workshop on Challenges in Game AI*, *4*(1), 1722 (cit. on pp. iii sq., 2, 7, 24, 26, 55).

iade. (2021, December 9). *Power Grid Tycoon - Strategy Idle Game* (1.4.9). https://play.google.com/store/apps/details?id=com.iadesuvpb.powergrid&hl=en&gl=US. (Cit. on p. 16)

ISB. (2004a). *7.1.1 Stromstärke, Spannung, Widerstand*. Retrieved April 21, 2022, from https://www.gym8-lehrplan.bayern.de/contentserv/3.1.neu/g8.de/id_27593.html. (Cit. on p. 6)

ISB. (2004b). *Lehrplan 11/12 Physik*. Retrieved May 9, 2022, from https://www.gym8-lehrplan.bayern.de/contentserv/3.1.neu/g8.de/index.php?StoryID=27147. (Cit. on p. 1)

ISB. (2004c). *Modell Wasserkreislauf*. Retrieved April 21, 2022, from https://www.gym8-lehrplan.bayern.de/contentserv/3.1.neu/g8.de/data/media/27593/Modell_Wasserkreislauf.pdf. (Cit. on p. 6)

ISB. (2022). *HSU3/4 3.2: Stoffe und Energie*. Retrieved May 9, 2022, from https://www.lehrplanplus.bayern.de/fachlehrplan/lernbereich/26099. (Cit. on p. 1)

Kipnis, N. (2009). A law of physics in the classroom: The case of ohm's law. *Science & Education*, *18*(3), 349–382 (cit. on p. 6).

Kusuma, G. P., Wigati, E. K., Utomo, Y., & Putera Suryapranata, L. K. (2018). Analysis of gamification models in education using mda framework [The 3rd International Conference on Computer Science and Computational Intelligence (ICCSCI 2018) : Empowering Smart Technology in Digital Era for a Better Life]. *Procedia Computer Science*, *135*, 385–392 (cit. on pp. 8, 27).

Merrill, M. D., Drake, L., Lacy, M. J., Pratt, J., & Group, I. R. (1996). Reclaiming instructional design. *Educational Technology*, 5–7 (cit. on p. 2).

Moseley, D., Baumfield, V., Elliott, J., Gregson, M., Higgins, S., Miller, J., & Newton, D. P. (2005). *Frameworks for thinking: A handbook for teaching and learning.* Cambridge University Press. (Cit. on pp. 3 sq.).

NamaTakahashi. (2021, October 14). *ElecHead*. https://store.steampowered.com/app/1456880/ElecHead/. (Cit. on p. 17)

National Education Association et al. (2012). Preparing 21st century students for a global society: An educator's guide to" the four cs." washington, dc. (Cit. on p. 1).

Rovio Entertainment Corporation. (2021, April 11). *Angry Birds 2* (2.64.0). https://play.google.com/store/apps/details?id=com.rovio.baba. (Cit. on p. 2)

simpleclub GmbH. (2016, March 10). *simpleclub - Die Lernapp* (8.6.0). https://play.google.com/store/apps/details?id=com.simpleclub.android&hl=en&gl=US. (Cit. on p. 12)

Squire, K., Barnett, M., Grant, J. M., & Higginbotham, T. (2004). Electromagnetism supercharged! learning physics with digital simulation games (cit. on p. 14).

University of Cambridge Engineering Department. (2018, July 24). *Wired*. https://store.steampowered.com/app/885470/Wired/. (Cit. on p. 15)

Appendix A. Revised Bloom's Taxonomy

MAJOR TYPES AND SUBTYPES	EXAMPLES
A. FACTUAL KNOWLEDGE—The basic elements students must know to be acquainted with a discipline or solve problems in it	
AA. Knowledge of terminology	Technical vocabulary, music symbols
AB. Knowledge of specific details and elements	Major natural resources, reliable sources of information
B. CONCEPTUAL KNOWLEDGE—The interrelationships among the basic elements within a larger structure that enable them to function together	
BA. Knowledge of classifications and categories	Periods of geological time, forms of business ownership
BB. Knowledge of principles and generalizations	Pythagorean theorem, law of supply and demand
BC. Knowledge of theories, models, and structures	Theory of evolution, structure of Congress
C. PROCEDURAL KNOWLEDGE—How to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods	
CA. Knowledge of subject-specific skills and algorithms	Skills used in painting with water colors, whole-number division algorithm
CB. Knowledge of subject-specific techniques and methods	Interviewing techniques, scientific method
CC. Knowledge of criteria for determining when to use appropriate procedures	Criteria used to determine when to apply a procedure involving Newton's second law, criteria used to judge the feasibility of using a particular method to estimate business costs
D. METACOGNITIVE KNOWLEDGE—Knowledge of cognition in general as well as awareness and knowledge of one's own cognition	
DA. Strategic knowledge	Knowledge of outlining as a means of capturing the structure of a unit of subject matter in a text book, knowledge of the use of heuristics
DB. Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge	Knowledge of the types of tests particular teachers administer, knowledge of the cognitive demands of different tasks
DC. Self-knowledge	Knowledge that critiquing essays is a personal strength, whereas writing essays is a personal weakness; awareness of one's own knowledge level

Figure A.1. Detailed list of terms in the knowledge dimension presented by the Revised Bloom's Taxonomy (Anderson Krathwohl, 2001).

CATEGORIES & COGNITIVE PROCESSES	ALTERNATIVE NAMES	DEFINITIONS AND EXAMPLES
1. REMEMBER—Retrieve relevant knowledge from long-term memory		
1.1 RECOGNIZING	Identifying	Locating knowledge in long-term memory that is consistent with presented material (e.g., Recognize the dates of important events in U.S. history)
1.2 RECALLING	Retrieving	Retrieving relevant knowledge from long-term memory (e.g., Recall the dates of important events in U.S. history)
2. UNDERSTAND—Construct meaning from instructional messages, including oral, written, and graphic communication		
2.1 INTERPRETING	Clarifying, paraphrasing, representing, translating	Changing from one form of representation (e.g., numerical) to another (e.g., verbal) (e.g., Paraphrase important speeches and documents)
2.2 EXEMPLIFYING	Illustrating, instantiating	Finding a specific example or illustration of a concept or principle (e.g., Give examples of various artistic painting styles)
2.3 CLASSIFYING	Categorizing, subsuming	Determining that something belongs to a category (e.g., Classify observed or described cases of mental disorders)
2.4 SUMMARIZING	Abstracting, generalizing	Abstracting a general theme or major point(s) (e.g. Write a short summary of the event portrayed on a videotape)
2.5 INFERRING	Concluding, extrapolating, interpolating, predicting	Drawing a logical conclusion from presented information (e.g., In learning a foreign language, infer grammatical principles from examples)
2.6 COMPARING	Contrasting, mapping, matching	Detecting correspondences between two ideas, objects, and the like (e.g., Compare historical events to contemporary situations)
2.7 EXPLAINING	Constructing models	Constructing a cause-and-effect model of a system(e.g., explain the causes of important 18th Century events in France)
3. APPLY—Carry out or use a procedure in a given situation		
3.1 EXECUTING	Carrying out	Applying a procedure to a familiar task (e.g., Divide one whole number by another whole number, both with multiple digits)
3.2 IMPLEMENTING	Using	Applying a procedure to an unfamiliar task (e.g., Use Newton's Second Law in situations in which it is appropriate)

Figure A.2. Detailed list of terms used in the cognitive process dimension presented by the Revised Bloom's Taxonomy (1/2) (Anderson Krathwohl, 2001).

Categories & Cognitive Processes	Alternative Names	Definitions and Examples
4. ANALYZE—Break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose		
4.1 DIFFERENTIATING	Discriminating, distinguishing, focusing, selecting	Distinguishing relevant from irrelevant parts or important from unimportant parts of presented material (e.g., Distinguish between relevant and irrelevant numbers in a mathematical word problem)
4.2 ORGANIZING	Finding coherence, intergrating, outlining, parsing, structuring	Determining how elements fit or function within a structure (e.g., Structure evidence in a historical description into evidence for and against a particular historical explanation)
4.3 ATTRIBUTING	Deconstructing	Determine a point of view, bias, values, or intent underlying presented material (e.g., Determine the point of view of the author of an essay in terms of his or her political perspective)
5. EVALUATE—Make judgments based on criteria and standards		
5.1 CHECKING	Coordinating, detecting, monitoring, testing	Detecting inconsistencies or fallacies within a process or product; determining whether a process or product has internal consistency; detecting the effectiveness of a procedure as it is being implemented (e.g., Determine if a scientist's conclusions follow from observed data)
5.2 CRITIQUING	Judging	Detecting inconsistencies between a product and external criteria, determining whether a product has external consistency; detecting the appropriateness of a procedure for a given problem (e.g., Judge which of two methods is the best way to solve a given problem)
6. CREATE—Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure		
6.1 GENERATING	Hypothesizing	Coming up with alternative hypotheses based on criteria (e.g., Generate hypotheses to account for an observed phenomenon)
6.2 PLANNING	Designing	Devising a procedure for accomplishing some task (e.g., Plan a research paper on a given historical topic)
6.3 PRODUCING	Constructing	Inventing a product (e.g., Build habitats for a specific purpose)

Figure A.3. Detailed list of terms used in the cognitive process dimension presented by the Revised Bloom's Taxonomy (2/2) (Anderson Krathwohl, 2001).

Appendix B. List Of Aesthetics Categories From The MDA Framework

- Sensation: sense of pleasure as the result of trying something new;
- Challenge: being challenged to finish certain tasks;
- Discovery: finding out new things through exploration or trying new strategy;
- Fellowship: engaged in social networking;
- Expression: ability to express player's choices in game;
- Fantasy: immersion to virtual world;
- Submission: devotion to the game;
- Narrative: storyline that catch player's interest.

Figure B.1. List of aesthetics categories (Kusuma et al., 2018).

Appendix C. Unifying Game Ontology

C.1 List Of Game Goals

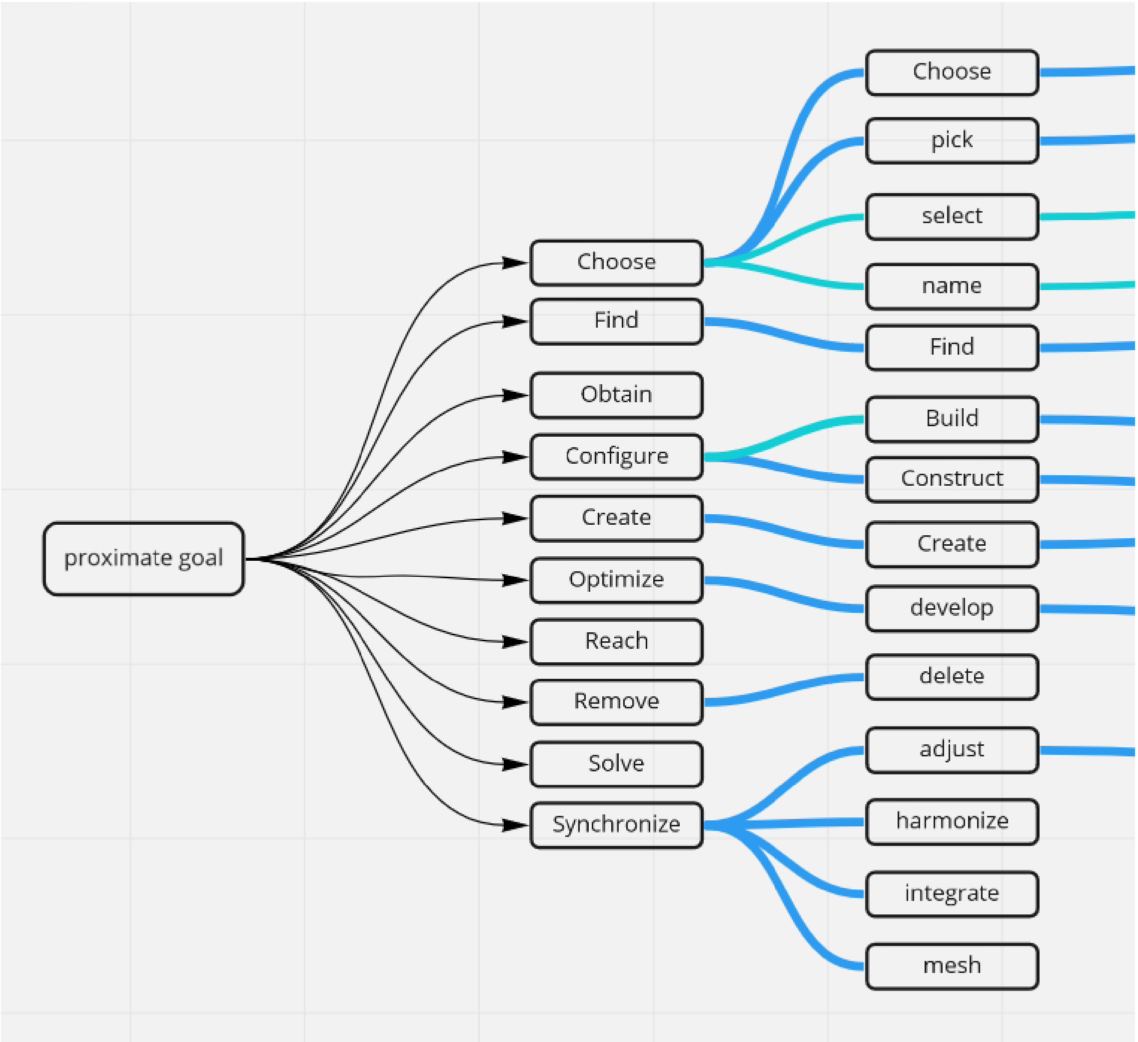


Figure C.1. List of proximate goals from tht UGO (work in progress by Chetitah von Mammen, 2021).

