Predicting Learning Effects of Computer Games Using the Gamified Knowledge Encoding Model

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Abstract

Game mechanics encode a computer game’s underlying principles as their internal rules. These game rules consist of information relevant to a specific learning content in the case of a serious game. This paper describes an approach to predict the learning effect of computer games by analyzing the structure of the provided game mechanics. In particular, we utilize the Gamified Knowledge Encoding model to predict the learning effects of playing the computer game Kerbal Space Program (KSP). We tested the correctness of the prediction in a user study evaluating the learning effects of playing KSP. Participants achieved a significant increase in knowledge about orbital mechanics during their first gameplay hours. In the second phase of the study, we assessed KSP’s applicability as an educational tool and compared it to a traditional learning method in respect to the learning outcome. The results indicate a highly motivating and effective knowledge learning. Also, participants used KSP to validate complex theoretical spaceflight concepts.

Keywords:
Gamified Knowledge Encoding model, Knowledge Learning, Game-based Learning

1. Introduction

Computer games consist of game mechanics that define a game’s rules, encode the underlying principles, and determine a player’s capabilities inside
of a particular computer game [1]. Game mechanics can be distinguished in player-bound and game-bound game mechanics [2]. Player-bound game mechanics allow a player to interact with the game world [3] being created and controlled by the game-bound game mechanics [1]. Game-bound game mechanics also create a game’s goals and challenges. The interaction between the two constructs creates a game’s gameplay and informs a player about the effects and correctness of the performed actions. The encoded principles and rules are trained and mastered [4, 5] during the gameplay due to repetition [6]. Thus, game mechanics and their interaction possibilities create learning affordances for the encoded knowledge by requiring a knowledge’s application and informing learners about the underlying principles [7, 8].

The ultimate goal of using computer games for educational purposes is to achieve a total internalization of the encoded knowledge allowing for a training transfer from the learning environment to a real world context [9, 10]. Game mechanics present, demonstrate, and require the learning content in an audiovisual way that supports the compilation of mental models [11, 12]. Mental models are mental representations of a particular knowledge that allow for an internal visualization, problem solving, and knowledge transfer [13, 14]. In addition, game mechanics can create similar requirements for the knowledge application to the targeted real world context. This facilitates a training transfer as mental models are situation-specific [15].

The actual process of knowledge learning using game mechanics is defined by the Gamified Knowledge Encoding model [16]. The Gamified Knowledge Encoding maps the learning content in form of game rules to interacting game mechanics. Gamified knowledge encoding is defined as the process of implementing, demonstrating, and requiring specific knowledge in a serious game for the purpose of achieving a transfer-oriented knowledge learning. However, to validate the proposed model, it is necessary to validate its applicability to encode specific knowledge as well as to predict the learning outcome of a serious game. A successful learning effect prediction would indicate the correctness of the model’s definition of gamified knowledge learning.

1.1. Contribution

In this paper, the Gamified Knowledge Encoding is used to 1) identify game mechanics and the encoded knowledge as well as to 2) predict the game’s learning effects during the gameplay. In particular, this paper analyzes the core game mechanics of Kerbal Space Program (KSP) [17] in respect to the encoded knowledge rules. The game implements orbital mechanics to
realistically simulate spaceflight [18]. This knowledge represents the grounding principles every aerospace student has to understand. Hence, facilitating and improving the learning of orbital mechanics most likely results in a better performance in later courses of an aerospace program’s curriculum. In a user study, participants played KSP for two weeks to test for the predicted learning effects. The results show a significant orbital mechanics knowledge gain during the initial hours of playing the game. In the second phase of the study, KSP’s effectiveness to assist the learning of orbital mechanics is assessed by comparing it to a traditional learning method, i.e., using paper-based assignments, in respect to the learning outcome. The study further analyzed the learning quality of utilizing KSP in a class-based tutorial setting. The results revealed a similar learning outcome between the two tested conditions. Participants showed a high motivation to tackle assignments when playing KSP.

1.2. Structure

The paper begins with an overview over game-based learning and introduces KSP. Then, the paper presents the background as well as the concept of the Gamified Knowledge Encoding and identifies the game mechanics that encode the orbital mechanics in KSP. Based on this analyzes, we predict KSP’s learning effects. Subsequently, the study design is described and the results are presented. The paper concludes with a discussion of the results and an outlook for future research.

2. Related Work

Computer games fulfill the conditions for optimal learning [19] by requiring a repetitive application of the encoded knowledge throughout the gameplay [6]. As the game goals increase in difficulty to compensate for a game’s training effect, a player’s pre-existing knowledge is required. Aside from providing clear goals and immediate feedback, this increase in difficulty is important for maintaining the flow-inducing aspects by keeping players challenged [20, 21]. Flow mainly influences enjoyment and performance of gaming action, thus also affecting and increasing a player’s motivation for knowledge learning [22].
2.1. Game-Based Learning

Research has shown that complex sets of human skills [23], such as skills of surgery [24], communication [25, 26], collaboration [27, 28], and leadership [29, 30] are practiced by playing computer games. Computer games can also be used to train human abilities such as cognitive flexibility [31], spatial resolution [32] and spatial visual attention [33]. The immersive effect of computer games [34] allows players to experience moral problems or to face ethical questions [35]. Gaming immersion describes the effect of a good computer game experience and features three stages: engagement, engrossment, and total immersion [36]. Depending on the gaming immersion’s stage, a player’s attention is partly or even completely absorbed by the gameplay. When in total immersion, players lost their self-awareness and are completely detached from reality [37]. Hence, computer games are utilized as a training environment for moral decision making [38].

The knowledge learning capabilities of computer games led to the emergence of serious games [39]. These special games are developed for an educative purpose [40] that goes beyond the usual entertaining approach of computer games [41]. In the case of complex, expensive or even dangerous learning contents, serious games and simulations present effective and safe learning environments. Learners can explore the learning content without the fear of bad consequences as even death is reversible [42].

