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Digital educational escape game design for STEM higher education

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In higher education, lecturers experience difficulties motivating their students. Within the scope of this project, learning outcomes are intended to be enhanced by an innovative teaching and learning method: digital educational escape games. Exploring the design of digital escape games as a modern and constructivist approach to enhance teaching and learning in STEM (science, technology, engineering, mathematics) higher education, this paper outlines evidence-based research based on semi-structured expert interviews and qualitative content analysis. Experts' insights into these thematic areas provide valuable perspectives on how digital escape games can effectively contribute to the teaching and learning experience in STEM disciplines. The results show expert opinions regarding key didactic aspects like the integration of educational content and learning processes into game design. It was found that the didactic and educational aspects of a game are inextricably linked and cannot be separated. In order to create an effective educational game, it is essential to establish the learning objective as the foundation for the game's narrative. In addition to the consensus on the integration of didactics and games, there were also aspects on which educators and learners held opposing views. Hence, controversially discussed game design elements need to be subject of further research.

KEYWORDS

escape game, gamification, serious game design, innovative teaching, digital learning, university, STEM

1 Introduction

University lecturers are faced with the challenge of actively encouraging student participation in lectures and offering attractive courses for students (Reeves and Reeves, 2015; Fthenakis and Walbiner, 2018). One strategy is to modify teaching and learning programs in a manner that enhances the appeal of the learning process (Harris-Huemmert et al., 2018). Approaches that are cooperative, interactive and digital have become established in the field of research. The objective is to encourage students to engage actively with the lecture material (Kerres, 2018; Bencsik et al., 2021; Harari et al., 2022).

One such approach is that of gamification, which is defined as the application of typical game elements and mechanisms in a non-game context, such as in educational or work environments (Deterding, 2011). A related concept is that of game-based learning, which involves the utilization of actual games or specially designed educational games with the objective of achieving specific outcomes (De Carvalho and Coelho, 2022; Zhang and Yu, 2022). Such games, which are designed with an educational objective in mind, are commonly referred to as serious games (Cheng et al., 2015).

Gamification and game-based learning are cooperative, interactive and digitally feasible teaching and learning methods that activate students in a playful manner and encourage them to learn (Cheng et al., 2020; Bencsik et al., 2021). Both formats support problem-based, constructivist, and interactive learning, thereby promoting learning to a greater

extent than traditional lecture formats or text-based work (Bassford et al., 2016). Such methods appeal to the learner's interest, thereby activating intrinsic motivation. It can therefore be concluded that these approaches are compatible with the self-determination theory (Deci and Ryan, 1993; Silva et al., 2021). Deci and Ryan's self-determination theory stipulates that individual motivation and psychological well-being are enhanced by the need for autonomy, competence and social integration. Intrinsic motivation is considered the archetypal example of self-determined behavior (Deci and Ryan, 1993).

Based on these promising characteristics of gamification and game-based learning, the following chapter outlines these didactic approaches.

2 Literature review

2.1 Gamification and game-based learning

Since 2010, researchers have been working on gamification and game-based learning, focusing on definitions as well as classifying game design elements (Nacke and Deterding, 2017). The following table illustrates the game elements identified in the relevant literature as well as their interrelation with the components of the self-determination theory.

Table 1 shows the three self-determination theory components, autonomy, competence and social integration. Game design elements addressing students' autonomy are activities, especially when freely chosen and avatars, badges, quests and storytelling. Badges, inventory, leaderboards, a level system, different quests and scores as well as virtual goods address students' competence perception. Social integration can be addressed by means of badges, leaderboards, teams and multiplayer games as well as communication with other users in the form of comments and likes. It can be concluded that badges address all three self-determination theory components and are therefore versatile in use.

The following table displays relevant studies investigating gamification and game-based learning, including the aforementioned game design elements.

Table 2 shows relevant studies on gamification and game-based learning conducted in higher education contexts. Most studies examine the impact on learning and motivation. Their findings indicate a positive impact of gamification and game-based learning. It follows that teaching and learning approaches like gamification and game-based learning that stimulate intrinsic motivation are worthy of consideration for use in higher education. Following these approaches, serious games address student intrinsic motivation (Ehrlich et al., 2020).