C.2 List Of Game Mechanics

Figure C.2. List of game mechanics from tht UGO (1/3) (work in progress by Chetitah von Mammen, 2021).

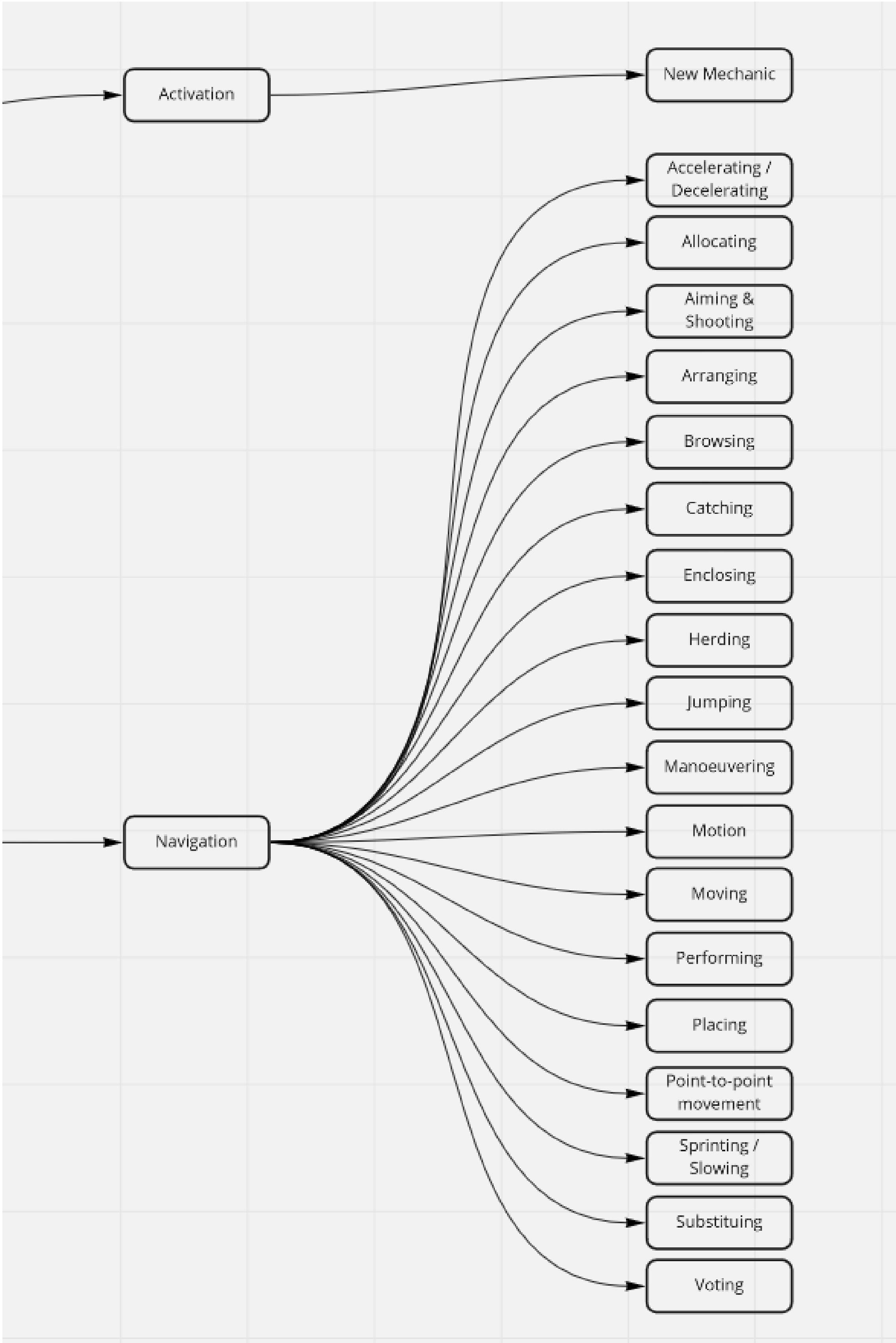


Figure C.3. List of game mechanics from tht UGO (2/3) (work in progress by Chetitah von Mammen, 2021).

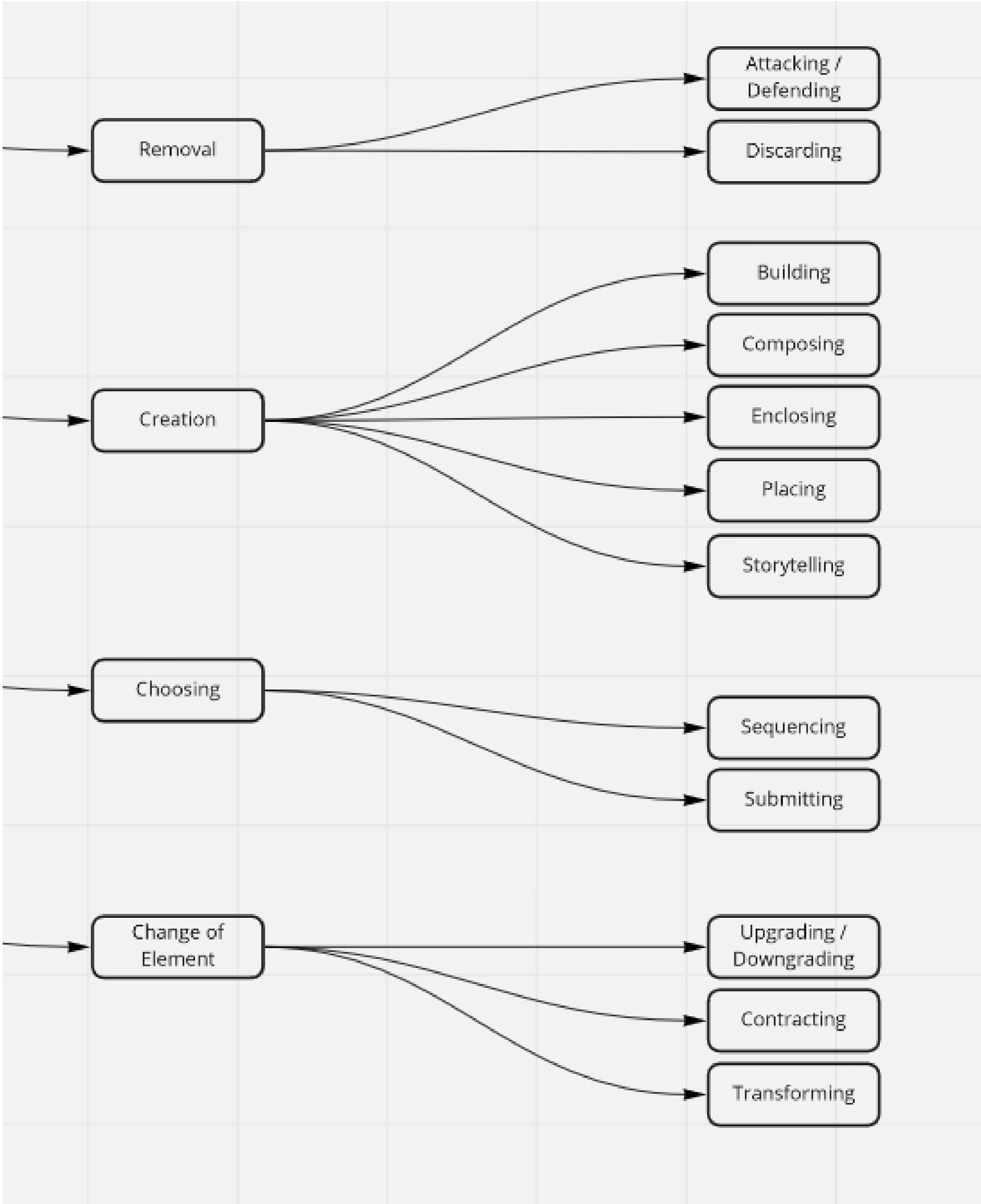


Figure C.4. List of game mechanics from tht UGO (3/3) (work in progress by Chetitah von Mammen, 2021).

Appendix D. Knowlege Retention Assessment

D.1 Assessment Test Template

D.2 Individual Questionnaire Answers

Electrified Playtesting

Hi! Vielen Dank, dass du dir die Zeit nimmst beim Test für meine Bachelor-Arbeit mitzumachen. Das ist eine große Hilfe!

Rahmen

Das Ziel der Umfrage ist es die Wissensvermittlung des Spiels *Electrified* zu testen, welches im Rahmen meiner Bachelor-Arbeit erstellt wurde. Dazu spielt man das Spiel und beantwortet einen Fragebogen. Der Fragebogen ist in zwei Teile aufgeteilt. Der erste Teil wird VOR dem Spielen ausgefüllt, der zweite Teil wird NACH dem Spielen ausgefüllt. Bei *Electrified* handeld es sich um ein kooperatives Lernspiel, weshalb ihr für das Playtesting zu zweit sein müsst.

Ablauf

1) Beide Spieler öffnen den Fragebogen und füllen diesen aus, bis der Fragebogen euch aufträgt nun das Spiel zu spielen. Schließt den Fragebogen dann allerdings noch NICHT!
2) Spielt nun das Spiel *Electrified* bis zum Ende.
3) Füllt den zweiten Teil des Fragebogen aus.

Link zur Umfrage

Link zur Umfrage: https://forms.gle/jkUcZRjVUuLMN7n88

Download des Spiels

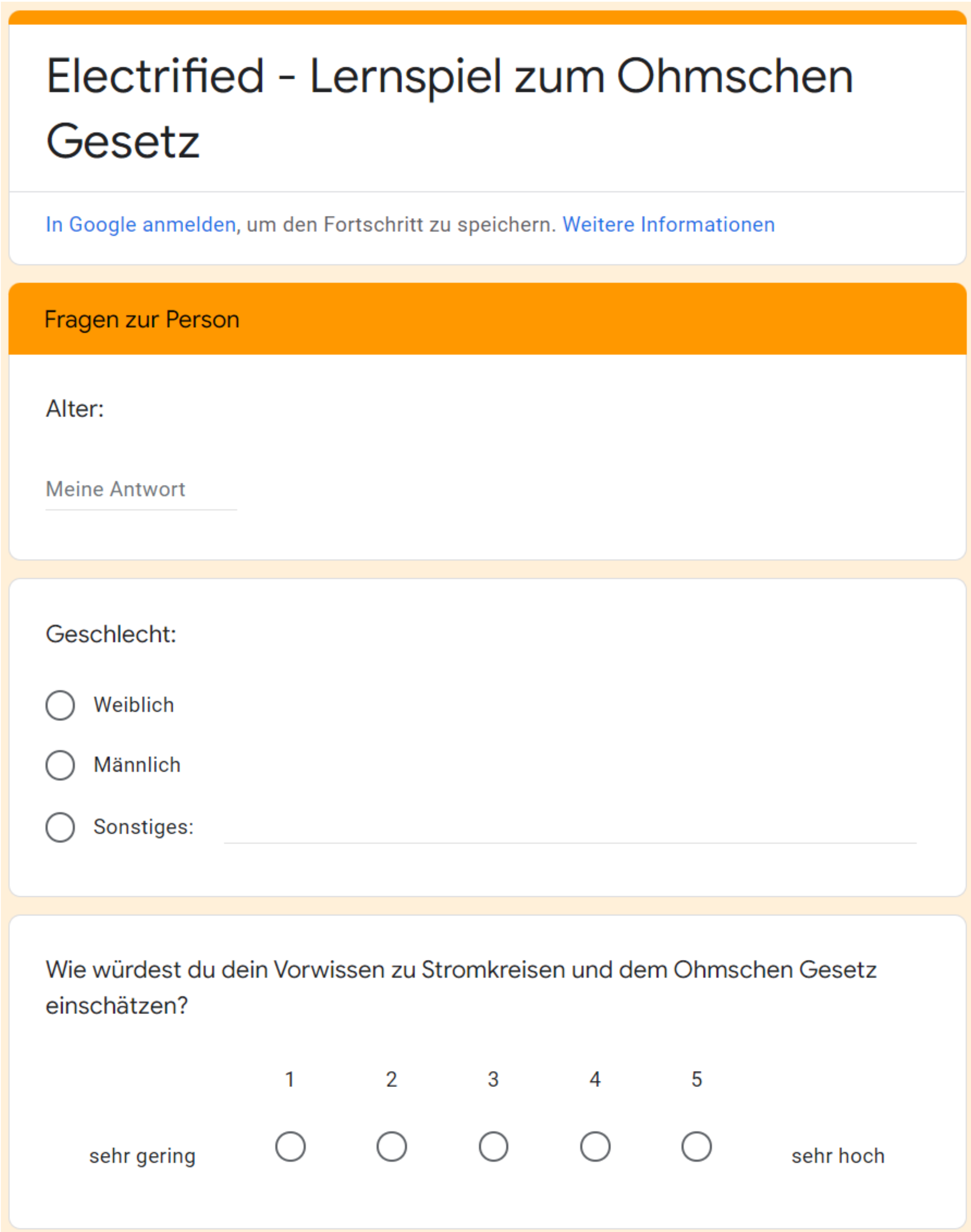
Über den folgenden Link könnt ihr das Spiel herunterladen. Dazu müsst ihr entweder die Version für Windows oder Linux herunterladen und entpacken. In den entsprechenden Ordnern findet ihr eine HILFE.txt Datei in der genauere Informationen stehen. Das Spiel unterstützt auch Controller-Input.