2.2. Kerbal Space Program

KSP allows its players to manage a space agency and to conduct spaceflight missions in a fictional solar system. The simulation game demonstrates spaceflight in a vivid and engaging way. It helps its users to develop a thorough understanding of common spaceflight terms and procedures. Players are able to construct and launch their own spacecrafts, to perform orbital maneuvers, to fly to other celestial bodies, and to land on them. For assembling a rocket, players can choose from a broad selection of various parts and attach them to their spacecraft (see Figure 1). As KSP implements a realistic physics-engine encoding orbital mechanics, the game allows for the application of spaceflight related equations, such as the ideal rocket equation and the calculation of transfer orbits [18]. The ideal rocket equation determines a spacecraft’s performance, i.e., delta-v. Orbital mechanics include the laws of Newton and Kepler to define the properties and characteristics of an orbit. Hence, orbital mechanics allow for a calculation of spaceflight maneuvers like the computation of a maneuver needed to fly from low Earth orbit.
to the Moon. Also, these physical principles define and explain a rocket’s ascent phase which represents the initial challenge for new KSP players. Although the game can be played by ‘trail and error’, developing an in-depth understanding of orbital mechanics allows players to construct more efficient spacecraft and to perform more efficient maneuvers.

![Image of KSP players assembling rockets](image)

Figure 1: Players assemble rockets in KSP from a wide selection of parts.

As KSP is a simulation game, players apply their spaceflight knowledge by directly controlling their virtual spacecraft (see Figure 2). By controlling a spacecraft’s attitude and executing a burn, a player performs an orbital maneuver that changes the current trajectory. KSP is normally played using keyboard and mouse but also supports other input devices like joysticks and gamepads. The user interface provides players with important information, such as the velocity, the altitude and the heading, to effectively play the game. Furthermore, players can switch to an orbital map that displays the current trajectory and orbital parameters, such as the apoapsis, the periapsis and the inclination (see Figure 3).

Although KSP is an open world exploration game that allows its players to set their own goals, players may also play in career mode. This mode requires them to manage their own space agency by fulfilling contracts to earn currencies mandatory for unlocking new technologies.
Figure 2: The simulation environment and user interface of KSP.

Figure 3: The orbital map displays essential information about the trajectories of all flying spacecraft, e.g., the apoapsis, periapsis, and inclination.
3. Knowledge, Human Performance and Game Mechanics

The definition of the Gamified Knowledge Encoding depends on two integral elements: the acquisition of new knowledge and the definition of game mechanics.

3.1. Knowledge and Human Performance

Knowledge generally consists of facts, information, and skills related to a specific subject. Learners acquire new knowledge through education, practice, and experience. Knowledge can further be distinguished in declarative knowledge and procedural knowledge [43, 44]. Declarative knowledge consists of information, facts, methods, and principles describing what a subject is. Procedural knowledge reflects motor or cognitive skills and describes how an action is performed. Internally, multiple cognitive systems encode the two knowledge types, thus forming a declarative and a procedural or non-declarative memory [45]. The declarative memory is located in the hippocampus and its related structures and rapidly forms connections between arbitrarily different stimuli [46]. It is conscious as well as flexibly available to multiple response systems and rapidly stores and modifies information. In contrast, depending on the activated response systems, multiple cognitive systems manage the non-declarative memory [47, 48]. The non-declarative memory steadily forms new associations, is non-conscious and less flexible. It mainly provides full access to response systems involved in the learning process.

The acquisition of a skill, i.e., procedural knowledge, requires a frequent training and passes through three stages [49]. At first, during the cognitive stage, a skill’s declarative encoding is memorized [43, 50]. The declarative encoding consists of facts and steps relevant to the skill’s performance. They are followed closely when executing the skill for the first time. During the cognitive stage, the skill’s performance is imperfect as the knowledge is merely stored in a declarative form. Subsequently, in the associative stage, errors are iteratively detected and removed, thus gradually improving the skill’s performance. The connections between each individual step are strengthened and the respective transitions are smoothed out. However, the declarative encoding remains memorized despite the development of a procedural encoding. For instance, a person can rapidly solve simple mathematical problems, e.g., multiplying numbers, but still recall the underlying principles and rules. Finally, in the autonomous stage, i.e., the last stage of skill acquisition, the
performance is gradually automated. This further increases the performance and achieves true mastery of the skill.

Although declarative knowledge is rapidly memorized, it requires training [51] and deliberate practice [19] to gain expertise [43]. As a general rule, an individual learner needs 10 years of experience to completely master the knowledge of a particular field [52, 53]. By gaining expertise, a learner removes errors in the memorized rules and generalizes them to schemata [54], thus deepening the understanding of the knowledge [55]. Developing an expertise also stores further information about encountered problems as well as special events of application in the long-term memory and facilitates their retrieval [43]. Experts in a particular field solve a new problem in a different way. They can rapidly visualize it and find more effective solutions [56]. Thus, the deliberate practice of declarative knowledge leads to a shift to a more pattern-driven and model-driven application.

Therefore, especially in the case of an abstract or complex learning content, practice is one of the most important aspects of learning new knowledge [57]. It achieves an automatization (acquisition of a new skill), deepening of the knowledge, its generalization (gaining expertise) and facilitation of its transfer [9, 10]. This process leads to a compilation of situation-specific mental models [13, 58]. A mental model is a complex as well as flexible mental representation of a knowledge and allows for its internal visualization as well as simulation [14]. Due to their flexibility, mental models are easily updated. They are utilized for either rapidly applying the knowledge in a familiar situation or for analyzing and solving unfamiliar problems [59, 60]. Overall, the compilation of mental models reflects the gain of expertise as well as automatization of a skill and allows for a knowledge transfer from the learning context to a new context of application.

The application of a specific knowledge manifests in the three levels of human performance [61]. Skill-based performance is automatically performed without a person’s conscious attention. It cannot be defined in terms of information needed and actions performed by the person, thus representing the application of procedural knowledge in the autonomous stage. The rule-based performance, i.e., the next higher level, bases on declarative knowledge rules which are explainable by the performing person. This level represents the application of procedural knowledge during the cognitive and partly associative stage of skill acquisition as well as the explicit application of declarative knowledge. Skill-based and rule-based performance results in a deliberate practice, i.e., skill acquisition and gain of expertise, leading to the compi-
lation of situation-specific mental models. During unfamiliar situations, a person must move to the knowledge-based performance, the next higher cognitive level. This level allows the person to transfer the compiled mental models to the new context of application, thus solving problems and completing self-defined goals.

In summary, knowledge is distinguished in procedural and declarative knowledge as depicted in Figure 4. By repetitively utilizing a specific knowledge, its application gets automated or pattern-driven depending on the category. The learning process results in the compilation of mental models that are complex mental representations allowing for an internal visualization. Mental models not only affect the actual in-context application, but also allow for a knowledge transfer to a different context. The actual application takes place on a skill-based, rule-based, and knowledge-based layer of human performance.

