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Termópolis- Deserto de Sadhi: development of a Role-Playing Game (RPG) focused on teaching thermodynamics

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ABSTRACT

Thermodynamics is tied to the study of various forms of energy and their respective transformations, serving as a field of study that permeates several other areas of knowledge. Despite its undeniable importance for understanding everyday phenomena, students show little interest in learning about the subject. Therefore, with the aim of making the teaching and learning process of classical thermodynamics more playful and motivating, this study presents the development of a prototype of an innovative serious game in the format of a tabletop narrative game or RPG (Role Playing Game). The research was conducted using a combination of the Design Science Research and Design Thinking methods, with a focus on the solution space. The game development proved to be a complex process, involving the creation of an entire game universe with its own story and narrative, in addition to the design of all its elements, such as the board, cards and game book. The development stages were organized into ideation, artifact prototyping, and game evaluation. The ideation phase aligned audience needs with educational objectives, using a cartoonish Steampunk aesthetic to merge science and playfulness, creating a visually cohesive and appealing environment. In prototyping, the materialization of the ideas in cards, maps and gamebook highlighted the importance of interactive design and validation of aesthetics and mechanics. Finally, in the game evaluation phase, extremely positive feedback was observed from users who participated in prototype testing, emphasizing aspects such as the design of game elements, the developed universe and narrative, as well as the interaction facilitated by the game. Despite promising results, further adjustments, improvements, and additional testing are still needed to expand its audience and attract new players, especially from the exact and natural sciences.

KEYWORDS

Thermodynamics; Teaching-learning;
Game;
Active methodologies;
Design Thinking

Termópolis- Deserto de Sadhi: desenvolvimento de um Role Playing Game (RPG) voltado ao ensino da termodinâmica

RESUMO

A Termodinâmica está atrelada ao estudo das diversas formas de energia e suas respectivas transformações, sendo um campo de estudo que permeia diversas outras áreas do conhecimento. Apesar de sua inegável importância para o entendimento de fenômenos do cotidiano, observa-se um baixo interesse por parte dos estudantes em aprender sobre o tema. Dessa forma, com o intuito de tornar o processo de ensino e aprendizagem da termodinâmica clássica mais lúdico e motivador, este estudo apresenta o desenvolvimento do protótipo de um jogo sério inovador no formato de jogo narrativo ou RPG (Role Playing Game) de mesa. A pesquisa foi desenvolvida a partir da combinação dos métodos Design Science Research e Design Thinking com enfoque no espaço da solução. O desenvolvimento do jogo mostrou-se um processo complexo, que envolveu a criação de todo o universo do jogo, com sua própria história e narrativa, além do design de todos os seus elementos, tais como tabuleiro, cartas e livro-jogo. As etapas de desenvolvimento foram organizadas em ideação, prototipação do artefato e avaliação do jogo. A ideação alinhou necessidades do público aos objetivos educacionais, usando a estética Steampunk cartoonizada para unir ciência e ludicidade, criando um ambiente visual coerente e atrativo. Na prototipação, a materialização das ideias em cartas, mapas e livro-jogo destacou a importância do design interativo e da validação da estética e mecânica. Por fim, na avaliação do jogo observou-se feedbacks extremamente positivos advindos dos usuários que participaram dos testes do protótipo, destacando aspectos como o design dos elementos do jogo, o universo e a narrativa desenvolvidos, bem como a interação proporcionada pelo jogo. Apesar dos resultados promissores, para expandir seu público e atrair novos jogadores, especialmente de ciências exatas e da natureza, ajustes, melhorias e testes adicionais ainda se mostram necessários.