Link zum Spiel: https://cloud.informatik.uni-wuerzburg.de/s/LcxFtjyjYWDaXDZ
Passwort: Playtesting2022

Falls Fragen auftauchen gerne bei mir über E-Mail (tobias.lengfeld@stud-mail.uni-wuerzburg.de) oder über Discord (Tobias L#2317) melden. Vielen Dank fürs Testen!

Beste Grüße,
Tobias

Figure D.1. Introduction to the playtesting.



Electrified - Lernspiel zum Ohmschen Gesetz

In Google anmelden, um den Fortschritt zu speichern. Weitere Informationen

Fragen zur Person

Alter:

Meine Antwort

Geschlecht:

- ○ Weiblich
- ○ Männlich
- ○ Sonstiges: ____

Wie würdest du dein Vorwissen zu Stromkreisen und dem Ohmschen Gesetz einschätzen?

	1	2	3	4	5	
sehr gering	○	○	○	○	○	sehr hoch

Figure D.2. Questions about the person participating in the questionnaire.

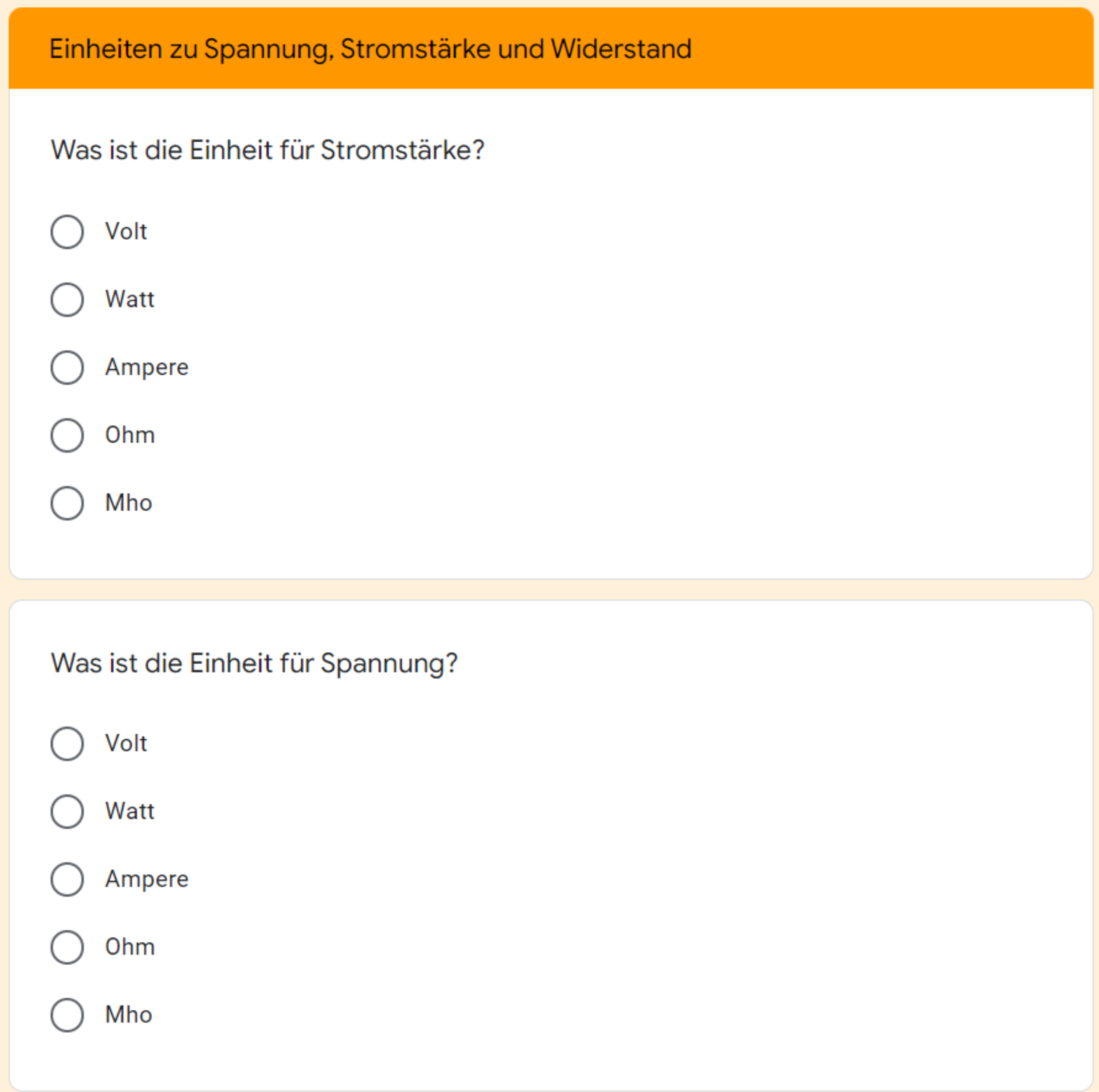


Figure D.3. Questions that belong to test 0 (1/2).

Was ist die Einheit für Widerstand?

- ◯ Volt
- ◯ Watt
- ◯ Ampere
- ◯ Ohm
- ◯ Mho

Aus welchen der folgenden Konzepten setzt sich das Ohmsche Gesetz zusammen?

- ☐ Stromstärke
- ☐ Spannung
- ☐ Frequenz
- ☐ Leistung
- ☐ Widerstand

Figure D.4. Questions that belong to test 0 (2/2).

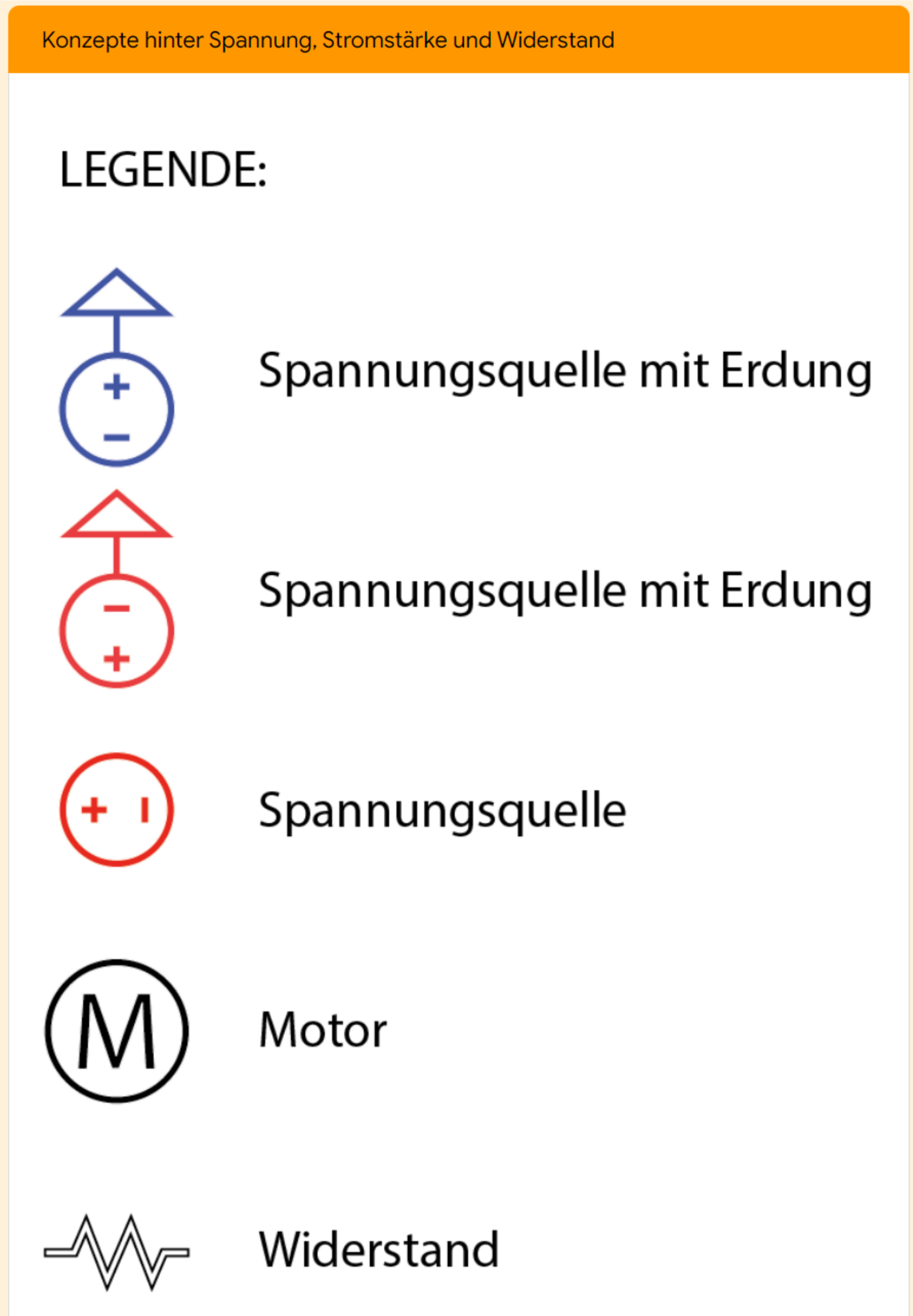
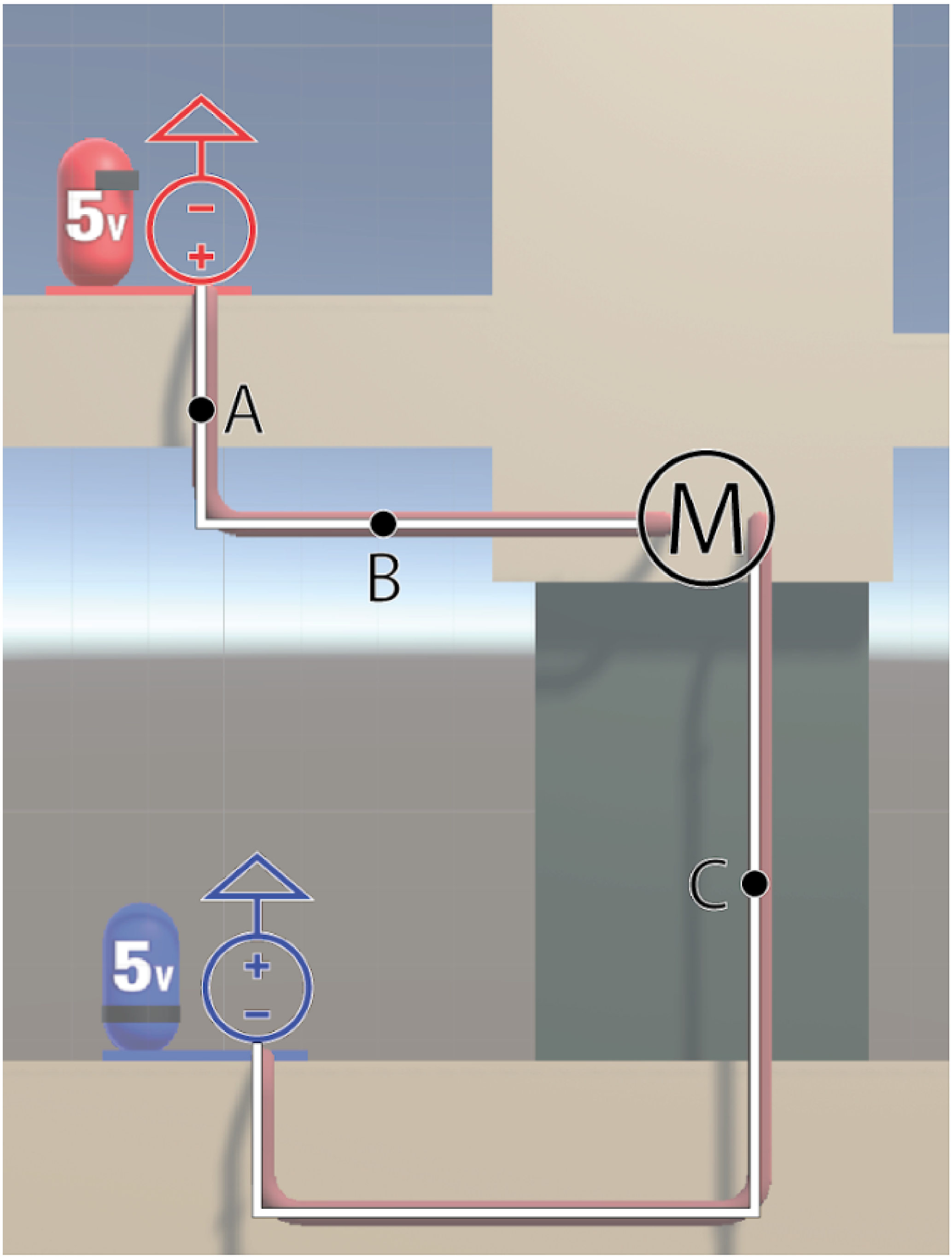


Figure D.5. Questions that belong to test 1 (1/4).