### 3.2. Game Mechanics

A computer game is not a compact entity. Instead, it consists of a series of game mechanics. Game-bound game mechanics create the virtual environment, a game’s challenges, and a game’s overall narrative. Hence,
these game mechanics encode methods and principles which describe the virtual environment. In this way, game-bound game mechanics only encode and demonstrate declarative knowledge. Player-bound game mechanics are explicitly executed by players to perform actions inside the virtual environment. Depending on the encoded type of knowledge, they are either procedural direct control game mechanics or declarative value configuration game mechanics. Direct control game mechanics require the performance of procedural knowledge, thus allowing for a direct movement, steering, and general action performance, i.e., they reflect sensorimotor skills. These game mechanics internally define the individual steps and effects of the encoded skill’s performance and hence represent the declarative form of procedural knowledge. Value configuration game mechanics, on the other hand, require an explicit application of specific rules, such as equipping gear in a role-playing game, choosing skills in a skill-tree, ordering helpful units in a strategy game, or using radio navigation in a flight simulation. Executing player-bound game mechanics to interact with the game world, i.e., the game-bound game mechanics, results in a computer game’s gameplay. This interaction simultaneously provides players with feedback about the correctness as well as effects of their actions. Depending on the player-bound game mechanic’s category, i.e., direct control or value configuration, and a player’s training stage, a game mechanic’s execution takes place on a skill-based or rule-based level of human performance (see Table 1).

Table 1: Overview of game mechanic categories, the corresponding level of human performance and the internally encoded knowledge

<table>
<thead>
<tr>
<th>Game Mechanic</th>
<th>Human Performance</th>
<th>Knowledge</th>
</tr>
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<tbody>
<tr>
<td>Direct Control</td>
<td>Skill-Based</td>
<td>Procedural</td>
</tr>
<tr>
<td></td>
<td>Partly Rule-Based</td>
<td></td>
</tr>
<tr>
<td>Value Configuration</td>
<td>Rule-Based</td>
<td>Declarative</td>
</tr>
<tr>
<td>Game-Bound</td>
<td>Rule-Based</td>
<td>Declarative</td>
</tr>
</tbody>
</table>

Ultimately, the gameplay results in a repetitive knowledge application, i.e., a learning process (automatization or gaining expertise), and the compilation of situation-specific mental models [13, 58, 11]. Also, this requires and demonstrates the encoded knowledge in an audiovisual way which supports the creation of mental models [7, 12]. Players internalize these visualizations
and use them as a part of their situation-specific mental model.

However, direct control game mechanics require the performance of procedural knowledge without presenting it in its declarative form. Therefore, it is necessary to inform players about the individual steps for the performance of the gamified skill. This allows them to store the knowledge in a declarative form. Well-designed computer games provide a so-called tutorial. This special gameplay phase demonstrates the underlying principles by explaining the existing game mechanics, showing the inputs needed to execute them, and providing an opportunity for practicing the skill’s performance. Afterwards, players continue with the main part of the game which furthers the learning as well as training of the encoded knowledge.

For example, consider the first time a racing simulation game is played by a new player. During the gameplay, players drive virtual racing cars, i.e., executing direct control game mechanics, on racetracks featuring various surface types realized by game-bound game mechanics. To improve their performance, players can change the setup of their cars by executing value configuration game mechanics, e.g., adjusting the gear ratio. At the start of the game, players complete a driving tutorial explaining the individual steps of controlling a car, e.g., using the handbrake to drift through narrow turns. Instead of automatically and subconsciously using the various game inputs, players have to focus on providing the correct input at the right time. They follow clear rules and perform conscious actions (cognitive stage of skill acquisition). During this stage, the driving skills are very poor. However, while progressing through the gameplay, players continuously execute the direct control game mechanics. This leads to an automatization and a subsequent shift (associative and autonomous stage of skill acquisition) from the rule-based to a skill-based level of human performance. Between the races, players follow clear rules, i.e., rule-based level of human performance, to setup their cars. Simultaneously, situation-specific mental models for the game-specific knowledge are compiled. They are used for a knowledge application inside of the current racing game and a training transfer between different games, i.e., racing in a different racing game [62], or even to a real world driving situation. Furthermore, the process of executing game mechanics requires a specific set of human skills [23]. Driving a virtual racing car challenges a player’s reaction time and hand-eye coordination.

Lastly, a computer game’s genre not only indicates a game’s gameplay, i.e., the predominantly provided game mechanics, but also classifies games by the encoded knowledge type. Action games, such as first-person shooter
and platforming games, and simulation games, like racing games and flight simulations, mainly provide direct control game mechanics. They are classified as procedural knowledge games. Mixed-genre games, such as role-playing games, real-time strategy games and action-adventure games, combine direct control with value configuration game mechanics. The gameplay of these games requires players to perform direct interactions and to deliberately use declarative knowledge. As a result of this, these games combine both knowledge types and are probably the most effective games for a learning of knowledge [63]. Finally, point-and-click adventure games, management games and turn-based strategy games mainly implement value configuration game mechanics. They represent declarative knowledge games. Table 2 provides an overview of the computer game genres and their core knowledge types.

Table 2: Overview of computer game genres, encoded knowledge and used game mechanics

<table>
<thead>
<tr>
<th>Genre</th>
<th>Knowledge</th>
<th>Game Mechanics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action Simulation</td>
<td>Procedural</td>
<td>Direct Control</td>
</tr>
<tr>
<td>Mixed-Genre Real-Time Strategy</td>
<td>Procedural, Declarative</td>
<td>Direct Control, Value Configuration</td>
</tr>
<tr>
<td>Adventure Management</td>
<td>Declarative</td>
<td>Value Configuration</td>
</tr>
<tr>
<td>Turn-Based Strategy</td>
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</table>

In conclusion, players are deliberately applying the required skills and game specific knowledge on a skill-based and rule-based level during the gameplay. This leads to a compilation of mental models [6, 64]. Therefore, game mechanics are used to directly encode and require a learning content’s application on a skill-based and/or rule-based level, thus enhancing the learning outcome of edutainment software [65]. Additionally, learning transfer between the game world and the real world is facilitated when the game as well as the target context share similar requirements [7, 15, 45]. As game mechanics can implement any scenario [66], they need to be adjusted in such a way that the learning environments share similar requirements with the real-world application of the knowledge to be learned.
4. Gamified Knowledge Encoding Model

The Gamified Knowledge Encoding relies on the theoretically grounded concepts discussed in Section 3. The Gamified Knowledge Encoding maps the learning content to interacting game mechanics to clearly define learning affordances [7] for the knowledge to be learned. Thus, working with the Gamified Knowledge Encoding, players entrain the encoded knowledge on a skill-based and rule-based level of human behavior [61] during the gameplay. As a result, learners compile a mental model [13] for the learning content [58] that allows them to transfer their knowledge to a different context.

