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

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***Abstract*—This thesis aims at developing a serious educational game to teach concepts and notions related to Ohm's Law and its application. The design process is based on established instructional design methodologies such as *Revised Bloom's Taxonomy* [1] and game design processes using the *MDA framework* [2] and the *Unifying Game Ontology* [3]. Several prototypes will be developed and refined and user tests as well as knowledge retention and transfer assessments will be conducted to evaluate the viability of our methodology.**

***Index Terms*—serious game, electromagnetism, learning, educational**

I. Motivation

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 fields and magnetic fields, and it is responsible for electromagnetic radiation such as light [4].

In order to convey knowledge about electromagnetism and its applications, this topic is usually introduced in high school curricula [5]. These curricula are designed by pedagogy experts who, using proper instructional design frameworks, define clear objectives and activities to convey the most important concepts of electromagnetism along with hands-on sessions to expose students to its applications.

Moreover, from a game design perspective, physics' concepts have always been suitable for deriving fun video game mechanics. In games such as Angry Birds, 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 could be utilized to repel the player or they could have to complete electric circuits in order to open a gate.

Since physical concepts can be successfully gamified there is the potential to implement learning theories into serious educational games in order to provide a fun learning experience for the players. The goal of this thesis is to help making the design and development process of serious educational games more systematic and therefore easier. This is done by designing and creating a video game that teaches about the concepts and processes of electromagnetism using well established frameworks in both game design and instructional design as a basis. According to the learning theory *Revised Bloom's Taxonomy* [1] there are six major cognitive process categories such as "Remember", "Understand", "Apply" and four types of knowledge, like "Conceptual Knowledge" or "Procedural Knowledge". The taxonomy provides an example where the learning objective is for students to learn to apply Ohm's law. The objective and its underlying activities are classified according to these two categories and can be directly mapped to elements within the game. Since the learning objectives and activities are well-defined and linked to concrete game elements, it will be easier to assess the knowledge retention of the players. More precisely, by achieving the game goals, the players would achieve the learning objectives.

II. Related Work

The Bavarian high school curriculum [5] highlights methods such as conducting experiments and creating models to help students visualize different concepts of physics. It recommends making references to the real world and technology in order to illustrate the outstanding position of physics and to utilize student activating methods, such as brainstorming, open discussions or mind mapping. Official school books [6] often contain concept explanations in text form, many images to visualize them and homework problems that test if the student is able to apply the concepts taught and to consolidate the knowledge.

In contrast to the approach taken in school, there are also many gamified learning environments, that aim to teach electromagnetism to pupils. Some focus more on the learning aspect, others more on the gamification. In order to create an effective serious educational game the developer has to properly balance the learning and the gaming side. During the thesis related work will be classified according to these two properties to see which learning objectives have been mapped successfully onto which game elements. For that we utilize two established frameworks in instructional and game design, which are called *Revised Bloom's Taxonomy* and *Unifying Game Ontology* [3]. An approximate classification of the related applications can be seen in Fig. 1.

One example is the simpleclub app [7] which chooses a similar approach to the high school curriculum by offering exercises but also animated videos about different topics such as how to build a current circuit or Ohm's law. Moreover, there are also interactive approaches such as this electromagnetism laboratory [8] where pupils can conduct experiments without

the constraints and dangers that exist when doing them in real life. Supercharged! [9] for instance is a 3D-game, where the player has to change the charge of their ship to move it closer to the goal by getting attracted or repelled by other charged objects. Wired [10] focuses more on electricity and solving puzzles related to electric circuits. It does so, in order to help children develop an intuition for these topics, to make it easier to learn the formal concepts later. Another game, that has learning only as a secondary goal is Electrician Simulator [11] where the player takes on the job of an electrician that has to fix various problems. It focuses more on fun and immersion than on effectively teaching a learning objective. A game that purely focuses on the gaming aspect and only utilizes electricity as an inspiration for mechanics is ElecHead [12] where one plays a robot that charges every surface they touch and by using that mechanic they have to solve different riddles.