Haben die jeweils zwei angegebenen Punkte das gleiche oder unterschiedliches elektrische Potenzial (Spannung)?



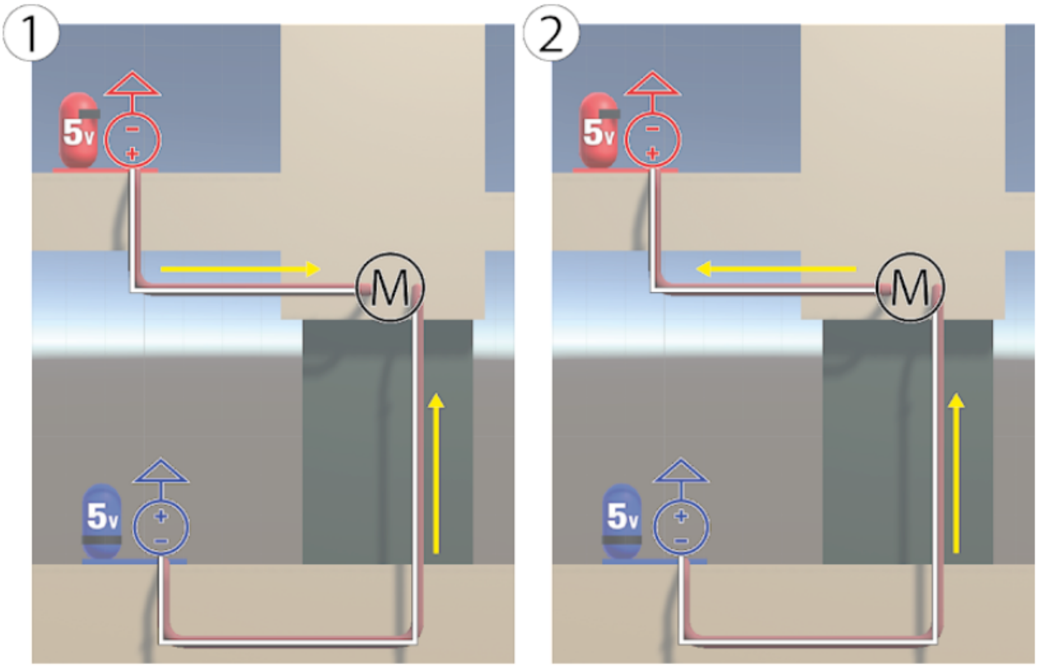
	gleich	unterschiedlich
A und B	○	○
A und C	○	○

Figure D.6. Questions that belong to test 1 (2/4).

Erkläre warum die Punkte der vorherigen Frage das gleiche oder unterschiedliches elektrische Potenzial (Spannung) besitzen.

Meine Antwort

Fließen die Elektronen im Stromkreis in Richtung der Pfeile in Abbildung 1 oder Abbildung 2?



○ Abbildung 1

○ Abbildung 2

Warum fließen die Elektronen auf die angegebene Art und Weise?

Meine Antwort

Figure D.7. Questions that belong to test 1 (3/4).

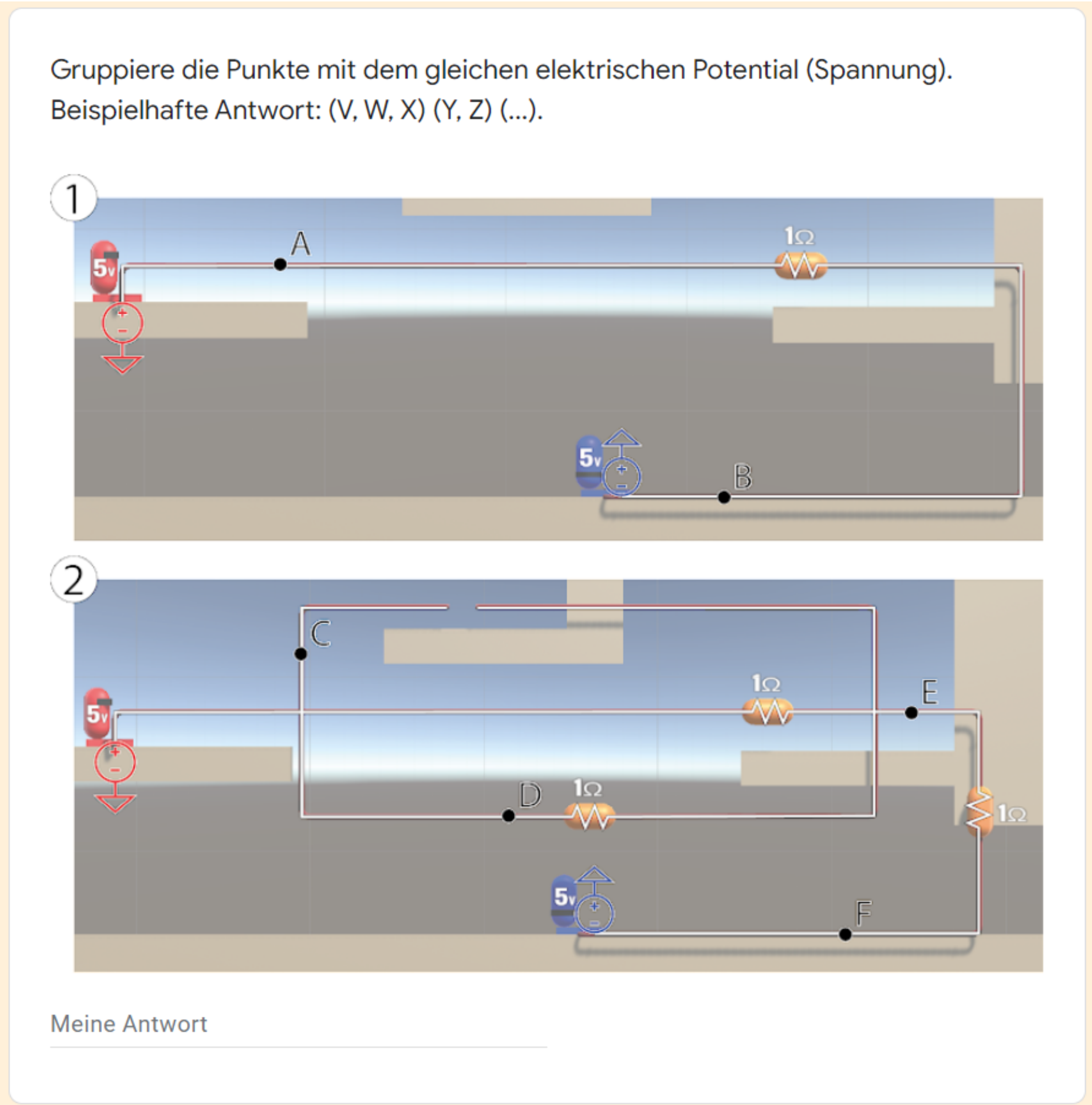


Figure D.8. Questions that belong to test 1 (4/4).

Effekt von Spannungsveränderungen im Stromkreis

Wie wirkt sich das Erhöhen der Spannung in einem Stromkreis auf die STROMSTÄRKE aus? Sie

- ◯ erhöht sich.
- ◯ bleibt gleich.
- ◯ verringert sich.

Wie wirkt sich das Erhöhen der Spannung in einem Stromkreis auf den WIDERSTAND aus? Er

- ◯ erhöht sich.
- ◯ bleibt gleich.
- ◯ verringert sich.

Figure D.9. Questions that belong to test 2.

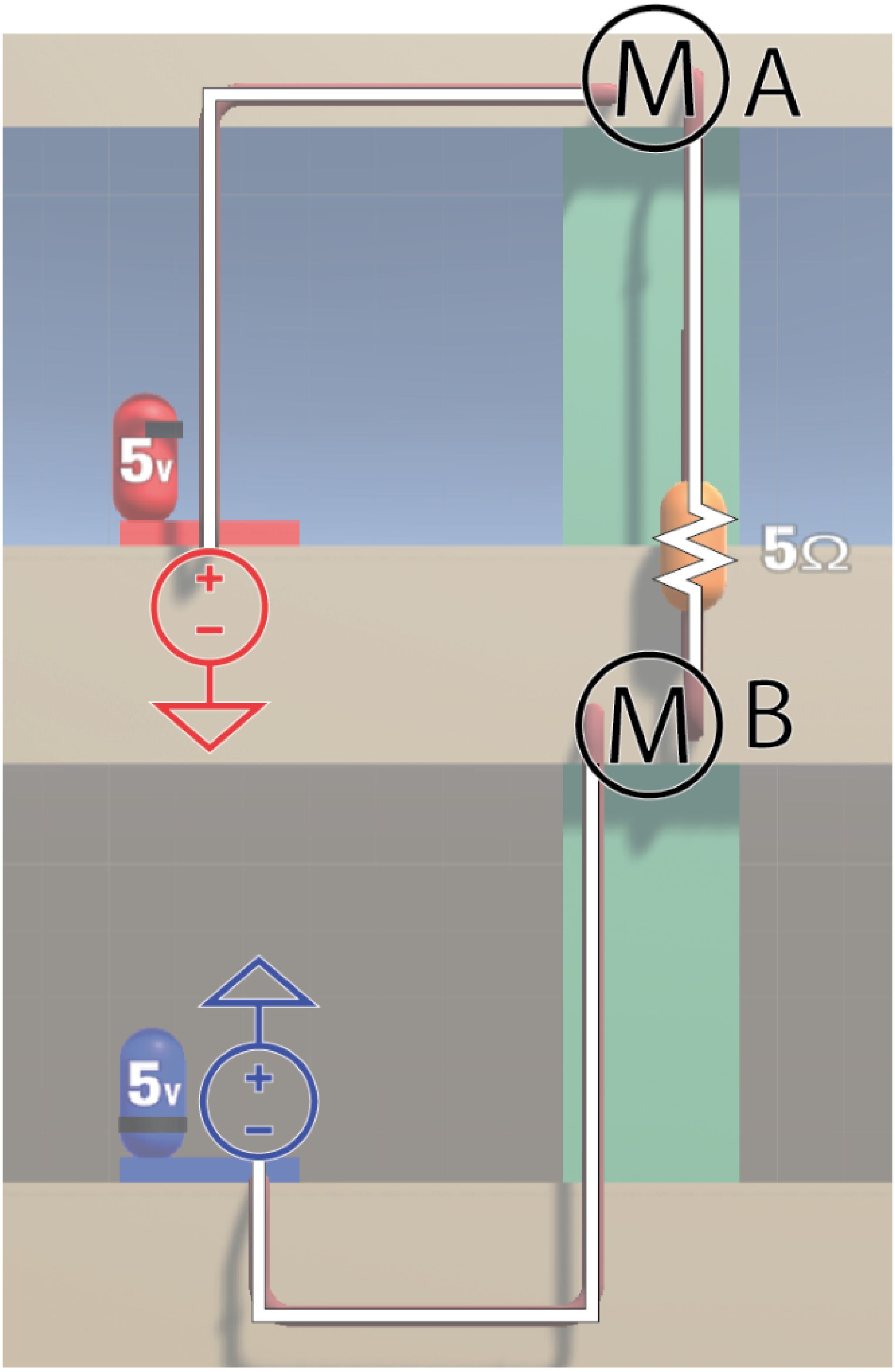
Effekt von Veränderungen bezüglich Widerständen im Stromkreis

Wie wirkt sich das Hinzufügen eines Widerstands zu einem in Reihe geschalteten Stromkreis auf die Stromstärke aus? Sie

- ◯ erhöht sich.
- ◯ bleibt gleich.
- ◯ verringert sich.