4.1. Knowledge Encoding

The Gamified Knowledge Encoding achieves a direct knowledge encoding by segmenting the learning content into smaller packages of which each describes a coherent part of the knowledge [2]. Each knowledge package then creates a gameplay element to allow for an application inside of the virtual environment. Applying the Gamified Knowledge Encoding, this is done by turning the knowledge packages into clear and well-defined game rules. These rules are mapped to interacting game mechanics. This mapping process generates a gamification metaphor representing and requiring the learning content inside of serious games. Player-bound game mechanics encode rules defining and requiring the actual application of the knowledge as game inputs. Game-bound game mechanics act as a verification system to check if a player’s inputs are correct or as a demonstration system visualizing the inputs’ effects. Ultimately, the interaction between a gamification metaphor’s game mechanics requires the knowledge’s application and informs about the underlying principles by providing immediate feedback.

4.2. Knowledge Presentation: Moderation and Mediation

However, directly encoding the learning content in gamification metaphors might not necessarily result in an intuitive knowledge learning. This especially is problematic in the case of abstract knowledge which is hard to visualize and often escapes an intuitive approach. Therefore, the Gamified Knowledge Encoding also includes a knowledge moderation and a knowledge mediation to adjust the level of abstraction of a given knowledge or individual fact. Also, the moderation and mediation determines the knowledge presentation inside of the serious game.
The *knowledge moderation* scales the level of abstraction of the encoded knowledge by adjusting the accuracy and selection of the sets of knowledge rules. Thus, the Gamified Knowledge Encoding creates a direct knowledge encoding that ranges from a non-moderated accurate simulation to a highly moderated simplified and very intuitive knowledge application. By adjusting the moderation over time, the level of abstraction is adjustable according to the learner’s knowledge gain.

For instance, an abstract knowledge learning process begins with a very intuitive and simplified demonstration of the learning contents. This is achieved by merely encoding a simplified set of rules, thus establishing a certain distance to the knowledge. Subsequently, as the learners progress through the learning process, more complex sets of rules are mapped to the gamification metaphor’s game mechanics. This reduces the initial distance to the knowledge over time. Finally, once the students have developed an in-depth understanding, the provided game mechanics encode the complete and non-moderated set of rules. The moderation completely closes the initial distance and achieves the knowledge’s simulation. As a result, the game’s challenge and difficulty level matches with the current knowledge and/or skill level of the players. Thus, the moderation allows for an adjustment of the serious game’s learning curve.

The *knowledge mediation*, i.e., the selection and design of game mechanics, partly depends on the degree of the knowledge moderation. A low degree of knowledge moderation requires game mechanics that accurately encode the knowledge rules, i.e., they remodel and simulate a particular real world application. In contrast, a high degree of knowledge moderation reduces the requirements and allows for game mechanics that represent complex knowledge rules with generalized and intuitive interactions. For instance, a driving simulation can allow for an individual utilization of the clutch but also automatically include it during a shifting process. In the former version, two separate game mechanics are required while in the latter implementation one game mechanic combines both activities resulting in a more simplified knowledge presentation. Thus, knowledge mediation also scales the level of abstraction as it allows for a direct encoding of non-moderated knowledge rules in game mechanics that integrate and combine several sets of rules to achieve an intuitive application. However, the design of the game mechanics depends on the type of knowledge. Procedural knowledge requires a skill-based human performance training and declarative knowledge requires a learning on the rule-based level. Hence, to achieve an efficient knowledge
learning, the gamification metaphor’s player-bound game mechanics need to be of the corresponding type (see Table 1).

The knowledge presentation using the Gamified Knowledge Encoding can achieve implicit learning yielding a subconscious acquisition and learning of complex knowledge [67]. For this purpose, the Gamified Knowledge Encoding’s moderation and mediation has to be adjusted in such a way that the resulting gameplay demonstrates the underlying principles in a very intuitive way that can subconsciously be internalized by the player [68]. For instance, a virtual agent could demonstrate the handling of a specific machine. As a result, players learn complex knowledge by repetitively executing the used game mechanics and observing the results of their actions.

4.3. Optimal Knowledge Learning

Working with the Gamified Knowledge Encoding allows for the development of serious games that fulfill the conditions for optimal learning [19]. Interacting game mechanics that encode a serious game’s learning content automatically provide learners with immediate feedback about the correctness of their inputs. Adjusting the learning content’s degree of realism, i.e., performing a knowledge moderation, achieves highly motivating flow, a requirement for pre-existing knowledge and an ideal learning curve. Finally, the repetitive requirement to execute the gamification metaphor’s game mechanics during the gameplay establishes a periodical knowledge application.

In conclusion, the Gamified Knowledge Encoding describes a direct encoding of learning contents in game mechanics as well as the resulting learning process (see Figure 5). The knowledge gets segmented into coherent sets of rules which are mapped to game mechanics. The mapping process includes a mediation, i.e., the design of the game mechanics, and a moderation, i.e., the scaling of the level of abstraction, of the knowledge. The interaction between at least one game-bound and one player-bound game mechanic generates a learning affordance for the knowledge. Player-bound game mechanics require the application of the knowledge, whereas game-bound game mechanics provide learners with feedback or demonstrate the encoded principles. The application of knowledge takes place on a rule-based or skill-based level of human performance. Subsequently, learners receive immediate feedback about the results of their actions and hence about their learning progress. Learners compile a mental model for the learning content during the gameplay. The mental model ultimately allows for an application of the knowledge on the knowledge level, i.e., transferring it from the serious game to a real
Figure 5: The Gamified Knowledge Encoding describes the process of knowledge encoding and learning using game mechanics.
world context. The game mechanics that encode the knowledge’s rules and interact with each other act as metaphors for the learning content. A *gamification metaphor* defines a knowledge’s *gamified metamodel* which can be fully internalized in the form of *mental models*. The Gamified Knowledge Encoding model already was used for the development of effective serious games [2, 69].

5. Analysis of Kerbal Space Program

KSP consists of seven core game mechanics, of which three are player-bound and four are game-bound game mechanics. KSP also provides other game mechanics, such as currencies, a tech-tree, upgradeable buildings, and contracts. These game mechanics realize the career mode and are not encoding any orbital mechanics related knowledge. Working with the Gamified Knowledge Encoding, the core game mechanics of KSP are analyzed in respect to the encoded knowledge to predict their learning outcome when executed during the gameplay. The analysis follows the concept of identifying human skills being required and hence trained by game mechanics [23].