Other aspects examined are participation and the suitability of gamified approaches for STEM students. Game elements are only sparsely investigated. Existing literature reviews and meta analyses conducted on gamification and game-based confirm that research mainly targeted the impact of gamified learning environments on learners and their motivation (Zhang and Yu, 2022).

Furthermore, researchers addressed the need to further investigate the following aspects:

TABLE 1 Game elements and their interrelation to self-determination theory.

Self-determination theory component	Game design element
Autonomy	Activities Avatars Badges Quests Storytelling
Competence	Badges Inventory Leaderboard Level system Quests Scores Virtual goods (for inventory)
Social integration	Badges Communication (comments, likes) Leaderboard Teams

Source: Hochschulforum Digitalisierung (2021).

TABLE 2 Impact of gamification and game-based learning in higher education.

Author(s), date	Findings
Cheng (2021)	Positive impact on student satisfaction
Egger and Witzel (2022)	Positive impact on student engagement
Ehrlich et al. (2020)	Positive impact on motivation Positive impact on student engagement
Gündüz and Akkoyunlu (2020)	Positive impact on intrinsic motivation Positive and negative impact of competition Positive impact on learning outcome
Huang et al. (2020)	Positive impact on learning outcome
Ishak et al. (2021)	Previous gaming experience is significant for interest Suitable for STEM higher education
Manzano-León et al. (2021b)	Positive impact on learning outcome Negative impact on motivation if only few game elements are used Recommendation: Use numerous game elements to enhance motivation Suitable for STEM higher education
Mora et al. (2017)	Often used without necessary preparation Partly contra productive effects of gamification
Silva et al. (2021)	Positive impact on intrinsic and extrinsic motivation Positive impact on attitude toward learning Positive impact on soft skills and problem-solving abilities

- Process of gamification design (Mora et al., 2017),
- Different game types, investigating game design, potential interactions of learners with the game (Nacke and Deterding, 2017),
- Determinants of motivation (Hamari et al., 2014),
- Individual learning behavior in different game types (Hamari et al., 2014),
- Empirical exploration of expert opinions, e.g., interviews (Seaborn and Fels, 2015),
- Integrated feedback (Lee et al., 2021),
- Time component in combination with learning effectiveness (Lee et al., 2021).

The research gap identified shows that one important research interest is different game types underlying the principles of gamification and game-based learning in higher education contexts. Among several options of serious games like business simulation games and quizzes, digital educational escape games (DEEG) particularly foster self-determined behavior in learning, making them interesting for educational purposes with a high degree of self-motivated and self-determined learning, like higher education (Anguas-Gracia et al., 2021).

2.2 Digital educational escape games

Forming a relatively new field of game-based learning, DEEG are problem-based digital games in which a group of players must solve virtual puzzles by collecting clues in order to open a room that has been locked by challenges within a given time (Wiemker et al., 2015). In their original format, escape games are conducted within a physical room, wherein players must collectively unlock the exit by deciphering clues and completing tasks in real time (Nicholson, 2015). In the context of university teaching, the subject matter is typically integrated into the puzzles in order to be conveyed in a manner that is both playful and disciplinary, while also reflecting a realistic scenario (Molina-Torres et al., 2021).

The objective of DEEG is to facilitate active participation of learners through cognitive engagement, in accordance with constructivist learning (Franco and DeLuca, 2019; Veldkamp et al., 2020a; Veldkamp et al., 2020b; Makri et al., 2021). This should facilitate the intrinsic motivation of learners and result in a state of profound mental engagement, also known as immersion (Cheng et al., 2015; De Carvalho and Coelho, 2022).

Given their promising didactic approaches, DEEG have the potential to be utilized in a multitude of applications, including corporate settings and academia (Ehrlich et al., 2020). However, it is notable that they have not been extensively studied in the context of higher education, while more studies were conducted in high schools (Sanchez and Plumettaz-Sieber, 2019; Lee et al., 2023). The field of DEEG in higher education is a relatively nascent area of research, which is consequently not yet well-developed in terms of the existing literature.

The following table shows an overview of relevant studies and their major findings.

Table 3 presents a comprehensive overview of 15 studies that have been identified in the extant research landscape in the field of DEEG in higher education teaching. The majority of relevant publications have been released since 2020, with one exception (Hämäläinen et al., 2006). While most studies focus on DEEG as learning method for students in the fields of pedagogy as well as healthcare, STEM fields are hardly studied (Rosillo and Montes, 2021). Therefore, the scope of this study is set on the STEM fields to investigate the suitability of DEEG for these study programs.