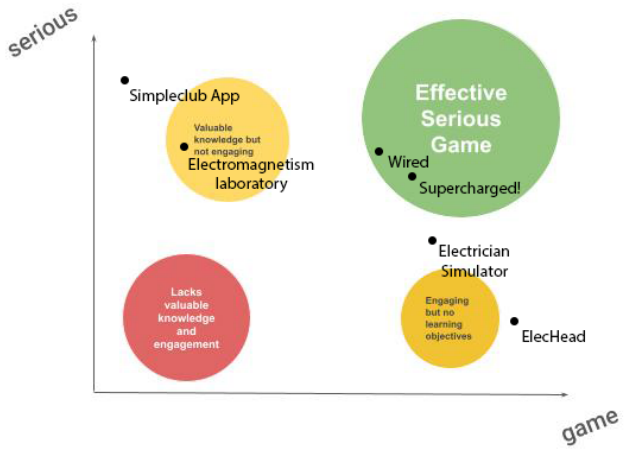

Fig. 1. Qualitative serious games classified according to their gamification and knowledge transfer.

III. Methodology

For the bachelor thesis an educational serious game is created that aims at providing a successful learning experience, while also being immersive and fun for the player. In this section the game's design details are presented starting with an overview of the instructional design in section III-A based on an example from *Revised Bloom's Taxonomy*. After this the concrete game elements, such as mechanics, theme and genre are outlined together with the overall steps taken to design the game in III-B. Then it is shown how the learning elements are represented within the game in III-C, followed by structure and implementation details of the project in III-D. In the last section it is presented how the game is tested in regards to gameplay and knowledge assessment.

A. Instructional Design

In order to check what knowledge the player has retained from the game, the learning elements must be well defined from the beginning. For this purpose, a key objective, tests and instructional activities a teacher may use, are classified according to six major cognitive process categories and four types of knowledge as shown in Fig. 2. In Revised Bloom's Taxonomy there is an example where the key objective is "Students should learn to use laws of electricity and magnetism (such as Lenz's law and Ohm's law) to solve problems". In addition to that smaller objectives, also known as learning activities are defined, that help accomplishing the main objective when executed. The corresponding classification can also be seen in Fig. 2.

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*			

Fig. 2. Classification example from Revised Bloom's Taxonomy [1] about Ohm's Law

- **Key Objective**: "Students should leam to use laws of electricity and magnetism (such as Lenz' law and Ohm's law) to solve problems."
- **A 1**: activities to help classify types of problems
- **A 2**: activities to help select appropriate laws
- **A 3**: activities to help implement proper procedures
- **A 4**: activities to help recall metacognitive strategies
- **A 5**: activities to help implement metacognitive strategies
- **A 6**: activities to help check their implementation of the procedure
- **A 7**: activities to help critique the correctness of their solution
- **Test 1A, 1B, 1C**: cells associated with the procedural aspect of each problem
- **Test 2**: cell associated with the correct "answer"

If the teacher defines activities according to this classification they lead to the pupil learning what is necessary for the key objective. While this example is originally targeted at a more traditional learning environment, it can serve as a blueprint for the learning objectives, instructions and assessment design.

B. Game Elements And Game Design

The game is a serious educational puzzle platformer that centers around electromagnetism. Two players must cooperate to solve puzzles. To do this, they use mechanics that fit the theme of electromagnetism, such as changing their character's charge and thus being attracted to magnets, or repelled by them. Another possibility to utilize the character's charge is to activate current circuits in order to advance to the next stage by opening a door, for example. There will be different levels, with increasing difficulty, that will serve to subliminally introduce concepts of electromagnetism step by step and then let the player experiment with them.