PALAVRAS-CHAVE

Termodinâmica;
Ensino-aprendizagem;
Jogo;
Metodologia ativa;
Design Thinking

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1. INTRODUCTION

Thermodynamics refers to a field of knowledge that originally focused exclusively on the study of converting heat (energy in motion) into work or power and was directly linked to the development of steam engines, which spurred the advent and acceleration of the first industrial revolution. Over time, thermodynamics expanded to encompass a broader scope, the study of various types of energy and their respective transformations. As a result, this branch of knowledge began to permeate numerous other fields, such as chemistry, physics, biology, and engineering in general, which use the theoretical and practical concepts of classical thermodynamics to explain and elucidate various natural phenomena.

The knowledge associated with thermodynamics is essential for understanding many everyday phenomena, from the energy required to heat a certain amount of water for preparing a delicious cup of tea or coffee to the energy transformations that occur within the human body. Despite the great importance of classical thermodynamics, students often show little interest in learning this subject. Moreover, much of this knowledge is not taught in a way that connects it to the natural phenomena people encounter in their daily lives (SOUZA; FONTES, 2019; SOUSA; GONÇALVES, 2024). Additionally, teaching in elementary schools, high schools, technical schools, and even universities often relies primarily on traditional methods, which involve lecture-based and content-heavy approaches, making learning demotivating and uninteresting for students (PEREIRA et al., 2020; BARROS; LIBERTI, 2024).

Previous studies by the authors indicate that the teaching and learning process of theoretical and practical concepts related to classical thermodynamics faces several obstacles, including: the exclusive use of lecture-based teaching, student demotivation, a disconnect between academic content and everyday life, student disinterest in the topic, and the use of overly abstract concepts and content, among others (NASCIMENTO et al., 2022; NASCIMENTO et al., 2023). In this context, it becomes essential to develop new educational technologies that can be used by professors and students to enhance learning while mitigating the observed challenges in the teaching and learning process.

A promising strategy to address these obstacles in thermodynamics education is the use of serious games. According to Prensky (2001), games captivate people because, in addition to motivation, they offer learning, creativity, satisfaction, pleasure, intense emotional engagement, structure, purpose, flow, ego gratification, adrenaline, social interaction, and various emotions. Moita (2007) states that games have the potential to generate knowledge and develop cognitive skills, improving players' problem-solving abilities and enabling them to reassess values, attitudes, and behaviors through interaction. Schell (2019) adds that experiences based on games evoke unique feelings such as choice, freedom, responsibility, and achievement, and these feelings may not be experienced in other ways. Thus, many researchers see serious games not only as tools to motivate students but also as effective promoters of learning.

Game-based learning methodologies demonstrate that it is feasible to teach academic content through various types of games. Digital games can be used in educational settings as tools to promote knowledge, stimulate playful learning, develop cognitive skills, and serve as motivational resources in the classroom (ARAUJO et al., 2024; ARAÚJO et al., 2024). These tools are particularly appealing to young students. However, a drawback is that these games may lead to excessive screen time, which can result in health issues such as eye strain, insomnia, poor posture, and reduced face-to-face social interaction (TIVERON et al., 2024).

Analog games, such as board games, card games, and puzzles, also play an important role in the teaching-learning process. Their inclusion in education not only broadens pedagogical possibilities, adapting to different learning styles, but also makes the process more dynamic and motivating. In addition to sharing benefits with digital games, such as cognitive skill development and playful learning (RAMIRES et al., 2024), analog games offer unique advantages: they avoid the negative effects of excessive screen exposure and encourage social interaction, cooperation, and teamwork that are essential skills for students' holistic development. From a practical standpoint, analog games also stand out for their accessibility. Formats such as "print and play" allow materials to be printed at home or school, reducing costs and simplifying implementation. This flexibility makes them a more accessible option, capable of reaching a wide audience.

Despite the many advantages of serious games in education, the availability of games designed for teaching classical thermodynamics in higher education, particularly in Engineering, is quite limited. This gap represents an opportunity for the development of new teaching materials. Therefore, creating games that address the principles of thermodynamics in an interactive and playful manner could revolutionize how students learn complex concepts, making them more accessible and understandable while increasing engagement in this fundamental area of Engineering.