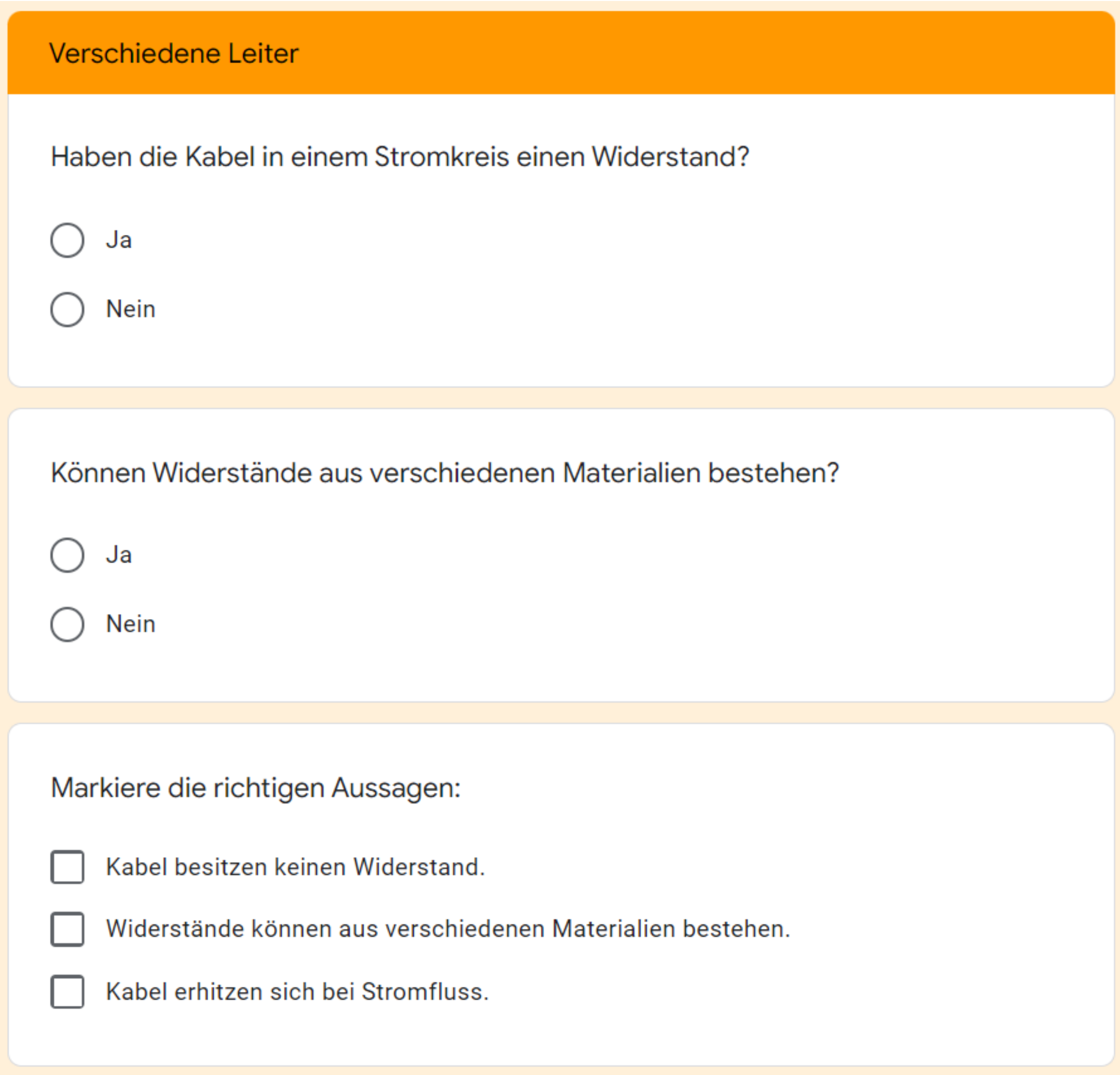
Figure D.10. Questions that belong to test 3 (1/2).

Wähle die korrekte Antwortmöglichkeit aus:



- ◯ Die Tür A öffnet sich schneller als die Tür B.
- ◯ Die Türen öffnen sich gleich schnell.
- ◯ Die Tür B öffnet sich schneller als die Tür A.

Figure D.11. Questions that belong to test 3 (2/2).



Verschiedene Leiter

Haben die Kabel in einem Stromkreis einen Widerstand?

- ◯ Ja
- ◯ Nein

Können Widerstände aus verschiedenen Materialien bestehen?

- ◯ Ja
- ◯ Nein

Markiere die richtigen Aussagen:

- ☐ Kabel besitzen keinen Widerstand.
- ☐ Widerstände können aus verschiedenen Materialien bestehen.
- ☐ Kabel erhitzen sich bei Stromfluss.

Figure D.12. Questions that belong to test 4.

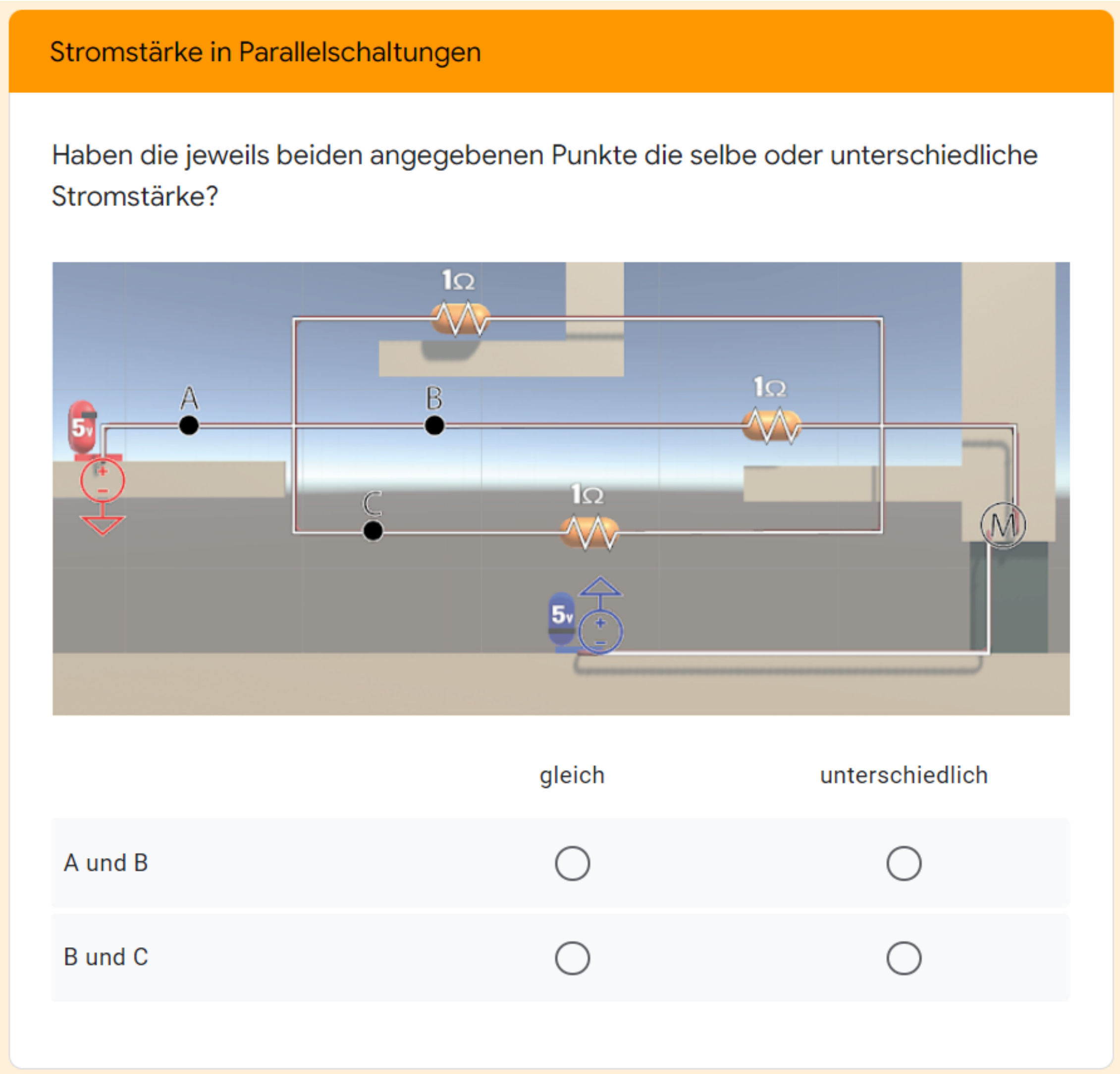
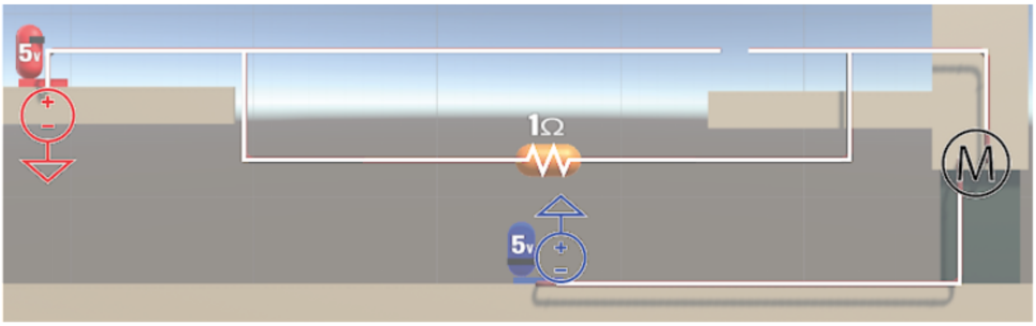


Figure D.13. Questions that belong to test 5 (1/2).

Wenn man einen zweiten Widerstand mit dem gleichen Wert in die Lücke einsetzen würde, wie würde sich das Verhalten der Tür ändern?

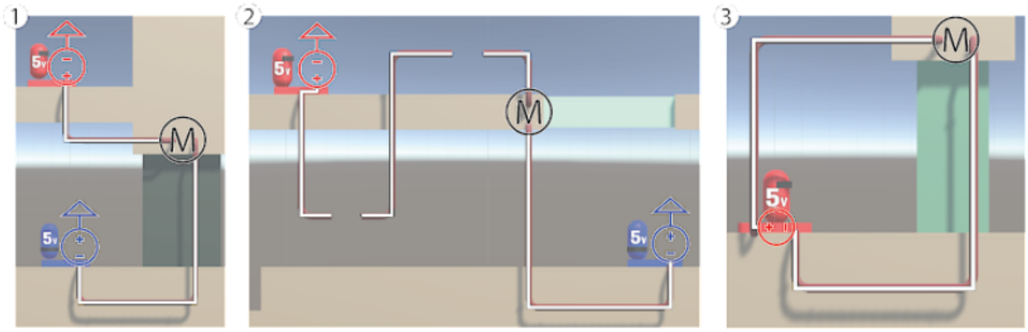


- ◯ Die Tür öffnet sich schneller.
- ◯ Die Tür öffnet sich langsamer.
- ◯ Es macht keinen Unterschied.

Figure D.14. Questions that belong to test 5 (2/2).

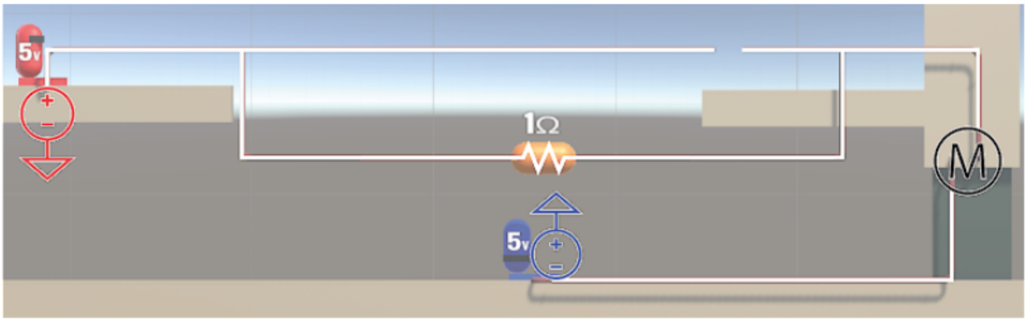
Lücken in Stromkreisen

In welchen der Stromkreisen fließt Strom?



- [ ] 1
- [ ] 2
- [ ] 3

Fließt im gegebenen Stromkreis Strom?



- ◯ Ja
- ◯ Nein

Figure D.15. Questions that belong to test 6.

Das Ohmsche Gesetz

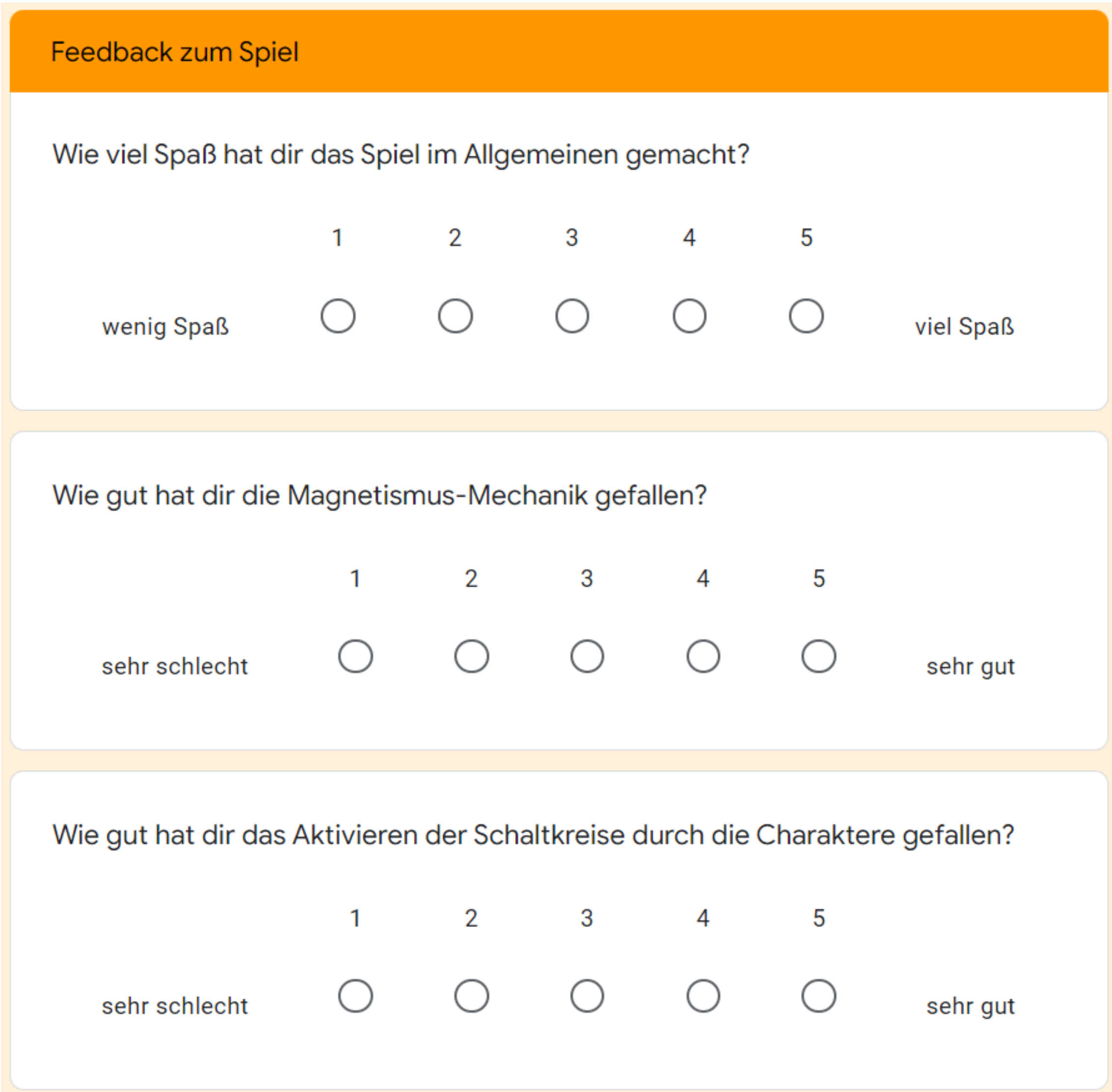
Was kann man dagegen tun, dass eine in einem Stromkreis verbaute Lampe druchbrennt?