It is notable that the majority of researchers employ descriptive statistics and variance analyses based on self-assessment questionnaires (Bilbao-Quintana et al., 2021; Borrás-Gené et al., 2022; Rodriguez-Ferrer et al., 2022). Qualitative approaches are a common feature of research methodology applied so far, however, specific information on the methodology is not mentioned by the respective authors (Manzano-León et al., 2021a).

While there is a consensus among researchers that DEEG have a positive effect on learners' perception, motivation, interaction and collaboration, there is still no standardized study situation regarding students' knowledge acquisition. There is controversy as to whether students demonstrate a notable enhancement in their performance or knowledge acquisition when exposed to DEEG. On the one hand, there is evidence that students demonstrate statistically significant improvements in knowledge as a result of engaging with DEEG (Krishnan et al., 2023). Conversely, other researchers have been unable to demonstrate any statistically significant impact of DEEG on students' learning outcomes (Pozo-Sánchez et al., 2022). It is also worth noting that no determinants of learning outcomes have yet been investigated.

2.3 Research gap and study objectives

Based on the current state of research described above, it can be concluded that there is no consensus on how DEEG impact learning outcomes. In addition, game elements of DEEG have been insufficiently investigated. Moreover, extant studies almost exclusively utilize descriptive statistics for data evaluation, underscoring the necessity for a versatile, evidence-based analysis in subsequent research projects. The present research endeavors to address this lacuna by undertaking an in-depth examination of DEEG within the STEM sector. For this reason, the aim of this superordinate mixed-methods project is to explore possible determinants of STEM higher education student learning outcomes when using DEEG. This project pursues several sub-goals:

- Qualitative explorative investigation of game elements with a focus on learning outcomes,
- Qualitative explorative investigation of didactic considerations' impact on learning outcomes and game development,
- Development of a DEEG for STEM higher education,
- Quantitative investigation of the DEEG within the framework of an intervention study.

This paper is part of the overall project and focuses on the first two sub-goals: The explorative investigation of game elements and the exploration of didactic considerations' impact on learning outcomes and game development. These two sub-goals form the basis for the subsequent quantitative study. Hence, the following research question

TABLE 3 Studies on digital educational escape games in higher education.

Author(s), date	Methodology and field	Major findings
Bellés-Calvera (2022)	Questionnaire and descriptive statistical analysis History (n = 29)	Positive impact on motivation Positive impact on knowledge consolidation
Bilbao-Quintana et al. (2021)	Questionnaire and quasi-experimental study Teacher education (n = 238)	No significant difference in learning outcomes Positive impact on motivation Positive: Time management
Borrás-Gené et al. (2022)	Questionnaire and descriptive statistical analysis Marketing (n = 56)	Significant difference in learning outcomes for students with sequential-global learning style
Cunha et al. (2023)	Questionnaire and descriptive statistical analysis Healthcare (n = 73)	Positive impact on ability to work in a team
Hämäläinen et al. (2006)	Interviews and qualitative data analysis Field not specified (n = 24)	Positive impact on ability to work in a team Positive: Avatars
Horn (2023)	Google Analytics Healthcare (58)	DEEG positively perceived Competition positively perceived
Krishnan et al. (2023)	Questionnaire and descriptive statistical analysis Healthcare (n = 337)	Significant difference in learning outcomes Acceptance of DEEG high
Manzano-León et al. (2021a)	Questionnaire and qualitative data analysis Teacher education (n = 56)	Interaction with DEEG positively perceived
Pozo-Sánchez et al. (2022)	Questionnaire and descriptive statistical analysis Teacher education (n = 105)	Positive impact on soft skills No significant difference in learning outcomes
Priesto et al. (2021)	Questionnaire and descriptive statistical analysis Teacher education (n = 42)	Significant difference in emotions while learning
Robrecht (2023)	Questionnaire and qualitative data analysis Engineering (n = 31)	Satisfaction with DEEG
Rodriguez-Ferrer et al. (2022)	Questionnaire and descriptive statistical analysis Healthcare (n = 306)	Inverse relationship between the learning flow and the degree of stigmatization reduction
Rosillo and Montes (2021)	Questionnaire and descriptive statistical analysis Healthcare (n = 106)	Positive impact on communication skills Positive impact on learning perception
Ang et al. (2020)	Questionnaire, no information on data analysis Chemistry (n = 53)	Positive impact on student engagement

arises for this paper: Which design elements of digital escape games promote STEM students learning outcomes?