For predicting the learning outcome, the Gamified Knowledge Encoding is used in reversed order in a three-step process. 1) The analysis starts with an identification of the learning affordances as well as the respective game mechanics that encode specific knowledge rules. This is achieved by analyzing the gameplay, i.e., finding phases that either require or demonstrate the application of specific knowledge. These phases are then examined in respect to the game mechanics and their internal knowledge rules. 2) Subsequently, the individual gamification metaphors are identified based on this mapping. To identify the gamification metaphors, the game mechanics are analyzed in respect to the interactions with other game mechanics requiring or demonstrating the same knowledge. 3) Finally, the learning outcome is predicted based on the gamification metaphors. The predicted learning outcome depends on the knowledge’s gamified metamodel, i.e., the total of all encoded knowledge rules, which can be internalized as mental models. In its current form, however, the Gamified Knowledge Encoding cannot quantify the learning outcome. Instead, it predicts the learning content that can fully be acquired when playing a game.
5.1. Player-bound Game Mechanics

**GM01: Assembly of own spacecraft.** As Figure 1 depicts, this game mechanic allows players to construct spacecraft out of a collection of parts (GM06). Aside from designing spacecraft, KSP challenges players to assemble a rocket that is powerful enough to overcome the drag of the atmosphere and the gravitational pull of the planet. Designing such a capable rocket requires a basic understanding of a typical rocket’s ascent phase and the concept of separating a rocket into different stages. GM01 requires the application of the ideal rocket equation as changing a rocket’s mass, payload or amount of fuel affects its performance. Thus, this game mechanic helps users to not only apply, but also to visualize this knowledge.

**GM02: Controllable spacecraft.** GM02 allows for a direct control of the spacecraft to perform orbital maneuvers with them. This game mechanic requires the application of the encoded orbital mechanics rules (GM05).

**GM03: Spacewalk.** Players are able to conduct spacewalks with their astronauts and to control them from a third person perspective. As astronauts are similarly affected by the physical principles, this game mechanic also requires the application of the encoded orbital mechanics rules (GM05).

5.2. Game-bound Game Mechanics

**GM04: Explorable solar system.** The solar system consists of a star and seven planets, of which four are orbited by at least one moon. During the gameplay, players can visit those celestial bodies with their spacecraft and try to land on them. Hence, this game mechanic provides players with potential goals they can fulfill. At the same time, GM04 provides information about the celestial bodies’ characteristics, e.g., mass and existence of an atmosphere. These information are needed to successfully calculate spaceflight maneuvers like a Hohmann transfer.

**GM05: Realistic physics engine.** GM05 simulates the underlying laws of nature, e.g., gravity and drag when flying through an atmosphere, and determines the behavior of the spacecraft based on the encoded principles of orbital mechanics.

**GM06: Technical data.** GM06 provides technical data for each individual part available for the assembly of own spacecraft (see Figure 6). Working with the ideal rocket equation, this allows for a calculation of a spacecraft’s performance. For determining the performance, the equation requires the mass of the fully fueled spacecraft, the empty spacecraft, and the specific impulse of the used engine to determine its performance. Internally, the
physics engine uses the technical data to compute the results of a player’s spacecraft designs (GM05).

Figure 6: Inside of the vehicle assembly screen, KSP displays technical information about each individual spacecraft part.

**GM07: Orbital map.** As Figure 2 depicts, the orbital map displays the current trajectory and orbital parameters of a spacecraft. This game-bound game mechanic not only provides users with a visual feedback about the outcomes of their orbital maneuvers, but also puts the orbital elements into context. In this way, GM07 visualizes the effects of the encoded knowledge rules and assists learners in compiling a mental model for them.

5.3. **Gamification Metaphors**

KSP provides two gamification metaphors: 1) the ideal rocket equation gamification metaphor and 2) the orbital mechanics gamification metaphor.

The ideal rocket equation gamification metaphor consists of GM01, GM05, GM06 and GM07. GM01 requires the actual application of the ideal rocket
equation by assembling new spacecraft out of the available spacecraft parts. These parts have unique technical properties (GM06) and hence determine a spacecraft’s performance (GM05). The achieved performance then is tried out in the simulation phase. It allows players to launch their spacecraft and to follow their trajectories on the orbital map (GM07). GM07 ultimately demonstrates the effects and the validity of a player’s spacecraft designs.

The orbital mechanics gamification metaphor consists of GM02, GM05 and GM07. GM02 requires players to execute orbital maneuvers following the grounding physical principles (GM05). For instance, by executing a pro-grade burn, i.e., a burn towards the direction of flight, players increase the altitude of the spacecraft’s orbit. GM07 then visualizes and demonstrates the effects of these spaceflight maneuvers by automatically changing the displayed trajectory based on a player’s inputs.

5.4. Prediction of Learning Effects

A typical gameplay session of KSP starts with a player’s intention to reach a specific destination in the virtual solar system. This requires the design of a new spacecraft capable of fulfilling the self-determined goals, i.e., it creates a learning affordance. Subsequently, players change to the simulation phase, try to complete their missions, and receive feedback about the correctness of their approaches. For instance, a player might intend to fly to the nearest moon, land on it and fly back home. This challenges players firstly to determine the needed performance and secondly to design a spacecraft fulfilling the requirements. Players validate their designs in the simulation phase by executing their missions.

Based on the analysis of KSP’s gamification metaphors, the gameplay creates learning affordances for the ideal rocket equation, i.e., designing capable spacecraft, and orbital mechanics, i.e., determining and executing correct maneuvers. Therefore, we predict a development of an in-depth understanding of the ideal rocket equation and orbital mechanics when playing the game. All player activities related to designing spacecraft will result in a learning of the ideal rocket equation. All activities related to conducting a space-going mission, e.g., flying to a different celestial body, will lead to an internalization of the knowledge of orbital mechanics. KSP requires the application of the encoded knowledge rules and subsequently provides audiovisual feedback. This feedback not only informs players about the effects of their actions, but also demonstrates the encoded underlying principles. As a result, players acquire new knowledge during the gameplay and practice its application.
6. Methods

Based on the theoretical considerations in Section 2, Section 3 as well as Section 4 and the game mechanics analysis in Section 5, the present study is guided by the following hypotheses (H):

H1 Players learn new knowledge about the ideal rocket equation and orbital mechanics by playing KSP.