In this context, aiming to make the teaching and learning process of classical thermodynamics more engaging and motivating for higher education students, this study seeks to employ Design Science Research and Design Thinking in the development of a prototype for an innovative serious game in the form of a narrative game or RPG (Role-Playing Game), as well as to evaluate it with users. It is worth noting that this study is the result of a multidisciplinary research project conducted by students and professors from the Chemical Engineering program at the Federal University of Southern and Southeastern Pará (UNIFESSPA) and the Design program at the Federal University of Maranhão (UFMA). The resulting artifact of this study is registered with the “Fundação Biblioteca Nacional” (Registration No.: 914.007, Book: 1,783, Page: 269) for copyright protection purposes.

Este é o modelo para a formatação dos artigos para a revista D&T. Todo o modelo está baseado em estilos específicos, como Título 1, Títulos 2, ..., Legenda, Figura. Os autores devem formatar o seu artigo utilizando estes estilos. A seguir, serão descritos os principais elementos do artigo e a sua formatação.

2. APPLYING DESIGN THINKING AND DESIGN SCIENCE RESEARCH TO SERIOUS GAME DESIGN

Design Science Research (DSR) is a methodological approach aimed at creating innovative artifacts designed to solve complex and relevant problems in specific contexts. In the educational field, this methodology combines scientific rigor with creativity in developing practical solutions, such as serious games, that can transform the teaching-learning process.

In the context of classical thermodynamics, a fundamental topic for Engineering but often considered difficult to grasp, DSR provides a structured pathway for designing serious games that integrate interactivity, playfulness, and scientific content. By employing DSR, it is possible not only to develop a game prototype but also to evaluate its effectiveness in terms of gameplay and usability, ensuring that the artifact meets users' needs and promotes more meaningful and engaging learning, overcoming the limitations of traditional methods.

Design Science Research (DSR) is the foundational method for conducting research when the goal is to develop an artifact (DRESCH et al., 2015). DSR seeks to understand a problem and then construct and evaluate new prototypes and products that can transform situations, improving their conditions to more desirable states, thereby bridging the gap between theory and practice (DRESCH et al., 2015). A key characteristic of research using DSR is its focus on solving specific problems, not necessarily seeking an optimal solution, but rather a satisfactory one, since the generated solutions should enable other researchers and professionals to also benefit from the knowledge produced (DRESCH et al., 2015).

Complementing DSR, Design Thinking emerges as a collaborative and user-centered approach, synergistically aligning with DSR's objectives in developing innovative solutions. Design Thinking is defined as a process that spans seven distinct stages, ranging from problem understanding to the final phase, which involves proposing a new artifact and falls within the solution dimension (LEWRICK et al., 2020). The complete Design Thinking process used in this research can be seen in Figure 1.

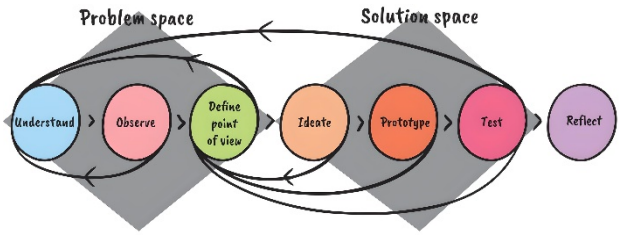


Figure 1 Design Thinking approach. Source: LEWRICK et al., 2020.

Although Design Science Research (DSR) and Design Thinking (DT) have different origins, they share similar phases focused on solving real-world problems. Both begin with the problem space and conclude with the solution space. DT emphasizes that understanding the problem or need (described in DSR) should be done with empathy (focusing on users' perceptions) and by defining a clear point of view. While DSR generates a solution through the development of an artifact, DT strongly emphasizes idea generation and prototyping (WIERINGA, 2014; DRESCH et al., 2015; VAISHNAVI; KUECHLER, 2015; TONOLLI, 2021).