3 Materials and methods

The aim of this paper focuses on the design of DEEG as a possible determinant of student learning outcomes in higher education with the aforementioned research question: Which design elements of digital escape games promote STEM students learning outcomes?

3.1 Research design

For this reason, a qualitative interview study was conducted with the objective of determining an appropriate design for DEEG in the context of university teaching and possible determinants of student outcomes. Based on the relevant research literature, a guideline was developed and contained the following topics derived from the research gap: the design elements of DEEG, the didactic pedagogy employed, and suitability for STEM students. An explorative approach is suitable for tackling this previously unexamined question. A method that allows for heterogeneous participants is chosen in order to take different opinion leaders into account. This applies to guided expert interviews, as these allow different groups of people to be interviewed. This makes it possible to give space to the individual expertise of the interviewees. Semi-structured guided interviews are deemed an appropriate methodology for the collection of data in explorative qualitative research (Kelle, 2008).

3.2 Interview guide design

The interview guide was developed based on an extensive literature review on DEEG and game-based learning and consists of three sections. The first section served as an introduction, while the main section targeted content-related questions. The latter consisted of questions regarding game development, didactical design and suitability for STEM fields. The third section served as an outro and allowed further discussion.

3.3 Participants

The objective was to conduct interviews with a heterogeneous group of people with knowledge in both gaming and higher education.

TABLE 4 Sample selection for the qualitative interview study.

Roles	Count	Gender
Research associates with teaching assignment	3	Male
Research associates with teaching assignment	2	Female
Students	3	Male
Data scientist (STEM alumna)	3	Female
Professor	1	Male
Commercial DEEG operator	1	Male

Potential interview candidates were identified through an investigation of relevant higher education initiatives and selected based on their demonstrated expertise in both gaming and higher education didactics. The participants selected for this study and their roles are presented in the following chart.

Table 4 shows the sample selection for the qualitative interview study. We selected 11 participants with different backgrounds to acquire different perspectives on game design and student outcomes. The selection comprised game design researchers, professors, software engineers, industry experts, teachers and students. In the literature, it is recommended to include 10 to 20 participants for guided interviews (Döring, 2023), which supports the sample size used in this study. Since we found that in the last interviews the answers of the interviewees were repetitive, this justifies the termination of the interviews as a criterion.

3.4 Data collection and preparation

The interviews were recorded and hosted either online on Zoom, or in person. Consent was obtained for the interview recording and data processing. The participants were interviewed between December 8th and 22nd, 2023, resulting in an average interview duration of one hour. The recordings were transcribed with the program f4x and thereafter analyzed using qualitative content analysis according to Philipp Mayring (2015). This method is based on data-driven, step-by-step coding and used to systematically analyze text material to infer meanings from the context.

4 Results

The transcribed material was analyzed applying the structuring qualitative content analysis according to Mayring with both deductive and inductive coding Mayring (2015). The deductive categories were based on the theoretical framework on which the interview guide is based, while the inductive categories were developed by screening the material. The material was analyzed twice, the second analysis was slightly more detailed and led to 1,218 coded text segments. After screening these results, the coded text segments were categorized as shown in the following table.

Table 5 shows the main categories and their absolute as well as relative frequency. It is noticeable that the first two categories only account for, respectively, 10% of the total distribution. This may be since these topics were used in the introductory part of the interviews. First, the participants were asked about their experiences in the field of university teaching, especially in connection with DEEG. Often, student learning outcomes and the design of these educational games were addressed in this context. Subsequently, the two subject areas learning outcomes and design, were discussed more intensively within the framework of the guideline and thus led to a stronger presence in the interview. The results were subjected to analysis in accordance with the established quality criteria for qualitative content analysis, including intra-coder reliability and standard error. The intra-coder reliability was determined to be 87% and a standard error was found to be 0.06%, which is assessed as a strong concordance (McHugh, 2012).

TABLE 5 Main categories.