H2 Utilizing KSP as an educational tool to visualize and to verify space-flight problems results in an increased learning outcome to traditional learning approaches.

H3 Utilizing KSP as an educational tool results in a higher motivation to practice the encoded knowledge in comparison to traditional approaches.

While H1 addresses the verification of the correctness of the learning outcome prediction, i.e., it bases on the identified gamification metaphors, H2 and H3 are aimed at analyzing KSP’s potential to assist the learning of orbital mechanics.

6.1. Experimental Design

To verify the hypotheses, we conducted a user study consisting of two phases. The study was designed to 1) confirm the educational effects of playing KSP and to 2) examine the learning as well as motivational effects when using it as an educational tool. This approach was chosen as it not only tests for the correctness of the learning outcome prediction, but also allows for an analysis of KSP’s potential to assist the learning of orbital mechanics as well as a comparison of the game’s educational effects to traditional methods. Hence, the second phase of the study tests for the effectiveness of using KSP as a learning method, i.e., it allows for a quantification of the learning outcome, and examines the applicability of using it in a class-based training course. For conducting the study, we offered an optional KSP-based class to aerospace students who participated in an ”Introduction Into Spaceflight” lecture. The assignments given in the KSP class were aligned with the assignments of a curricular class to ensure for a comparability. The curricular class provided traditional paper-based assignments and hence acted as a control group for the present experiment.
6.1.1. Phase 1: Learning by Gaming

Phase 1 took place during the first two weeks of the lecture period and had to be finished before orbital mechanics were presented and discussed in the lecture. This phase consisted of two 90-minute sessions which took place in two consecutive weeks. At the beginning of the first session, the participants were introduced to KSP’s general gameplay and the game controls. Subsequently, the participants were given specific tasks (see Table 3). Each assignment ensured a utilization of both gamification metaphors. The assignment of the first week required the participants to design a spacecraft and to launch it into an orbit around the home planet Kerbin, i.e., an Earth-like planet in KSP’s fictive universe. The second week’s assignment challenged the participants to design a new spacecraft and to fly it to the Mun, i.e., the moon that orbits Kerbin.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Session</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Achieve an orbit around Kerbin</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Fly to the Mun</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Delta-v calculation, rocket staging</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Delta-v calculation, rocket staging, thrust to weight ratio</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Computation of orbital maneuvers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Changing apoapsis, periapsis and inclination</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Geostationary orbits:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Calculating the orbit’s altitude</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deploying a spacecraft in this orbit using a Hohmann transfer orbit</td>
</tr>
</tbody>
</table>

During the study’s first phase, the advisors were not allowed to assist the participants in a direct way or to provide them with information about orbital mechanics. However, the participants were allowed to conduct research on the internet to find useful information about orbital mechanics or spaceflight procedures. Although this was an option, conducting research on the internet was not mandatory as the participants were also allowed to play the game by ‘trial by error’. The participants were allowed to continue playing the game between the two lab sessions as assembling a spacecraft in KSP is a very time intensive task, especially for new KSP players.
This experimental design ensured that the participants’ knowledge gain on orbital mechanics was mainly caused by playing KSP. The design also allowed for an analysis of KSP’s motivating effects to search for additional information to play the game more efficiently and to learn more about the presented spaceflight topic, i.e., tangential learning.

6.1.2. Phase 2: Educational Tool

Phase 2 began after orbital mechanics were discussed in the lecture. During this phase, the participants practiced their orbital mechanics knowledge with similar assignments to the ones used in curricular class-based learning (see Table 3). However, in contrast to the traditional paper-based assignments, the KSP group utilized the game to visualize and to validate the assignments as well as their self-obtained computational results.

The second phase consisted of four 90-minute sessions. Each session began with the discussion of the previous task’s sample solution and the presentation of a new assignment. After initial questions were answered, the participants began to solve the assignments and had the chance to discuss further questions with the advisors. These four sessions took place every other week to align with the progress in the lecture and in the traditional class. Also, this design was implemented to give the participants enough time to visualize and to solve the assignment in KSP. The assignments were made available via the university’s learning management system to allow participants to solve the tasks in the case they missed one of the lab sessions.

6.2. Measures

To validate our hypotheses, we measured the learning effectiveness and learning quality when playing KSP.

6.2.1. Effectiveness

During Phase 1, the learning outcome of playing KSP was measured with a pre-test post-test experimental design. Both knowledge assessment tests were designed to be of equal difficulty and to assess the knowledge encoded in KSP (see Section 5). They consisted of 9 exercises assessing a participant’s knowledge on the ideal rocket equation and on orbital mechanics.

The effectiveness of KSP as an educational tool during Phase 2 was measured with a final knowledge assessment test consisting of 3 complex orbital mechanics assignments. Students who visited the curricular class were invited to take part in this test to form a control group. The participants were able to obtain a maximum of 30 points in the test.
6.2.2. Learning Quality

At the end of Phase 1, the learning quality was measured with a short questionnaire consisting of the following questions:

1. Did you enjoy playing KSP?
2. Did you learn new facts about orbital mechanics during the gameplay?
3. Did you do additional research to understand a specific rocket part or to complete the assignments?
4. Did you do additional research to build more efficient rockets or to solve the assignments in a more efficient way?

At the end of Phase 2, the learning quality was measured with a short questionnaire consisting of the following questions:

1. Did you enjoy playing KSP?
2. Did you learn new facts about orbital mechanics during the gameplay?
3. Did you use KSP to visualize or test certain facts presented in the lecture?
4. Was the KSP-based class interesting?
5. Would you like to see KSP being implemented as a learning environment in future classes?
6. Were the KSP-based assignment more engaging than traditional paper-based assignments?
7. Do you think that KSP is a useful tool to visualize and to test space-flight related problems and facts?

Question 4 to 7 use a 5-point Likert scale (1 = completely disagree, 5 = fully agree).

6.3. Technology

The participants played the free demo version of KSP (based on version 0.18.3) on their own computers. In contrast to the game’s full version, the demo only provided a limited selection of spacecraft parts which made the design process simpler for new players. Participants who owned the full version were allowed to use it instead of the demo. Using the own computers was critical as most of the assignments were too complex to be completed during a single lab session.
6.4. Participants

The KSP-based class was offered as an alternative optional class to the participants of the lecture “Introduction Into Spaceflight” held at the University of Würzburg. All participants were enrolled as freshmen in the Bachelor program of Aerospace Informatics. In total, thirteen participants (12 males, 1 female) volunteered to take part in the study. All of these participants had previous experience with computer games, 7 participants reported to play computer games on a regular basis, and 2 participants had played KSP before.