In the context of designing serious games for teaching classical thermodynamics, DT enables a deep understanding of students' and instructors' needs, difficulties, and expectations, ensuring that the final product is effectively engaging. By integrating these two approaches, it becomes possible not only to create an artifact aligned with the scientific principles of thermodynamics but also to ensure its adaptation to the educational context where it will be applied. Thus, the combination of DSR and DT in this study aimed to enhance innovation in the teaching-learning process, transforming educational challenges into opportunities to develop a tool that revolutionizes learning.

3. METHODOLOGY

This research is characterized as an applied and evaluative study, as it aims to develop a serious game to address specific needs in teaching classical thermodynamics and to evaluate gameplay and usability of the created prototype. The research was conducted using a combination of DSR and DT methods to propose a new artifact intended to bring about real-world improvements, considering the needs of a specific group or the users of the proposed prototype. This study focuses on the second phase (the solution space) of a research project developing a serious game about theoretical and practical concepts associated with classical thermodynamics.

3.1 Methodological Stages and Procedures

As an innovation-focused tool aimed at creating new products, processes, and services through an empathetic and user-centered approach, this research employs the Design Science Research (DSR) method combined with the Design Thinking (DT) methodology for the development of a serious game, as outlined in Table 1.

Table 1 Research /., method and proposed approach for study development.

Research Method: Design Science	Approach: Design Thinking
Need identification	Empathy (Understanding and observation)
	Defining a point of view
Proposal of alternatives	Ideation
Development	Prototyping
Evaluation	Testing the proposed prototype
Conclusion	Reflection & feedback

Source: Prepared by the authors.

The solution phase constitutes the second stage of the Design Science Research (DSR) methodology, specifically addressing solution development. The corresponding methodological procedures are systematically outlined in Table 2.

Prior to commencing the game evaluation procedures, all study participants received comprehensive information regarding the Informed Consent Form (ICF). This document explicitly detailed: the complete research protocol and procedures, the absence of any potential risks, physical discomfort, or psychological distress, the assurance of absolute confidentiality and data anonymity. Following a thorough explanation of these provisions, all participants formally and voluntarily attested to their understanding and agreement by providing written consent to participate in the research study.

Table 2 Methodological Procedures Applied in Solution Design.

Phase 02 of Design Thinking: Solution Conception	
Stages	Procedures
Ideation	1. Alignment meetings in brainstorming format with the entire research team via Google Meet® 2. Analysis of games in the same category; research of aesthetic references; presentation of ideas through sketches
Game Narrative Prototyping	1. In-person alignment meetings in brainstorming format with part of the research team 2. Alignment meetings in brainstorming format with the entire research team via Google Meet® 3. Game structuring through rule conception, interactions, characters, and scenarios 4. Discussion of game mechanics, dynamics, and personality
Graphic Design Prototyping	1. Alignment meetings in brainstorming format with the entire research team via Google Meet® 2. Presentation of finalized models (scenario and card prototypes for evaluation)
Preliminary Evaluation of the Developed Game	1. Low-fidelity prototype testing with a mixed team consisting of one external participant and three development team members 2. Systematic observation during prototype testing
User Evaluation of the Developed Game	1. Prototype testing with a group of 11 undergraduate Chemical Engineering students from UNIFESSPA. 2. Systematic observation during prototype testing 3. Prototype analysis using an evaluation criteria checklist, including: gameplay, aesthetics, narrative, mechanics, usability, and educational value
Team Reflection on Findings	1. Alignment of strengths and improvement points

Source: Prepared by the authors.

4. RESULTS AND DISCUSSION

The primary outcome of this research was the development of a serious game in the format of a tabletop narrative game or tabletop RPG, named "Termópolis" by the authors. The game comprises five stages: “Deserto de Sadhi”, “Montanha de Helmholtz”, “Floresta das Almas Perdidas”, “Cidade do Aço” and “Entropópolis”. This study focuses on presenting the first stage, “Deserto de Sadhi”. The research outcomes are presented according to the methodological execution phases.