Meine Antwort

Was kann man dagegen tun, dass eine Lampe in einem Stromkreis nur schwach glimmt?

Meine Antwort

Figure D.16. Questions that belong to the learning objective's test.



Feedback zum Spiel

Wie viel Spaß hat dir das Spiel im Allgemeinen gemacht?

	1	2	3	4	5	
wenig Spaß	○	○	○	○	○	viel Spaß

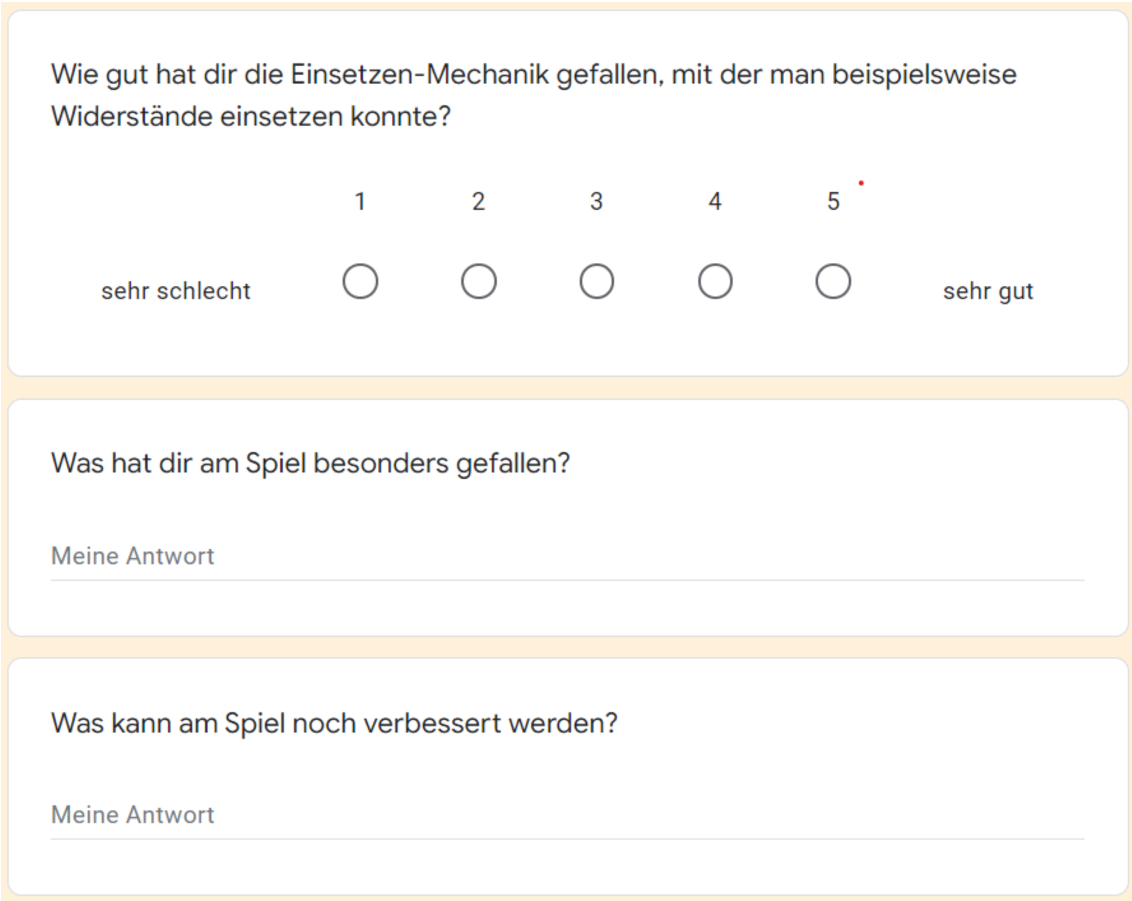
Wie gut hat dir die Magnetismus-Mechanik gefallen?

	1	2	3	4	5	
sehr schlecht	○	○	○	○	○	sehr gut

Wie gut hat dir das Aktivieren der Schaltkreise durch die Charaktere gefallen?

	1	2	3	4	5	
sehr schlecht	○	○	○	○	○	sehr gut

Figure D.17. Questions regarding the game elements (1/2).


Wie gut hat dir die Einsetzen-Mechanik gefallen, mit der man beispielsweise Widerstände einsetzen konnte? *

	1	2	3	4	5	
sehr schlecht	○	○	○	○	○	sehr gut

Was hat dir am Spiel besonders gefallen?

Meine Antwort

Was kann am Spiel noch verbessert werden?

Meine Antwort

Figure D.18. Questions regarding the game elements (2/2).

Alter	24		26	
Geschlecht	Kampfhelikopter		Männlich	
Vorwissen (1-5)	1		2	
	Vorher:	Nachher:	Vorher:	Nachher:
Test 0.1	Volt	Volt	Ampere	Volt
Test 0.2	Ampere	Ampere	Volt	Volt
Test 0.3	Ohm	Ohm	Ohm	Ohm
Test 0.4	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1	gleich	gleich	gleich	gleich
Test 1.1.2	gleich	unterschiedlich	gleich	gleich
Test 1.2	Die Spannung nimmt auf dem kurzen weg nicht merklich ab.	Nach dem Motor sollte die Spannung umgekehrt sein.	Beides 5V	Selber Stromkreis
Test 1.3	Abbildung 2	Abbildung 2	Abbildung 1	Abbildung 2
Test 1.4	Die Elektronen fließen vom Minuspol zum Pluspol	Strom fließt von minus zu plus	Sind das 2 verschiedene :	Weils im Spiel so war
Test 1.5	d, c	Keine der Punkte haben die gleiche Spannung.	(C)(D)(E)(F)	(A,C,D)(E,B)(F)
Test 2.1	erhöht sich.	bleibt gleich.	erhöht sich.	erhöht sich.
Test 2.2	bleibt gleich.	bleibt gleich.	bleibt gleich.	bleibt gleich.
Test 3.1	verringert sich.	verringert sich.	bleibt gleich.	verringert sich.
Test 3.2	Die Türen öffnen sich gleich schnell.	Die Tür B öffnet sich schneller als die Tür A.	Die Türen öffnen sich glei	Die Tür A öffnet sich schneller als die Tür B.
Test 4.1	Ja	Ja	Ja	Ja
Test 4.2	Ja	Ja	Ja	Ja
Test 4.3	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1	unterschiedlich	unterschiedlich	gleich	gleich
Test 5.2	gleich	gleich	gleich	gleich
Test 5.3	Es macht keinen Unterschied.	Es macht keinen Unterschied.	Die Tür öffnet sich schneller.	Die Tür öffnet sich schneller.
Test 6.1	1, 3	1, 3	1	1, 3
Test 6.2	Ja	Ja	Ja	Ja
Test Obj	Einen Widerstand einsetzen? Oder eine Sicherung?	Den Stromwiderstand erhöhen.	Weniger Stromspannung	Widerstand einbauen?
Test Obj 2	Die Spannung erhöhen?	Den Stromwiderstand senken.	Mehr Spannung	Widerstand wegnehmen
Fragen richtig	18	18	14	16
Mehr richtig	0		2	
Allgemein (1-5)	5		4	
Magnetismus (1-5)	5		5	
Aktivieren (1-5)	4		3	
Manipulieren (1-5)	3		4	
besonders gut	Man konnte sich super trollen. 10/10. kam einem gar nicht vor wie ein lernspiel		Dass man sich gegenseitig abfucken kann	
Verbesserungen	Man clipt gegen die Wand im sprung & aufeinander zu landen um sich zu boosten könnte mMn etwas einfacher sein :)		Die magnetmechanik muss cleaner werden. Am besten eine Tutorial müsste einen mehr an die Hand nehmen. Das movement müsste mehr gepolished werden. Multiplayer, der nicht lokal ist wäre gut, dass man auch leertaste zum springen nehmen kann. Multi controller support, dass man nicht verschiedene stellen am Keyboard nehmen muss.	

Figure D.19. Answers from the playtesting questionnaire.

Alter		22			22	
Geschlecht		Männlich			Männlich	
Vorwissen (1-5)		3			2	
		Vorher:	Nachher:		Vorher:	Nachher:
Test 0.1		Ampere	Ampere		Ampere	Ampere
Test 0.2		Volt	Volt		Volt	Volt
Test 0.3		Ohm	Ohm		Ohm	Ohm
Test 0.4		Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand		Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1		gleich	gleich		gleich	gleich
Test 1.1.2		unterschiedlich	unterschiedlich		gleich	unterschiedlich
Test 1.2		Im Kabel kein/geringer Widerstand, der Motor hat einen Eigenwiderstand	durch den Motor wird die Spannung auf der einen Seite negativ		Es entsteht kein Spannungsverlust	Weil das Spiel das gezeigt hat
Test 1.3		Abbildung 2	Abbildung 2		Abbildung 2	Abbildung 2
Test 1.4		Elektronenüberschuss bei blau, Elektronenmangel bei rot, daher von Süd nach Nord	Elektronen fließen von - nach +		Negativ zu positiv	Minus zu Plus
Test 1.5		(A, C, D) (B, E), (F)	(A, C, D) (B, E) (F)		(A,D) (E,B) (F)	(A,D) (B,E,) (F)
Test 2.1		erhöht sich.	erhöht sich.		bleibt gleich.	bleibt gleich.
Test 2.2		erhöht sich.	erhöht sich.		erhöht sich.	verringert sich.
Test 3.1		verringert sich.	verringert sich.		bleibt gleich.	verringert sich.
Test 3.2		Die Tür B öffnet sich schneller als die Tür A.	Die Türen öffnen sich gleich schnell.		Die Tür B öffnet sich schneller als die Tür A.	Die Tür A öffnet sich schneller als die Tür B.
Test 4.1		Nein	Ja		Ja	Ja
Test 4.2		Ja	Ja		Ja	Ja
Test 4.3		Kabel besitzen keinen Widerstand., Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.		Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1		gleich	gleich		gleich	gleich
Test 5.2		gleich	gleich		gleich	gleich
Test 5.3		Es macht keinen Unterschied.	Es macht keinen Unterschied.		Es macht keinen Unterschied.	Es macht keinen Unterschied.
Test 6.1		1, 3	1, 3		1, 3	1, 3
Test 6.2		Ja	Ja		Ja	Ja
Test Obj		Widerstand vorschalten	Widerstand davor schalten		Widerstand erhöhen	Widerstand erhöhen
Test Obj 2		Stromstärke erhöhen	Stromstärke erhöhen		Widerstand reduzieren	Widerstand reduzieren
Fragen richtig		16	20		15	17
Mehr richtig		4			2	
Allgemein (1-5)		5			4	
Magnetismus (1-5)		5			5	
Aktivieren (1-5)		5			4	
Manipulieren (1-5)		4			4	
besonders gut		Abstossen vom anderen Spieler durch Magnetismus			Das reine Movement macht schon sehr viel spaß	
Verbesserungen		Um auf dem anderen Spieler zu landen, muss sehr exakt gearbeitet werden, da man sonst unerwünscht schräg zueinander steht, hier sollte mehr Toleranz dabei sein			Weitere Level, Elektronische Bauteile und Hindernisse hinzufügen. Double-/Walljump wäre nice	

Figure D.20. Answers from the playtesting questionnaire.