Category	Absolute frequencies	Relative frequencies
Challenges in higher education	107	9%
Suitability of DEEG for STEM	123	10%
Learning outcomes with DEEG	243	20%
Design of DEEG	745	61%

4.1 Structural content analysis: results by categories

Furthermore, it should be noted that the course of the conversation often returned to the student learning outcomes with and the design of DEEG when discussing other aspects. It can therefore be concluded that there is a connection between the design of the game as a teaching method and student learning outcomes. This claim is based on the interview results. The following table indicates the results on a deeper level, summarized by category, DEEG element as well as the suspected influence on a construct according to the experts' opinions.

Table 6 shows the suspected effects of both didactic and game design elements, a conclusion that has been reached unanimously by all participants involved in the qualitative interview study. This table presents a summary of the most important findings from the study. Since these findings show the experts' consensus, they provide a foundation for the formulation of conclusions.

4.2 Didactic design considerations

The experts stressed that a DEEG is always to be based on learning objectives. A direct influence on learning outcomes through targeted addressing of learning objectives by the game was implied. Moreover, it is important to communicate the learning objectives for the purpose of transparency toward the learner. All participants agreed that students can be motivated by being transparent about expectations and learning processes. In this context, a briefing is mentioned to enhance transparency when using DEEG. In addition, a briefing facilitates to get started with the game and enhances technology acceptance. The latter was not expected as a possible determinant and resulted from inductive category formation. However, there is evidence in the literature that technology can have an impact on learners, such as cognitive load. Models such as technology acceptance are also used in studies on learning platforms (Liaw et al., 2007). It can therefore be concluded that the literature supports these findings.

TABLE 6 Didactic and game design elements.

Category	Element	Suspected influence on construct according to experts
Didactics	Learning objective	Learning outcomes through targeted addressing of learning objectives
Didactics	Communicating learning objective	Motivation by transparency about expectations
Didactics	Applying competences, repetition	Learning outcomes through repetition of content
Didactics	Embedding content in story	Learning outcomes through recontextualization of knowledge
Didactics	Story	Learning experience through perception, immersion
Didactics	Feedback	Learning outcomes through direct evaluation
Didactics	Game data analysis	Learning outcomes through targeted feedback
Didactics	Briefing	Motivation through transparency about expectations, technology acceptance
Didactics	Debriefing	Learning outcomes through repetition of content
Didactics	Comment function	Acceptance of teaching/learning method
Game	Game progress	Immersion, technology acceptance
Game	Difficulty progression	Learning outcomes through coordinated learning progress, technology acceptance
Game	Paths of varying difficulty	Learning process, motivation
Game	Tutorial	Learning process, technology acceptance
Game	Sequence and variation of puzzles	Learning process, technology acceptance
Game	Hints	Learning process
Game	Single Player	Learning process
Game	Multi Player	Social skills

Feedback is another important didactic element which can easily be applied to a DEEG. Students can receive immediate feedback to their digital input, for example in the form of pop-up windows. It is recommended to use game data to provide individualized feedback and allow assessing students' performance in the game. Educators will then be able to identify individual knowledge gaps and problem areas.

Following that, another important finding is that in a DEEG, students' competences are developed by repeating the learning content throughout the game. Therefore, it is important to embed the learning content in the game as often and in as varied a way as possible. Embedding the learning content in a story with a narrative helps to recontextualize the knowledge. Consequently, storytelling is an important element to get students interested in the game and to keep them interested through an engaging and interesting story.

4.3 Conducive game design elements

In the same context, the importance of varying puzzles and their sequence was mentioned. Keeping students engaged and interested in the game helps both, the learning process as well as technology acceptance. It motivated students to pursue different paths of difficulty and allows them to learn at their individual learning pace. Likewise, difficulty progression is one element that is recommended to use in a DEEG. The experts interviewed stated that it is helpful to start with an easy puzzle and give students the opportunity to get used to the DEEG as a learning format. Increasing the difficulty over the game keeps students interested in the game and enhances their skill development as the learning process is coordinated and thought through.

It is agreed by all participants that DEEG as a learning method are highly suitable for STEM fields due to two main reasons. For one, the scientific path of knowledge allows exercises to be solved using the same strategy, beginning with a problem definition, a hypothesis, execution of a task, observation and an analysis. These steps are usually repeated in every STEM lecture, leading to a good transferability to DEEG logic. In addition, STEM exercise results are often easily measurable and unambiguous, hence easily convertible into a DEEG solution password. While experts consider DEEG to be well suited to STEM students, they do not rule out its use in other subject areas. With an appropriate definition of the learning objectives and structuring of the learning content, the experts consider it possible to use DEEG in other subject areas.