4.1 Contextualization of the Problem and Viewpoint

During the empathy phase, the authors observed significant challenges in thermodynamics education. Students generally struggle to grasp theoretical and practical concepts related to classical thermodynamics. Prior studies by the authors confirm these observations, identifying key learning difficulties: conceptual definitions of energy types, understanding entropy, applying the first law of thermodynamics to open and closed systems and distinguishing between heat and temperature (NASCIMENTO et al., 2022; NASCIMENTO et al., 2023).

These challenges are not unique to Brazil, international literature corroborates these findings, with studies from various countries reporting similar student difficulties (LOVERUDE et al., 2002; TATAR; OKTAY, 2011; SREENIVASULU; SUBRAMANIAM, 2013; WOLDAMANUEL et al., 2015; SUTARJA; WULANDARI, 2021; BRUNDAGE et al., 2024). To address these issues, the authors developed "Termópolis: Deserto de Sadhi", a serious game that extends beyond question-solving, as in the previous game created by authors (NASCIMENTO et al., 2025). This new game aims to: Create an immersive, motivating learning environment, sustain engagement through flow state mechanics, maintain low production costs for classroom accessibility and target specific user needs through interactive design.

4.2 Idealization and Prototyping

The ideation stage begins with the findings obtained in the empathy phase, as described in Nascimento et al. (2023). Classical thermodynamics covers various theoretical and practical concepts that form the theoretical basis for multiple areas of knowledge, such as: thermodynamic properties of fluids (liquids, gases, and vapors), work, heat, the statement of the first law of thermodynamics, thermal effects, the statement of the second law of thermodynamics and the concept of entropy, thermodynamic cycles, flow process thermodynamics, among others.

However, considering the different specificities and the large volume of content to be covered, the concepts were distributed across five stages of the game, each corresponding to a territory within the kingdom named "Termópolis". The program content of the first stage, titled "Deserto de Sadhi" as well as a summary of the main suggestions defined in the ideation phase, are presented in Table 3.

Table 3 Compilation of Suggestions and General Definitions for the Main Features of the Game “Termópolis - Deserto de Sadhi”.

Game Features	Suggestions and Definitions
Target Audience	1. Undergraduate students enrolled in courses where classical thermodynamics is part of the foundational curriculum.
Program Content	1. Temperature, pressure, and heat; 2. Study of ideal gases: understanding gas behavior under different temperature and pressure conditions; 3. Ideal gas processes: adiabatic (no heat exchange), isobaric (constant pressure), isothermal (constant temperature), and isochoric (constant volume); 4. Heat capacity; 5. Work; 6. Types of energy; 7. Energy transformations.
Game Aesthetics	1. The chosen aesthetic is Steampunk, with game elements featuring a cartoonish style and semi-realistic details.
Game Mechanics	1. Pen and paper; 2. RPG (Role-Playing Game); 3. Hand management; 4. Q&A (Questions and Answers); 5. Narrative choices.
Game Dynamics	1. Survival; 2. Opponent elimination; 3. Problem-solving; 4. Item and resource collection.
Game application strategies	1. Individual use by a single player; 2. Group use by students; 3. Classroom use: a. The game as part of the course’s assessment activities; b. Use as a didactic activity to be conducted in class with student groups; c. During gameplay, students may consult course materials provided by the professor and use a scientific calculator; d. Symbolic prizes for the first three groups to achieve the game’s final objective.

Source: Prepared by the authors.

Game mechanics can be understood as the effective point of contact between the "game" and the "player" (MUNHOZ; BATTAIOLA, 2018), meaning they define how the user interacts with the game. The mechanics chosen for the proposed serious game are: pen and paper, RPG, hand management, Q&A (Questions and Answers), and finally, narrative choice. The definitions of these selected mechanics and their applications in the proposed narrative game are described in Table 4, based on the definitions provided by "Ludopedia" (http://www.ludopedia.com.br), the largest Brazilian platform for board games and RPGs for entertainment.