Alter	22		22	
Geschlecht	Männlich		Männlich	
Vorwissen (1-5)	3		2	
	Vorher:	Nachher:	Vorher:	Nachher:
Test 0.1	Ampere	Ampere	Ampere	Ampere
Test 0.2	Volt	Volt	Volt	Volt
Test 0.3	Ohm	Ohm	Ohm	Ohm
Test 0.4	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1	gleich	gleich	gleich	gleich
Test 1.1.2	gleich	unterschiedlich	unterschiedlich	unterschiedlich
Test 1.2	in reihe geschaltet bleibt die spannung auf jedem Widerstand gleich	in spannung vor einem Motor und danach	links vor rechts	weil a und b vor dem Motor liegen; a und c liegen zwischen dem Motor
Test 1.3	Abbildung 2	Abbildung 2	Abbildung 2	Abbildung 2
Test 1.4	Stromrichtung ist von minus pol nach Plus pol	Von Minus nach Plus	weil Strom immer vom negativen zum positiven Pol fließt	strom fließt von negativ zu positiv
Test 1.5	(A;B;E;F) (D) (C)	(A,B,F,E) (D) (C)	(b,f); (a,e);(d,c)	(b,f); (a,e)
Test 2.1	erhöht sich.	erhöht sich.	erhöht sich.	erhöht sich.
Test 2.2	erhöht sich.	erhöht sich.	bleibt gleich.	verringert sich.
Test 3.1	verringert sich.	verringert sich.	verringert sich.	bleibt gleich.
Test 3.2	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.
Test 4.1	Ja	Ja	Ja	Ja
Test 4.2	Ja	Ja	Ja	Ja
Test 4.3	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1	unterschiedlich	unterschiedlich	unterschiedlich	gleich
Test 5.2	gleich	gleich	gleich	unterschiedlich
Test 5.3	Es macht keinen Unterschied.	Die Tür öffnet sich langsamer.	Die Tür öffnet sich langsamer.	Es macht keinen Unterschied.
Test 6.1	1, 3	1, 3	1	1
Test 6.2	Ja	Ja	Ja	Nein
Test Obj	Widerstand erhöhen	widerstand vergrößern	Einen Widerstand einsetzen	einen Widerstand einbauen
Test Obj 2	Widerstand erniedrigen	Widerstand verringern; mehr spannung	Auch einen Widerstand einsetzen	den Widerstand erniedrigen
Fragen richtig	18	20	18	15
Mehr richtig	2		-3	
Allgemein (1-5)	5		4	
Magnetismus (1-5)	5		5	
Aktivieren (1-5)	5		3	
Manipulieren (1-5)	5		4	
besonders gut	die Mechanic ist ganz nice		Die reine Mechanik hat wirklich viel Potenzial	
Verbesserungen	Skins für die Tic Tacs; Die wände verbessern		die jump mechanic	

Figure D.21. Answers from the playtesting questionnaire.

Alter	22		20	
Geschlecht	Männlich		Weiblich	
Vorwissen (1-5)	1		1	
	Vorher:	Nachher:	Vorher:	Nachher:
Test 0.1	Watt	Watt	Volt	Ampere
Test 0.2	Volt	Volt	Watt	Volt
Test 0.3	Ampere	Ohm	Ohm	Ohm
Test 0.4	Spannung	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung
Test 1.1.1	gleich	gleich	gleich	gleich
Test 1.1.2		gleich	unterschiedlich	unterschiedlich
Test 1.2	hab absolut keine ahnung	kein wiederstand	unterschiedlich, wenn sie an unterschiedlichen stellen sind	
Test 1.3	Abbildung 1	Abbildung 2	Abbildung 2	Abbildung 2
Test 1.4		- zu +	wegen der anordnung von motor und spannungsquelle???	
Test 1.5		D,C	(A,B) (C,D) (E,F)	(B,F), (C, D), (A) (E)
Test 2.1	erhöht sich.	erhöht sich.	erhöht sich.	erhöht sich.
Test 2.2	verringert sich.	erhöht sich.	bleibt gleich.	bleibt gleich.
Test 3.1	verringert sich.	bleibt gleich.	verringert sich.	verringert sich.
Test 3.2	Die Tür A öffnet sich schneller als die Tür B.	Die Tür B öffnet sich schneller als die Tür A.	Die Tür A öffnet sich schneller als die Tür B.	Die Tür B öffnet sich schneller als die Tür A.
Test 4.1	Ja	Ja	Ja	Ja
Test 4.2	Ja	Ja	Ja	Ja
Test 4.3	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1	unterschiedlich	gleich	gleich	gleich
Test 5.2	unterschiedlich	unterschiedlich	unterschiedlich	unterschiedlich
Test 5.3	Die Tür öffnet sich langsamer.	Es macht keinen Unterschied.	Die Tür öffnet sich langsamer.	Die Tür öffnet sich langsamer.
Test 6.1	1	1, 3	1	1
Test 6.2	Ja	Ja	Ja	Nein
Test Obj	wiederstand einbauen	Spannung veringern	Stromstärke verringern	widerstand einbauen
Test Obj 2	mehr spannung	Spannung erhöhen	Stromstärke erhöhen	keinen wiederstand einbauen
Fragen richtig	11	14	15	13
Mehr richtig	3		-2	
Allgemein (1-5)	4		4	
Magnetismus (1-5)	4		3	
Aktivieren (1-5)	4		3	
Manipulieren (1-5)	5		3	
besonders gut	Speedrun Potenzial (Lehrreich)		dass es ein multi player ist	
Verbesserungen	Timer und Leaderbord für Speed runs		zu schwierig	

Figure D.22. Answers from the playtesting questionnaire.

Alter	21		28	
Geschlecht	Männlich		Weiblich	
Vorwissen (1-5)	3		3	
	Vorher:	Nachher:	Vorher:	Nachher:
Test 0.1	Ampere	Ampere	Volt	Ampere
Test 0.2	Volt	Volt	Watt	Volt
Test 0.3	Ohm	Ohm	Ampere	Ohm
Test 0.4	Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1	gleich	gleich	gleich	gleich
Test 1.1.2	unterschiedlich	unterschiedlich	unterschiedlich	unterschiedlich
Test 1.2	A und B sind gleich, da zwischen ihnen kein Verbraucher liegt und der Widerstand des Kabels vernachlässigbar ist. C hat eine andere Spannung, da im Motor Arbeit verrichtet wird.	siehe antwort aus erster runde	Gleiche quellen	Gleiche Richtung
Test 1.3	Abbildung 2	Abbildung 2	Abbildung 2	Abbildung 2
Test 1.4	Da Elektronen vom minus Pol zum plus Pol fließen. (Anders als in der technischen Stromrichtung)	siehe antwort aus 1. Runde	Gleiche Richtung	Gleiche Richtung
Test 1.5	(B,F)(E)(A,D,C)	(F,B)(E)(A,C,D)	cde	a,b
Test 2.1	verringert sich.	verringert sich.	erhöht sich.	erhöht sich.
Test 2.2	bleibt gleich.	bleibt gleich.	erhöht sich.	verringert sich.
Test 3.1	verringert sich.	verringert sich.	bleibt gleich.	erhöht sich.
Test 3.2	Die Türen öffnen sich gleich schnell.	Die Türen öffnen sich gleich schnell.	Die Tür A öffnet sich schneller als die Tür B.	Die Tür A öffnet sich schneller als die Tür B.
Test 4.1	Ja	Ja	Ja	Ja
Test 4.2	Ja	Ja	Ja	Ja
Test 4.3	Widerstände können aus	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen.	Widerstände können aus verschiedenen Materialien bestehen.
Test 5.1	unterschiedlich	unterschiedlich	unterschiedlich	unterschiedlich
Test 5.2	gleich	gleich	gleich	gleich
Test 5.3	Die Tür öffnet sich schneller.	Die Tür öffnet sich schneller.	Die Tür öffnet sich langsamer.	Die Tür öffnet sich langsamer.
Test 6.1	1, 3	1, 3	1	1
Test 6.2	Ja	Ja	Ja	Nein
Test Obj	niedrigere Spannung anlegen	Niedrigere Spannung anlegen	Spannung reduzieren	Widerstand verringern
Test Obj 2	höhere Spannung anlegen	höhere Spanung anlegen	Stromstärke reduzieren	Stromstärke erhöhen
Fragen richtig	22	23	11	13
Mehr richtig	1		2	
Allgemein (1-5)	5		1	
Magnetismus (1-5)	5		4	
Aktivieren (1-5)	4		3	
Manipulieren (1-5)	3		1	
besonders gut	Speedrun Potential, Zusammenarbeit/Koordination mit Partner		Quizmechanik	
Verbesserungen	Steuerung der Charaktere in der Luft		Niedrige lernkurve	

Figure D.23. Answers from the playtesting questionnaire.

Alter	54		30	
Geschlecht	Männlich		Weiblich	
Vorwissen (1-5)	1		1	
	Vorher:	Nachher:	Vorher:	Nachher:
Test 0.1	Ampere	Ampere	Watt	Ampere
Test 0.2	Volt	Volt	Volt	Volt
Test 0.3	Ohm	Ohm	Ampere	Ohm
Test 0.4	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1	gleich	gleich	gleich	gleich
Test 1.1.2	gleich	gleich	unterschiedlich	gleich
Test 1.2	kein Widerstand		?	?
Test 1.3	Abbildung 2	Abbildung 2	Abbildung 1	Abbildung 1
Test 1.4	von Minus nach Plus	von Minus nach Plus	?	?
Test 1.5	A;B C;D E;F	D;E	(A, B) (C, D, F) (E)	(A, B) (C) (D) (E) (F)
Test 2.1	verringert sich.	bleibt gleich.	bleibt gleich.	erhöht sich.
Test 2.2	erhöht sich.	erhöht sich.	erhöht sich.	bleibt gleich.
Test 3.1	verringert sich.	verringert sich.	verringert sich.	verringert sich.
Test 3.2	Die Tür A öffnet sich schneller als die Tür B.	Die Tür A öffnet sich schneller als die Tür B.	Die Türen öffnen sich gleich schnell.	Die Türen öffnen sich gleich schnell.
Test 4.1	Ja	Ja	Nein	Nein
Test 4.2	Ja	Ja	Ja	Ja
Test 4.3	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Kabel besitzen keinen Widerstand., Widerstände können aus verschiedenen Materialien bestehen.	Kabel besitzen keinen Widerstand., Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1	gleich	unterschiedlich	gleich	unterschiedlich
Test 5.2	gleich	gleich	gleich	gleich
Test 5.3	Die Tür öffnet sich langsamer.	Es macht keinen Unterschied.	Die Tür öffnet sich langsamer.	Die Tür öffnet sich schneller.
Test 6.1	1	1	1, 3	1
Test 6.2	Ja	Ja	Ja	Ja
Test Obj	Spannung drosseln	Spannung reduzieren	?	Widerstand einbauen?
Test Obj 2	Spannung erhöhen	Spannung erhöhen	Einen Widerstand einbauen?	Widerstand entfernen?
Fragen richtig	15	16	10	16
Mehr richtig	1		6	
Allgemein (1-5)	4		4	
Magnetismus (1-5)	4		3	
Aktivieren (1-5)	5		5	
Manipulieren (1-5)	4		5	
besonders gut	das Kooperative und die Abwechslung zwischen Aktion und Knobeln, hat sich nicht wie Lernen angefühlt, schönes Design		Der kooperative Charakter und dass über die Lösung für das jeweilige Problem erstmal nachgedacht werden muss, dass das, was man gelernt hat aufeinander aufbaut, je weiter man im Spiel fortschreitet. Wieder einmal in ein Wissensgebiet zu schauen, mit dem man normalerweise wenig zu tun hat.	
Verbesserungen	Schön wären Wissensbuttons, unerfahrene Spieler sind stärker auf die Handlung als den Inhalt konzentriert		Spielen zwei Spieler mit unterschiedlichem Wissensstand zusammen, schmälert das unter Umständen den Lerneffekt für den "schwächeren" Spieler, da der "stärkere" Spieler die Lösungen schneller versteht und anwendet, bevor der "schwächere" Spieler sie nachvollziehen kann. Andererseits kann der "stärkere" Spieler ggf. Zusammenhänge erklären, die ansonsten aus dem Kontext hätten erschlossen werden müssen bzw. kommt man notfalls durch Ausprobieren weiter Magnetismus-Mechanik ist ein schöne Idee - war nur etwas frickelig für ungeübte Spieler den anvisierten Punkt zu erreichen.	

Figure D.24. Answers from the playtesting questionnaire.

Alter	26		25	
Geschlecht	Männlich		Weiblich	
Vorwissen (1-5)	1		2	
	Vorher:	Nachher:	Vorher:	Nachher:
Test 0.1	Volt	Ampere	Ampere	Ampere
Test 0.2	Watt	Volt	Volt	Volt
Test 0.3	Ohm	Ohm	Ohm	Ohm
Test 0.4	Stromstärke, Spannung, Leistung	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1	gleich	gleich	gleich	gleich
Test 1.1.2	gleich	unterschiedlich	unterschiedlich	unterschiedlich
Test 1.2	Zum Betrieb gleich starker Batterien ist die gleiche Spannung erforderlich.	Durch den Motor wird die Spannung von positiv auf negativ geändert.	Der Motor zwischen A und C ist ein Widerstand und verringert die Spannung. Zwischen A und B ist kein Widerstanc also bleibt die Spannung gleich	Der Motor verringert die Spannung.
Test 1.3	Abbildung 2	Abbildung 2	Abbildung 2	Abbildung 2
Test 1.4	Elektronen fließen von - z	Weil Elektronen sich immer zum Pluspol hinbewegen.	Sie fließen vom Minus- zum Pluspol. Außerdem fließen die Elektronen nicht aufeinander zu.	Die Elektronen fließen vom Minus- zum Pluspol und auch niemals aufeinander zu.
Test 1.5	(B, F) (A, E) (C, D)	(B, F) (E, A) (D) (C)	(B,F)(A,E)(D,C)	(B,F) (A,E) (D)(C)
Test 2.1	erhöht sich.	erhöht sich.	erhöht sich.	erhöht sich.
Test 2.2	erhöht sich.	bleibt gleich.	erhöht sich.	erhöht sich.
Test 3.1	verringert sich.	verringert sich.	verringert sich.	verringert sich.
Test 3.2	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.
Test 4.1	Ja	Ja	Ja	Ja
Test 4.2	Ja	Ja	Ja	Ja
Test 4.3	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1	unterschiedlich	unterschiedlich	gleich	gleich
Test 5.2	gleich	gleich	gleich	gleich
Test 5.3	Die Tür öffnet sich schneller.	Es macht keinen Unterschied.	Es macht keinen Unterschied.	Es macht keinen Unterschied.
Test 6.1	1	1	1, 3	1
Test 6.2	Ja	Ja	Ja	Ja
Test Obj	Spannung reduzieren	Widerstand hinzufügen	Auslassen oder einen Widerstand einbauen, um die Stromstärke zu verringern	Widerstand erhöhen davor
Test Obj 2	Spannung erhöhen	Widerstand entfernen, Spannung oder Stromstärke erhöhen		Widerstand wegnehmen/ verringern, Stromstärke erhöhen
Fragen richtig	15	20	18	18
Mehr richtig		5		0
Allgemein (1-5)		5		4
Magnetismus (1-5)		5		5
Aktivieren (1-5)		5		4
Manipulieren (1-5)		5		5
besonders gut	Kooperatives Spiel, Logikelemente, überraschendes Zusammenkommen der Charaktere, stufenweiser Aufbau der Schwierigkeit		Man musste sich Lösungsmöglichkeiten überlegen, um schwierige Stellen zu überwinden, und dabei die Eigenschaften wie die Anziehungskraft nutzen; der kooperative Aspekt	
Verbesserungen	Manchmal wurde nicht deutlich, welche Spannung man zum Türen öffnen brauchte; Hauptsteuerung mit Links war etwas schwierig			

Figure D.25. Answers from the playtesting questionnaire.