All participants agree that a predefined hint system is important to keep students motivated and offer on-demand support. Thus, it is important to start the game not only with a didactic briefing, but also a game tutorial. Showing how to navigate the game helps technology acceptance as well as the learning process. One potential implementation example could be a chemical laboratory with a leaking toxic substance, which can be neutralized by applying an antidote. The storyline may be enhanced by the fact that students are given only 1 h to produce the antidote before it becomes too dangerous for humans to be in the vicinity of the leakage. In order to produce the antidote, students must utilize learning content on toxic substances and their antidotes in a variety of puzzles in order to find a way to produce the correct substance. The learning content necessary for the exercises can be embedded in a hint system.

A further design element that was discussed is the number of players. All experts concur that escape games are originally a multiplayer activity, although they can be played both individually and in a group in a digital format. The advantages of the multiplayer format include the promotion of social skills such as teamwork and communication skills, as well as the consolidation of the learning content through the exchange with other players. Whereas advantages

of the single-player mode are the flexibility in the game and the ability to follow an individual learning pace.

4.4 Controversially discussed game design elements

While all participants agree on the positive effects of the DEEG elements indicated in Table 6, the impact of some elements are controversially discussed. These three elements whose influence on learning outcomes is the subject of controversial debate among the participants are rewards, competition and timer.

In a digital escape game, rewards like coins and credits can be used to incentivize players to engage in the game. The participants interviewed in this study do not agree on whether to recommend the use of rewards in an educational context. The question of the sense and meaning of such credits arose in the course of the interviews with the three students. While the three students interviewed stated that credits only make sense if they can be used in the game, like to unlock hints, the educators promote rewards as a motivating incentive in a DEEG. Since students are the target group focused on when designing educational games, it is necessary to further investigate this game design element in further research projects.

Similarly, competition and timer have been discussed as questionable regarding their influence on learning outcomes. In general, experts state that competition and timers are helpful for skill development, for instance in sports. These two elements address ambition and competitive spirit, enhancing motivation. In a DEEG, competition and timer can enhance learning outcomes by creating urgency and therefore pushing students to work on puzzles. Experts stated that a DEEG with a timer can simulate an examination environment. For competitive students, this approach may work effectively. In contrast, sensitive students may not respond positively to this approach. The introduction of urgency in a learning environment has the potential to precipitate a highly stressful situation that could prove overwhelming for students, to the extent that they may be unable to complete the assignment. The latter is the worst possible outcome teaching and learning methods and should therefore be avoided. There is evidence in the literature that stress affects the learning process and might impair knowledge retrieval (Vogel and Schwabe, 2016). Considering these arguments, both possible effects of competition and timer in a DEEG, these two elements need to be further investigated.

Interrelatedness of didactic considerations and game design elements.

The following figure illustrates the relationship between didactic and game design elements and their suspected impact on learning outcomes.

Figure 1 shows the relation between didactic and game design elements, illustrating that these two factors are interrelated. Didactic elements form the basis for some game design elements and vice versa, showing the complexity of DEEG as a learning method. The game design elements have a suspected influence on the learning process, the latter mediating the suspected influence on learning outcomes. These suspected impact structures need to be evaluated in further research.

In summary, the expert interviews show a multitude of elements which can have a positive impact on learning with DEEG. On a deeper level, both didactical as well as game design elements have been identified to enhance learning outcomes of students in STEM higher education. While all participants of the expert interviews agree on the helpfulness of most identified elements, there are three game design elements which need to be further discussed: rewards, competition and timer.

5 Discussion

In the light of the aforementioned points, it is evident that the controversially discussed game design elements offer potential for both positive as well as negative effects on learning outcome of students in STEM higher education. These areas have been identified as meriting further investigation. In continuation, this sheds light on the limitations on this interview study. Within the scope of this study, elements for the design of DEEG as a game-based learning approach were investigated regarding their impact on learning outcomes of STEM higher education students.