On the other hand, game dynamics emerge from the interaction between the defined mechanics, shaping the core gameplay (BRITO, 2015; VAHLO et al., 2017; OMARALI, 2022). The primary gameplay of "Termópolis" in the "Deserto de Sadhi" stage was determined by combining four dynamics commonly used in entertainment board games: survival, opponent elimination, problem-solving, and item/resource collection. The definitions of these selected dynamics and their applications in the proposed narrative game are described in Table 5, based on the definitions provided by Brito (2015).

Another crucial aspect in the creative process and development of a game is defining its aesthetic. A highly popular style in games, animations, comics, and cinema is Steampunk, a science fiction genre that portrays an alternate universe powered by steam from a punk perspective, blending contemporary technological contexts with reimagined 19th-century elements (PEGORARO, 2013). Due to its intrinsic connection to the history of thermodynamics, which emerged in the 19th century alongside the Industrial Revolution with a focus on improving steam engine performance, Steampunk, with its cartoonized and semi-realistic visual style, was adopted as the core aesthetic of the "Termópolis" universe.

The illustrations for "Termópolis" were created in a caricatural cartoon style, featuring vibrant and contrasting colors, stylized and simplified designs, and an isometric perspective. This style is associated with playful and fun elements, aligning with the profile of the game's target audience, primarily young university students. As highlighted by Silva et al. (2024), illustrations in this format are particularly effective in educational settings, offering an engaging experience that can deepen understanding and engagement, especially when presenting theoretical information. The visual references that inspired the game's design are detailed in Figure 2.

Table 4 Definitions and Application of Mechanics in “Termópolis - Deserto de Sadhi”.

Mechanic	Definition	Application in "Termópolis - Deserto de Sadhi"
Pen and Paper	Use of paper and pen to record important data, which is later used to tally points and determine the winner.	Used for: 1. Documenting question resolutions; 2. Tracking "dobrões" (currency) spent and earned; 3. Monitoring calories burned and gained during gameplay.
RPG (Role-Playing Game)	A mechanic where players assume a character role that can evolve throughout the game.	Players take on the role of apprentices traveling from Fowler Village to the capital, “Entropópolis”.
Hand Management	Players accumulate cards in their hand to score points or play combos.	During the game, players use cards to: 1. Answer questions, 2. Earn extra lives, 3. Unlock paths on the board.
Q&A (Questions and Answers)	Players ask and answer questions within rule-based constraints.	At each challenge, players must answer theoretical or practical questions on the programmatic content to progress.
Narrative Choice	Players are presented with multiple action options through a narrative format.	At certain stages, players choose their path on the board, shaping their character’s story.

Source: Prepared by the authors.

Table 5 Definitions and Application of Dynamics in “Termópolis - Deserto de Sadhi”.

Dynamic	Definition	Application in "Termópolis - Deserto de Sadhi"
Survival	Players must constantly take actions to ensure their continued participation in the game.	Players must monitor their supplies (calorie count) and remaining "dobrões" (currency), as the game ends if either resource is depleted.
Opponent Elimination	Players must eliminate all adversaries to achieve victory.	Players must defeat opponents encountered throughout the game to advance and win.
Problem-Solving	Players must solve puzzles or problems to progress toward the game’s conclusion.	Players must solve theoretical or practical problems related to classical thermodynamics to advance.
Item/Resource Collection	Players gather specific items to consume or use as in-game points.	Players collect various card types, which must be used to solve problems during gameplay.

Source: Prepared by the authors.

Drawing from these visual references (Figure 2), the authors freely explored and refined their ideas, establishing fundamental concepts for the game's design: setting, colors, composition, and atmosphere. In "Termópolis - Deserto de Sadhi", the arrangement of visual elements was meticulously planned to immerse players in the game's atmosphere. This can be seen in the sketches presented in Figure 3. The deliberate symmetry of the oasis, in contrast with the rest of the scenery, reinforces the idea of artificiality, a human-made structure embedded in the arid landscape of the desert. This composition, combined with the oasis's color palette, aims to convey a sense of abundance, wealth, and power, concepts associated with royalty.