Alter	22		23	
Geschlecht	Männlich		Männlich	
Vorwissen (1-5)	1		2	
	Vorher:	Nachher:	Vorher:	Nachher:
Test 0.1	Ampere	Ampere	Ampere	Ampere
Test 0.2	Volt	Watt	Volt	Volt
Test 0.3	Ohm	Ohm	Ohm	Ohm
Test 0.4	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1	gleich	gleich	unterschiedlich	gleich
Test 1.1.2	gleich	unterschiedlich	unterschiedlich	unterschiedlich
Test 1.2	liegen auf dem gleichen leiter	nach dem motor fallt die spannung ab	keine Ahnung	motor nimmt spannung weg sozusagen
Test 1.3	Abbildung 1	Abbildung 2	Abbildung 2	Abbildung 2
Test 1.4	ich wüsste nicht warum einer vom motor abgeht und einer eingeht		alles muss in eine Richtung?	nur eine richtung
Test 1.5	(CD)(E)(F)	(A)(B)(F)(D)	(A,E) (B,F) (D) (C)	A,B,C,D,E,F
Test 2.1	bleibt gleich.	erhöht sich.	verringert sich.	verringert sich.
Test 2.2	bleibt gleich.	verringert sich.	erhöht sich.	bleibt gleich.
Test 3.1	verringert sich.	verringert sich.	verringert sich.	verringert sich.
Test 3.2	Die Türen öffnen sich gleich schnell.	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.	Die Tür B öffnet sich schneller als die Tür A.
Test 4.1	Ja	Nein	Ja	Ja
Test 4.2	Nein	Ja	Ja	Ja
Test 4.3	Kabel besitzen keinen Widerstand., Kabel erhitzen sich bei Stromfluss.	Kabel besitzen keinen Widerstand., Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1	gleich	unterschiedlich	gleich	gleich
Test 5.2	gleich	unterschiedlich	unterschiedlich	gleich
Test 5.3	Es macht keinen Unterschied.	Es macht keinen Unterschied.	Es macht keinen Unterschied.	Die Tür öffnet sich langsamer.
Test 6.1	3	1	1, 3	1, 3
Test 6.2	Ja	Ja	Ja	Ja
Test Obj	wiederstand einbauen	spannung durch wiederstände senken	wiederstände einbauen?	mehr wiederstand
Test Obj 2	dimmen	stromfluss verringern	mehr POWER!	wiederstand weg?
Fragen richtig	12	13	14	18
Mehr richtig	1		4	
Allgemein (1-5)	4		5	
Magnetismus (1-5)	5		4	
Aktivieren (1-5)	3		4	
Manipulieren (1-5)	4		4	
besonders gut	einfacher einstieg und viel spaß durch koop		mitspieler cooperation	
Verbesserungen	abspann und fahrstuhlmusik		mehr mitspieler cooperation nicht nur durch zusamm	

Figure D.26. Answers from the playtesting questionnaire.

Alter	31	
Geschlecht	Männlich	
Vorwissen (1-5)	5	
	Vorher:	Nachher:
Test 0.1	Ampere	Ampere
Test 0.2	Volt	Volt
Test 0.3	Ohm	Ohm
Test 0.4	Stromstärke, Spannung, Widerstand	Stromstärke, Spannung, Widerstand
Test 1.1.1	gleich	gleich
Test 1.1.2	unterschiedlich	unterschiedlich
Test 1.2	A und B haben das gleiche Potential, weil sie direkt mit einer Leitung verbunden sind und die Leitung (fast) keinen eigenen Widerstand hat. A und C haben ungleiches Potential, weil der Moder einen eigenen inneren Widerstand hat. Er ist ein verbraucher im Schaltkreis.	Im Standard/Normalfall nimmt man an, dass Leitungen in Schaltkreisen keinen Widerstand haben. Das macht für die Berechnung und Design und auch hier Sinn. So wurde wohl auch im Spiel der Stromfluss in den Leitungen berechnet. Z.b.die Länge der Leitung war egal. Sonst hätte jedes Stück des Drahtes ein leicht anderes Potential. Aber es gab ein Rätsel im Spiel und auch im Fragebogen hier im Fragebogen, wo es um den Widerstand der Leitung geht. Was ist jetzt die Annahme? Soll man davon ausgeben, dass die Leitungen einen Widerstand hat oder kann man das vernachlässigen, wie in sehr vielen Anwendungen? Ich gehe weiter davon aus, dass die Leitungen keinen Widerstand hat. Also A und B haben gleiches Potential, weil sie direkt über eine Leitung verbunden ist, die keinen Widerstand hat. A und C haben unterschiedliches Potential, weil sie an den beiden verschieden Polen hängen und zwischen ihnen ein Verbraucher ist.
Test 1.3	Abbildung 2	Abbildung 2
Test 1.4	Elektronen sind negativ geladen. Beim Minus-Pol ist ein Elektronenüberschuss. Beim Plus-Pol ist ein Elektronenmangel. Deswegen fließen sie von Minus nach Plus.	Elektronen sind negativ geladen. An Minus-Pol gibt es einen Elektronen Überschuss. Am Pluspol einen Elektronen-Mangel. Deswegen bewegen sich sich vom Minus- zum Pluspol.
Test 1.5	(A,C,D) (E) (F,B)	(A,C,D) (E) (B,F)
Test 2.1	erhöht sich.	erhöht sich.
Test 2.2	bleibt gleich.	bleibt gleich.
Test 3.1	verringert sich.	verringert sich.
Test 3.2	Die Türen öffnen sich gleich schnell.	Die Türen öffnen sich gleich schnell.
Test 4.1	Nein	Ja
Test 4.2	Ja	Ja
Test 4.3	Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.	Kabel besitzen keinen Widerstand., Widerstände können aus verschiedenen Materialien bestehen., Kabel erhitzen sich bei Stromfluss.
Test 5.1	unterschiedlich	unterschiedlich
Test 5.2	gleich	gleich
Test 5.3	Die Tür öffnet sich schneller.	Die Tür öffnet sich schneller.
Test 6.1	1	1
Test 6.2	Ja	Ja
Test Obj	Vorwiderstand verwenden	Vorwiderstand.
Test Obj 2	Vorwiderstand verringern oder Spannung erhöhen	Vorwiderstand verringern oder Spannung erhöhen.
Fragen richtig	22	22
Mehr richtig	0	
Allgemein (1-5)	4	
Magnetismus (1-5)	4	
Aktivieren (1-5)	4	
Manipulieren (1-5)	4	
besonders gut	Das Rätsel, bei dem man sich gegenseitig anziehen musste, um die lange Schlucht zu überwinden war gut. Das habe ich nicht auf Anhieb kapiert ;-)	
Verbesserungen	Der Begriff "Magnetismus-Mechanik" ist hier echt schräg. Die physikalische Kraft im dem Spiel ist nämlich die Elektrostatik. Zwei Ladungen ziehen sich entweder an oder stoßen sich hab. Das ist zwar ähnlich wie Magnetismus, ist aber eine andere physikalische Kraft! Die Annahmen für die Beurteilung der Schaltkreise war nicht klar. Soll der Widerstand in der Leitung berücksichtigt werden oder nicht. Normalerweise wird der Leitungswiderstand vernachlässigt, weil er zu gering ist. Ein Rätsel und eine Frage hat aber nach diesem Leitungswiderstand gefragt. Soll man ihn jetzt also berücksichtigen? Wenn ja, dann wären immer alle Potential unterschiedlich. Hier ist das Physikalische Modell nicht konsistent. Die Figuren unterscheiden sich nur in der Farbe: rot und plus. Für mich war dann im Spiel nicht klar was der Minus und was der Plus-Pol war. In den Grafiken im Fragebogen ist das klar, weil dort nochmal die Zeichen "+" und "-" verwendet werden. Es wäre schön, wenn man die Minus und Plus Unterscheidungen auch im Spiel sehen kann und sich nicht nur aus den Farben erschließen kann. Es ist zwar für die Spielmechanik nie relevant, wo plus oder minus ist, aber nur so machen die Gelben Ladungen, die sich in den Leitungen bewegen, Sinn. Erst nachträglich habe ich jetzt erkannt, dass es die Elektronen darstellen soll. Das wäre klarer, wenn man Plus und Minus nicht nur an den Farben im Spiel unterscheiden kann. Die gelben Ladungen hätten auch genauso gut imaginäre Positiv-Ladungen sein können, die sich im Stromkreis von Plus- um Minus-Pol bewegen. Das ist ein gängiges Erklärungsbild, wenn man Schlatkreise erklärt. Man sag ja auch, dass der Stromfluss von Positiv nach negativ geht. Ist in der Geschichte doof gelaufen, dass man am Anfang noch nicht wusste, was Elektronen sind und dass sie negativ geladen sind. Die Spielmechanik ist am Anfang echt etwas tricky. An manchen Sprungrätsel hat man länger gebraucht, bis man die Figuren richtig aufeinander positioniert hat, um einen Abstoß boost zu holen. Das die Figuren oben rund sind hat es nicht leichter gemacht, die Figuren richtig aufeinandern zu stellen. Die Abstoß-Kraft war auch nicht richtig einzuschätzen. Manchmal flog man sehr weit, manchmal hat es nicht gereicht. Und es war nicht klar woran das liegt. Gefühlt war die Figure immer gleich nah an der anderen. Die Angaben von Volt und Amper an den Toren war irgendwie im Endeffekt irrelevant. Man hat zwar kurz draufgeschaut, aber nie wirklich nachvollzogen, wie der Wert zustanden kommt. Es war auch an den Toren nicht offensichtlich, wie hoch die Ampre/Volt hätten sein müssen. Man hat einfach so lange probiert, bis das Tor aufging.	

Figure D.27. Answers from the playtesting questionnaire.

Selbstständigkeitserklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig und ohne Benutzung anderer als der angegebenen Quellen und Hilfsmittel angefertigt habe.

Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder nicht veröffentlichten Schriften entnommen wurden, sind als solche kenntlich gemacht.

Die Arbeit hat in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegen.

Würzburg, May 10, 2022

Vorname Nachname

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Versicherung zur Leistungserbringung

Titel der Abschlussarbeit:

____

Thema bereitgestellt von (Titel, Vorname, Nachname, Lehrstuhl):

____

Eingereicht durch (Vorname, Nachname, Matrikel):

____

Ich versichere, dass ich die vorstehende Arbeit selbstständig und ohne fremde Hilfe angefertigt und mich keiner anderer als der in den beigefügten Verzeichnissen angegebenen Hilfsmittel bedient habe. Alle Textstellen, die wörtlich oder sinngemäß aus Veröffentlichungen Dritter entnommen wurden, sind als solche kenntlich gemacht. Alle Quellen, die dem World Wide Web entnommen oder in einer digitalen Form verwendet wurden, sind der Arbeit beigefügt.

Weitere Personen waren an der geistigen Leistung der vorliegenden Arbeit nicht beteiligt. Insbesondere habe ich nicht die Hilfe eines Ghostwriters oder einer Ghostwriting-Agentur in Anspruch genommen. Dritte haben von mir weder unmittelbar noch mittelbar Geld oder geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Arbeit stehen.

Der Durchführung einer elektronischen Plagiatsprüfung stimme ich hiermit zu. Die eingereichte elektronische Fassung der Arbeit ist vollständig. Mir ist bewusst, dass nachträgliche Ergänzungen ausgeschlossen sind.

Die Arbeit wurde bisher keiner anderen Prüfungsbehörde vorgelegt und auch nicht veröffentlicht. Ich bin mir bewusst, dass eine unwahre Erklärung zur Versicherung der selbstständigen Leistungserbringung rechtliche Folgen haben kann.

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Ort, Datum, Unterschrift