Using the rule-based analysis following Philipp Mayring's approach, the findings from the qualitative expert interviews offer a comprehensive and nuanced understanding of the perspectives held within the field of DEEG design for higher education purposes. A thorough examination of the data yielded several pivotal themes, which represents the

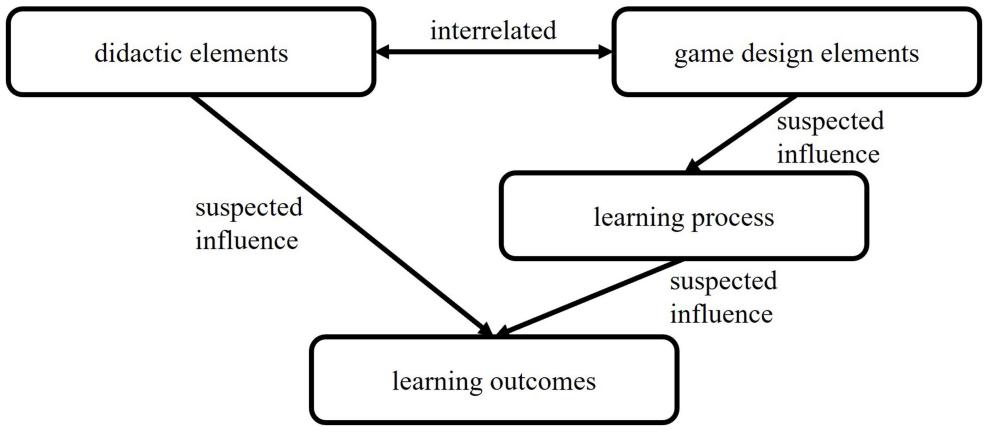

FIGURE 1
Relation between didactic and game design elements.

multifaceted perspectives and experiences of the participants. The conclusions of the interview study can be summarized as follows:

- **Didactical conception and game design are inextricably linked**: Defining learning objectives is the first step of designing DEEG. A game story is to be conceptualized in alignment with the learning objectives in order to keep learners engaged and interested in the DEEG. This finding supports the concept of game-based learning, meaning the game is designed for specific educational purposes.
- **Time, competition and rewards are controversially discussed**: These game design elements are appreciated by some experts regarding their positive impact on learners' extrinsic motivation by incentivizing them. On the contrary, other interview participants stated that pressure is not helpful in a learning environment. Therefore, these three elements are recommended to be subject to future research.
- **Repetition is key**: By repeating learning content in various puzzles throughout the game, students engage automatically with the content in different contexts. Recontextualization of learning content enhances student learning in both expertise and methodological skills. Applying content to different contexts and scenarios enhances employability as well as analytical skills. Moreover, the diversity of puzzles used in a DEEG keeps the game interesting, having a positive impact on motivation.
- **Technology acceptance and learning outcomes are linked**: A noteworthy discovery is that all experts advocate for transparency in the utilization of DEEG in STEM higher education. The sharing of learning objectives and expectations in conjunction with this teaching and learning method encourages students to actively participate in the learning process and to understand how playing a serious game in STEM classes can support their learning outcomes. Moreover, transparency regarding the efficacy of DEEG in STEM higher education classes enables students to comprehend the rationale behind their lecturers' selection of this teaching method, thereby fostering technology acceptance. Once students have accepted the chosen teaching method, it is less likely that they will resist, which ultimately impacts their learning outcomes. It can therefore be concluded that transparency and technology acceptance are pivotal factors for learning outcomes.
- **DEEG are highly suitable for, but not limited to STEM subjects**: STEM subjects often lead to measurable and replicable results, which allows them to be transferred into DEEG puzzles without major adjustments. While STEM subjects show a good fit for DEEG exercise structure, DEEG can also serve as learning method in other subject areas. Consequently, the results of this study can be extended beyond the STEM context.

In conclusion, it can be stated that the didactic pedagogical approaches and the aspects of game design are closely interrelated. This combination is essential for the development of an effective educational game as well as the acceptance of the teaching and learning method. In brief, DEEG are a promising innovative learning method for higher education which is recommended for further implementation.