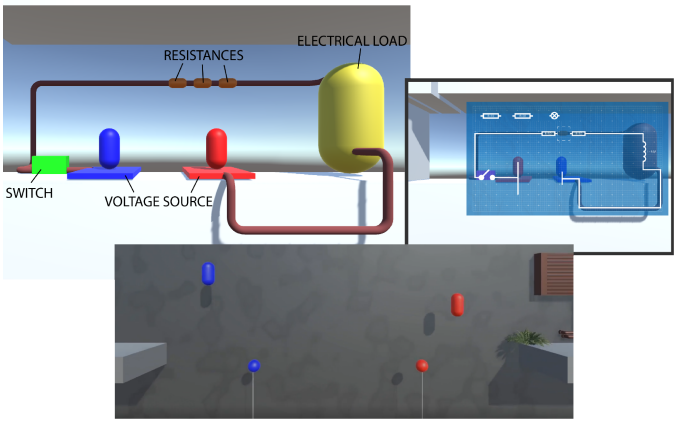

Fig. 3. Game prototype showcasing multiple game elements

The game elements in which these concepts are encoded can be classified according to the *Unifying Game Ontology* (*UGO*). It defines game mechanics like "Navigation" or "Creation", for example, but also *Imperative Goals* like "Find" or "Optimize" which lead to the *Ultimate Goals*, such as "Winning" or "Finishing".

The design process of the game is based on the Mechanics-Dynamics-Aesthetics framework [2]. At the beginning, simple mechanics like jumping, changing the charge of the character or activating elements by electrical contact plates are defined. This results in the dynamics and aesthetics of the game. The dynamics describe how the mechanics work together and which strategies emerge from using them in the game, while the effect those dynamics have on the player are called aesthetics. These elements are refined and developed in an iterative development process. Especially during level design, it is important to rely on the learning activities defined in III-A in order to integrate them into the game in a meaningful and successful way.

C. Learning elements representation in game elements

In order to successfully convey a learning objective through a game, clear instructional activities must be defined, which are then translated into mechanics or goals in the game. The possible actions that a player can perform and their relationships are described in the *Unifying Game Ontology*. To successfully teach a learning objective, the game must contain a model of the learning process and map the actions described in the *UGO* to the learning activities defined through the *Revised Bloom's Taxonomy*. More concretely, in the game, separate levels are created for each learning objective, in which multiple actions or riddles are embedded that represent the different learning activities and by solving them the player is brought closer to the learning objective step by step. This is similar to a gamified tutorial on a concept of electromagnetism.

D. Implementation

Since the concepts of electromagnetism are to be taught in the game, a physics system is needed that simulates the corresponding interactions. The game therefore uses the Unity3D engine in its 2020.3 version as a basis, which has a physics subsystem and thus simplifies the implementation of, for example, magnetic forces. The implementation process starts with a whitebox level without visual effects, animations or audio. The goal is to implement the basic mechanics and learning theories in a minimal model and to refine and expand them in later iteration cycles. In addition, the goal is to make the different puzzle elements as modular as possible, since the riddles build on each other and thus many parts can be reused.

Since an educational game should be accessible to everyone it would be ideal to offer it as a browser game. Through that it would not require an installation on the machine, but can be played in any browser. Another advantage of a web application is that many evaluation tools are also web based, simplifying their integration and therefore the evaluation process.

E. Playtesting And Knowledge Retention Assessment

After the first activities are implemented in the playable prototype as described in section III-A, the game is tested by humans. Ideally the testing then becomes part of the iterative development process to constantly attain player feedback. The testers are given questionnaires that ask about the level of knowledge regarding the learning objective before playing the game and afterwards in order to check if the players have achieved the learning objective. In addition, the testers are asked to rate the game's playability and fun. The resulting data will be used to determine whether the activities have been successfully integrated into the game and to improve the game where necessary.

IV. Schedule

A. Literature Review

- Week 1-3
- Research about frameworks regarding instructional and game design
- Definition of proper mapping process between learning and game elements

B. Concept And Development

- Week 4-9
- Creation of level design that is supposed to teach Ohm's Law
- Iterative implementation of electromagnetic concepts and fun mechanics

C. Testing

- Week 6-9
- Iterative knowledge retention and gameplay tests with different groups of players

D. Thesis writing

- Week 10-12
- Writing of Bachelor Thesis
- Description of systematic design and development process
- Discussion of success with regard to feedback from testing

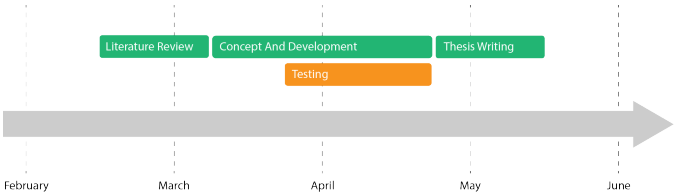

Fig. 4. Planned schedule for the thesis

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