It is worth noting that, during the project's development, the initial versions of the drawings were produced using physical media (e.g., paper) and later digitized and finalized in Krita, a software used for image editing and photo retouching.

In graphic interfaces, colors play an essential role as they have the power to evoke sensations like joy, sadness, warmth, or cold, while also influencing emotions, impulses, and desires (OU et al., 2004). According to Tamega (2025), the player's experience is shaped by colors, even subconsciously, since they communicate feelings and emotions. In "Termópolis - Deserto de Sadhi" two distinct visual configurations were employed. In the cards, the goal was to capture the essence of the Steampunk style through the use of muted, dark tones reminiscent of metallic materials such as copper, iron, brass, and bronze. Additionally, details such as gears and bolts were incorporated into the card layouts to further reinforce the characteristic Steampunk aesthetic in the game's card design.



Figure 2 Visual reference. Source: Compilation carried out by the authors.

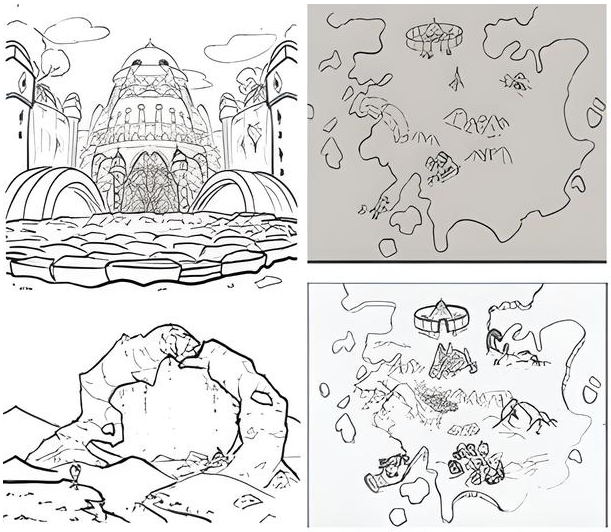


Figure 3 Sketches of the prototype's visual elements. Source: Prepared by the authors.

Four distinct types of cards were created for "Termópolis - Deserto de Sadhi", all sharing the same base layout: object cards, representing tools to be used in the game; concept cards, featuring theoretical definitions of thermodynamic principles; trivia cards, highlighting notable figures in thermodynamics; and the information cards, containing relevant data for gameplay progression (Figure 4).

In contrast to the cards, the game map was designed using a predominantly warm color palette (oranges, browns, and reds) to emphasize the desert setting's atmosphere, as seen in Figure 5. The deliberate use of cool colors (blues, purples, and greens) for the oasis creates intentional contrast with the warm tones dominating the rest of the map. This chromatic distinction aims to convey to players a sense of exclusivity, abundance, and royal prosperity within the "Deserto de Sadhi" suggesting that the oasis serves as a unique refuge amid the surrounding barren landscape.



Figure 4 Concept card layout. Source: Prepared by the authors.

4.3 Evaluation

DSR (Design Science Research) should not be limited solely to the development of the artifact itself but must also provide evidence that the artifact can be used to solve real-world problems (TREMBLAY et al., 2010; DRESCH et al., 2015). For this purpose, several methods and techniques can be employed, such as observational evaluation, analytical evaluation, experimental evaluation, testing, and descriptive evaluation (HEVNER et al., 2004; DRESCH et al., 2015). In this study, testing and experimental analysis techniques were implemented.

4.3.1 Mock-up Evaluation

The controlled experimental analysis involves studying the artifact in a controlled environment to verify its qualities through mock-ups (full-scale models) designed to represent a real-world setting, thereby assessing and demonstrating the artifact's behavior.