Nevertheless, the results of this study include controversial results on the suspected impact of game elements of reward, timer and competition on learning outcomes. In the context of previous research, the expert discussion on the topic of time pressure and competition is very interesting. The learners interviewed in this study clearly stated that time pressure as well as competition motivate and encourage them to be better at the game and to learn more. This contrasts with the results of previous studies on gamification and game-based learning in which learners have expressed frustration under time pressure and a counterproductive influence on learning has emerged (Lee et al., 2021; Priesto et al., 2021; Fotaris and Mastoras, 2022; Robrecht, 2023). In contrast, extant studies on DEEG demonstrate outcomes that are concordant with the findings of this study, specifically the potential positive impact of competition and timers (Bilbao-Quintana et al., 2021; Pozo-Sánchez et al., 2022; Horn, 2023). While a difference can be suspected between competition and timer impact on gamification and game-based learning and on DEEG, there is a consensus in previous studies that there is a need for further research into the time component in connection with learning outcomes (Hamari et al., 2014; Seaborn and Fels, 2015; Bilbao-Quintana et al., 2021; Lee et al., 2021). Further implications for future research and limitations of this study are described in the next section.

6 Limitations and implications for future research

It should be noted that aspects outside the scope of this study are not considered and are recommended to be subject to further research. These include, for example, the investigation of other subject areas than STEM or the targeted investigation of the influence of the analyzed game elements on other typical constructs in educational research, such as self-efficacy or cognitive load. Additional recommendations for future research are studies on student performance, long-term investigations and evaluations of the identified elements in quantitative studies. Furthermore, this study does not claim to provide a comprehensive analysis based on multiple data sources. This study is purely qualitative and employs qualitative content analysis of transcribed interview data.

Considering these findings, the practical implications need to be discussed. The recommended DEEG elements, allowing researchers as well as lecturers to evaluate the suspected effects in higher education classroom and their own studies. Regarding the implementation of DEEG in daily lecture practice, it needs to be stated that there are some challenges to overcome. Several resources are needed to develop and maintain DEEG, among others the technical requirements like authoring tools or code environments, internet and hardware availability as well as financial resources for licensing fees. Time constraints and student accessibility need to be taken into account as well. DEEG need to be designed accessible for students with disabilities to avoid exclusion as well as ethically justifiable, considering GDPR. Authoring tools offer support in these affairs and can be a first step toward DEEG development for higher education classes.

Reflecting the methodological approach, it is concluded that the expert interviews offered a variety of insights to the research subject. The involvement of both students and experts in the field as participants in this interview study proved invaluable in providing insights that addressed the research question. In alignment with the methodological approach, it can be posited that qualitative content analysis yielded a multitude of insights pertaining to the research subject. Utilizing an explorative approach allowed us to shed light to previously unexpected areas, including those of transparency and technology acceptance. The insights gained serve to emphasize the complexity of appropriately

designing DEEG for higher education, offering valuable contributions to both academic discourse and practical applications. The results of this study serve as the basis for a subsequent quantitative study in which the possible determinants identified are examined in terms of their influence on the learning outcomes of students.

7 Conclusion

The purpose of this study was to explore DEEG as an innovative teaching and learning method in higher education. More specifically, this study explored the experiences educators have gained applying DEEG to higher education settings. Also, design elements were discussed to shed light on serious game development with didactic objectives in mind. Students' opinions representing the target group have been crucial to exploring the expectations toward DEEG as an effective as well as enjoyable learning method. This study concludes that didactic considerations form the basis for serious game development, on which playful elements such as the story, the puzzles and the structure of a DEEG are built.

This paper has pioneered an investigation focusing on the design elements of DEEG for higher education. Insights on didactical design elements and their suspected influence on learning outcomes are novel and contribute to the knowledge of the peer community. Moreover, the suspected positive impact of game design elements like storytelling as well as the repetitive character of puzzles are key findings of this research. Other elements such as timer, competition and rewards are recommended to be subject of further research. This conclusion agrees with previous studies, as these competitive game design elements need further investigation.

Thus, it can be concluded that DEEG represent a promising learning method for higher education. Nevertheless, the resources required should not be underestimated, not least the time needed to develop the game and technical resources such as laptops for learners and high-speed internet connection. These challenges need to be considered in everyday teaching in order to enable the successful use of DEEG in higher education contexts.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval did not need to be provided by the University of Education Karlsruhe ethics committee, as no underage persons participated in the study. The study was conducted in accordance with the local legislation and institutional requirements. It was stressed to all participants that participation in the interview study was optional. The participants provided their written informed consent to participate in this study.

Author contributions

MG: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. SF: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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