7. Results

7.1. Educational Effects of Playing KSP

7.1.1. Phase 1

The two participants who reported to have played KSP before were removed from the results of Phase 1. In the pre-test, they achieved a score of 76.11% and 94.44%, respectively. Thus, their previous gameplay already resulted in a compilation of a mental model for the encoded knowledge.

<table>
<thead>
<tr>
<th>Test</th>
<th>Mean Result (%)</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>43.69</td>
<td>23.31</td>
<td>8.33</td>
<td>71.67</td>
</tr>
<tr>
<td>Post</td>
<td>70.12</td>
<td>13.70</td>
<td>42.04</td>
<td>93.70</td>
</tr>
</tbody>
</table>

The new KSP players (n = 11, 1 female, 10 males) yielded a mean result of 43.69% (SD = 23.31) in the pre-test. In the post-test, they scored a mean result of 70.12% (SD = 13.70) as Table 4 and Figure 7 display. Thus, they achieved a mean knowledge gain of 26.43% (SD = 15.97). Computing a paired t-test and Cohen’s d revealed a significant improvement in the participants’ knowledge with a very large effect size (t(10) = 5.49, p < 0.001, d = 1.65). Aside from the two game sessions in the lab, the new KSP players played the game for additional 207.27 minutes (SD = 98.09) based on self-report. Calculating Pearson’s correlation revealed a significant correlation between the time played and the knowledge gain (cor = 0.76, p = 0.007).

Five of the eleven new KSP players were frequent computer game players and achieved a mean knowledge gain of 29.22% (SD = 17.17). They played
the game for additional 216 minutes ($SD = 109$) on average between the two lab session. The remaining six participants yielded a mean knowledge gain of 24.11% ($SD = 16.13$). These participants played KSP for additional 200 minutes ($SD = 97.98$) on average between the two sessions. A two sample t-test revealed no significant difference in respect to the knowledge gain between both groups ($t(9) = -0.51, p = 0.623$). This indicates no moderating effect of previous computer game experience on the knowledge gain.

Figure 7: Comparison between pre-test and post-test spaceflight knowledge assessment results of new KSP players ($n = 11$), error bars denote the standard deviation.

7.1.2. Phase 2

Table 5: Overview of the Final Knowledge Assessment Test Results at the end of Phase 2

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean Points</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>All participants</td>
<td>21</td>
<td>12.81</td>
<td>7.41</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>KSP Group</td>
<td>10</td>
<td>14.00</td>
<td>8.93</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Control Group</td>
<td>11</td>
<td>11.73</td>
<td>5.93</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>KSP players</td>
<td>4</td>
<td>14.75</td>
<td>4.65</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>Non-KSP players</td>
<td>7</td>
<td>10.00</td>
<td>6.19</td>
<td>2</td>
<td>17</td>
</tr>
</tbody>
</table>

The final knowledge assessment test was completed by 21 students (3 females, 18 males) of which 10 belonged to the KSP group. Three participants
dropped out between the beginning and the end of Phase 2. Four of the control group students reported to have independently played KSP. As the overview Table 5 displays, the KSP group achieved a mean result of 14 points ($SD = 8.93$) and the control group scored an average result of 11.73 points ($SD = 5.93$). A two sample t-test was applied, but no significant difference between the two groups could be found ($t(19) = 0.69, p = 0.5$).

The KSP group had the greatest difference in the performance with a range of 25 points. One participant of the KSP group achieved the worst result of the test, four participants of the KSP group achieved a result above 20 points and two of them even achieved a result above 24 points. The best participant of the control group achieved a result of 21 points and was a KSP player based on self-report. The subset of the control group students, who reported to have independently played KSP, achieved a mean result of 14.75 points ($SD = 4.65$). The seven remaining students, who never played KSP, achieved a mean result of 10 points ($SD = 6.19$). A one-way ANOVA was applied to compare all three groups, but no significant difference was found ($F = 0.75, p = 0.49$).

7.2. Learning Quality

7.2.1. Phase 1

All thirteen participants agreed that they enjoyed playing KSP (Q1) and that they learned new facts about orbital mechanics (Q2). Ten of them also reported that they performed research on orbital mechanics to develop a better understanding of the encoded spaceflight knowledge, thus allowing them to complete the two tasks given during Phase 1 (Q3). Nine of them reported that they did research to build more efficient rockets or to complete a task in a more efficient way (Q4).

7.2.2. Phase 2

All ten participants agreed that they enjoyed playing KSP (Q1) and that they learned new facts about orbital mechanics (Q2). Nine of them reported that they utilized KSP to test and/or to visualize facts they learned in the lecture (Q3). The question (Q4), if the KSP tutorial was interesting, received an average rating of 4.4. The question (Q5), if they like to see KSP as a learning method in future learning sessions, received an average rating of 4.4. The question (Q6), if the KSP related tasks were more engaging than the regular assignments, received an average rating of 4.1. The final
question (Q7), if KSP is a useful tool to visualize problems related to orbital mechanics, received an average rating of 4.4.

8. Discussion

8.1. Educational Effects of Playing KSP

8.1.1. Phase 1

The participants achieved a significant gain in knowledge during their first hours of playing KSP. In particular, they acquired knowledge on the ideal rocket equation and on orbital mechanics. The study also revealed a strong correlation between the playtime and the knowledge gain. The two knowledge assessment tests were designed to assess the knowledge encoded in KSP’s gamification metaphors. Hence, the test results validate the learning outcome prediction (see Section 5). The active participation led to a learning effect as defined by the Gamified Knowledge Encoding. During their gameplay, participants repetitively practiced the application of the encoded knowledge and gained expertise with it [6, 64]. This resulted in a compilation of mental models [11, 12]. The correlation between the playtime and the knowledge gain supports this definition of the learning process. The longer the participants played the game, the better they scored in the post-test.

The strong educational effect is explainable by the general structure of KSP and the resulting initial gameplay hours. KSP is a spaceflight simulation game that features a steep learning curve. Players must develop a basic understanding of the two main knowledge packages encoded in KSP’s gamification metaphors to reach space and to enter an orbit with one of their self-designed spacecraft. Only when new players have developed a basic understanding of this knowledge, they can successfully launch a virtual rocket into an orbit. While new players are progressing towards this goal, they subconsciously internalize the encoded knowledge by observing the results of their actions.

Therefore, hypothesis H1 is supported. Playing KSP led to an acquisition of knowledge about the ideal rocket equation and orbital mechanics. The results also confirm the learning outcome prediction guided by the Gamified Knowledge Encoding.

8.1.2. Phase 2

The test results of phase 2 revealed no significant difference in the learning outcome of the KSP group in comparison to the control group. Although
a lack of statistical significance does not imply an equivalence, the results indicate that KSP has a similar learning effect to traditional learning methods using paper-based assignments. This provides an initial quantification of the acquisition of knowledge using game mechanics. When comparing the descriptive statistics, KSP indicates a trend of being the more effective learning method. The three best results in the test were scored by participants of the KSP group. Moreover, some of the control group participants have independently played KSP and achieved a mean result that lies above the overall mean. This outcome indicates a potential positive impact of playing KSP on the understanding of orbital mechanics. Playing KSP helped the students to visualize the effects of orbital mechanics which resulted in the compilation of more accurate and detailed mental models. These mental models allowed for an effective knowledge transfer from the practice sessions to the knowledge assessment test.

The huge range in the results of the KSP group participants is explainable by the fact that the second phase of the study suffered from several issues. The date for the lab sessions overlapped with an optional course that started in the middle of the term. This resulted in a drop of the participants during the first and second lab session. In addition, the participants had to prepare themselves for upcoming mid-term exams during the second half of this phase. This resulted in a greatly reduced number of participants in the lab in the last two sessions. In the end, it is possible that the best three participants of the KSP group were present until the very end of Phase 2. The participants who achieved a result below average potentially have never visited one of the Phase 2 lab sessions or tried to solve the assignments at home. This aligns with the gamified learning process. For an effective gamified learning, players have to play the game, i.e., execute the player-bound game mechanics to apply and hence practice their knowledge. However, if a learner avoids playing the game, then no gamified knowledge learning can occur. The best three participants might have played the game throughout the entire Phase 2 whereas the participants who yielded a result below average rarely or never played KSP. This is supported by the outcome that participants of the control group who played KSP independently achieved a result above the overall mean. If this assumption is true, then KSP would greatly enhance the learning outcome. Unfortunately, due to the requirements of the aerospace informatics department, a completely anonymous test was written, thus no validation of these assumptions is possible.

Therefore, hypothesis H2 cannot be verified as there is no clear evidence
for a better learning outcome on the side of the KSP group. Nevertheless, the results indicate a positive impact of playing KSP on the learning outcome that is beneficial for future aerospace classes.

8.2. Learning Quality

At the end of both phases, all participants reported to have enjoyed playing KSP and to have acquired knowledge on orbital mechanics. They additionally reported to have been inspired by playing KSP to search for additional information about orbital mechanics. Finally, they used KSP to visualize spaceflight problems that were discussed in the lecture to develop a better understanding of them.

The participants enjoyed the optional KSP-based class and would like to utilize the game as a learning environment in future courses. Furthermore, the participants reported that using KSP as a tool to verify self-obtained computational results was enjoyable and more interesting than solving paper-based assignments only.

Altogether, this revealed a higher motivation to practice the knowledge and hence a higher learning quality when implementing KSP as a learning method. Therefore, hypothesis H3 is supported.

8.3. Overall Effectiveness

In conclusion, playing KSP achieves a significant knowledge gain on the ideal rocket equation and on orbital mechanics. KSP encodes these two learning contents in its game mechanics. Playing the game, i.e., executing player-bound game mechanics to interact with the virtual environment and observing the results of own actions, leads to a repetitive application of the encoded principles and hence in an acquisition of knowledge. In comparison to a traditional paper-based learning method, KSP yielded a similar learning outcome and achieved a higher motivation to tackle the assignments. Hence, KSP represents a very effective learning method that not only allows learners to visualize spaceflight-related principles, but also to validate self-obtained computational results. This visual demonstration supports the compilation of mental models for the learning content. These mental models ultimately allow for a training transfer from KSP to other contexts, e.g., the knowledge assessment test. Therefore, the study’s results confirm the prediction of the learning effect and the learning process as defined by the Gamified Knowledge Encoding.
While this outcome contributes to the overall validation of the Gamified Knowledge Encoding model, it also creates the need for future research. Working with the model, the analysis of KSP identified the game’s gamification metaphors. Based on the identified gamification metaphors, the learning effects of playing KSP were predicted. To evaluate the correctness of the analysis, the present study only evaluated the learning effects of the overall gameplay. Despite confirming the predictions made, it generates the need to isolate the gamification metaphors and to individually assess their educational effects. Therefore, future work needs to evaluate the learning outcomes of specific gameplay phases, e.g., assembling and launching rockets, to fully validate the model’s potential for a learning effect prediction.

9. Conclusion

This paper analyzed the structure of KSP using the Gamified Knowledge Encoding. The model identified relevant game mechanics that encode orbital mechanics knowledge as their rules, thus creating gamification metaphors for the learning content. Based on the identified game mechanics, we predicted the learning effects of playing KSP.

In a user study, we tested KSP’s learning effects to validate the predictions made with the Gamified Knowledge Encoding. Participants firstly played KSP in a pre-test post-test setting and secondly utilized it as an educational tool in a class-based learning scenario. The study revealed that KSP effectively educates players in orbital mechanics and even motivates them to search for additional information to successfully and efficiently play the game. When used as an educational tool, KSP achieves a similar learning outcome to a traditional paper-based learning method. While playing the game, the participants reported a high motivation to tackle the assignments. In this way, knowledge learning using KSP yields a high learning quality. KSP allows for a visualization of spaceflight relevant problems that would otherwise be hard to demonstrate due to the high costs and risks of a real world demonstration. Thus, KSP can be recommended as a supplementary educational tool for grounding aerospace courses. Finally, the results of the present study indicate the Gamified Knowledge Encoding’s potential to predict the learning effects of serious games.

Future research is needed to validate the findings and to examine the learning effects of KSP when used as an educational tool under more controlled conditions. Also, a future research goal is to further analyze the
educational effects of game mechanics and to validate the process of gamified knowledge encoding. The Gamified Knowledge Encoding-driven analysis of KSP identified the game’s gamification metaphors. Working with the model, this identification process led to a prediction of the learning effects. However, instead of individually analyzing the gamification metaphors, the present study focused the learning effects of the overall gameplay. For validating the Gamified Knowledge Encoding’s potential to predict a game’s learning outcome, it is of high importance to isolate identified gamification metaphors and to assess their educational effects.

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Declarations of interest: none

References