In this phase of the study, an external participant, holding bachelor's and master's degrees in Mechanical Engineering, conducted an experimental playtest using a mock-up of the game. The participant had access to all materials in both printed and digital formats, in color and black-and-white versions. After the playtest, the participant provided an evaluation and analysis of the prototype through an interview. The assessment covered the following aspects: programmatic content, design and aesthetics of the prototype elements, difficulty level, and content compatibility with the target audience. Additionally, errors and improvement suggestions were reported.

At the end of the analysis, the external participant deemed the game's content appropriate and aligned with its initial premise of teaching classical thermodynamics to undergraduate students. From a design perspective, the game was considered interesting, engaging, and functional. However, several minor flaws were identified and corrected across different game elements.

For the narrative, adjustments were suggested, such as emphasizing the requirement for players to acquire supplies at the “Mercado do Sol” (Sun Market). Another issue involved reducing price discrepancies in the Sun Market to broaden player choices. Finally, parts of the gamebook text were recommended for revision to enhance clarity.

Regarding the game map (board), the absence of the old oil platform, an important point of interest, was noted. Additional minor improvements were suggested, such as indicating the number of travel days between points of interest. For the cards, minor formatting errors and incorrect information were observed. Lastly, adjustments to contrast, font length, and size were recommended.



Figure 5 Map of the Sadhi Desert. Source: Prepared by the authors.

4.3.2 Prototype Evaluation

Functional testing aims to execute the artifact's interfaces to uncover potential flaws and defects, primarily verifying whether the artifact meets desired user parameters (KHAN, 2011; DRESCH et al., 2015). Here, users need not understand the artifact's internal structure but rather its functionality and utility (DRESCH et al., 2015).

In the second evaluation phase, a functional test was conducted with a group of 11 volunteer students matching the target profile, undergraduate engineering students. All volunteers were graduating Chemical Engineering students from UNIFESSPA. They were divided into three groups: two received color-printed materials, while the third received a black-and-white version (Figure 6). To each group was assigned a game master, a developer team member, responsible for reading instructions, monitoring progress, checking challenge answers, and tracking calorie expenditure.

To assess users' perception of the prototype, a questionnaire was administered to the volunteer students at the end of the gameplay session using the Google Forms platform. The questionnaire was designed based on suggestions and observations reported by SAVI et al. (2010), with questions structured around six main axes, as presented in Figure 7. It is important to emphasize that before the game began, all participants were duly informed about the research procedures, which involved no risks, discomforts, or penalties, and were assured that the results would not reveal their individual performance. Subsequently, all participants signed the Free and Informed Consent Form.

In this study, the participant profile primarily consisted of young individuals aged between 20 and 23. Although the participants were familiar with physical games, particularly card games (54.5%), most reported limited experience with RPGs. Despite expressing interest in analog games, their gameplay frequency was relatively low, with 54.5% stating they played only a few times a year. This scenario is unsurprising, given that Generations Z and Millennials primarily rely on digital games for entertainment (GE, 2021).



Figure 6 Prototype evaluation. Source: Prepared by the authors.

An analysis of the students' responses to the game mechanics section of the questionnaire (Table 6) revealed that most reported a positive experience with the game prototype. Aspects such as the level of interaction between players, story quality, immersion, and the clarity of written instructions and rules were well-rated by the students, achieving an average score above 4.3 on a scale from 1 (very low) to 5 (very high).

Only in the categories of difficulty and gameplay pacing were the average scores slightly below 4. This less prominent result, particularly in gameplay pacing, may be directly linked to the students' limited experience with RPG-style games. A potential improvement for the artifact, one that could not only provide a smoother and more dynamic gameplay pace but also enhance player immersion in the "Termópolis" universe, would be the development of a smartphone app to serve as a supplementary tool. This app could take on functions such as rule management, calorie tracking, and event narration, thereby eliminating the need for a game master and enabling a "Single Player" mode. Additionally, sound and visual effects could be introduced, making the game even more appealing to younger generations of student

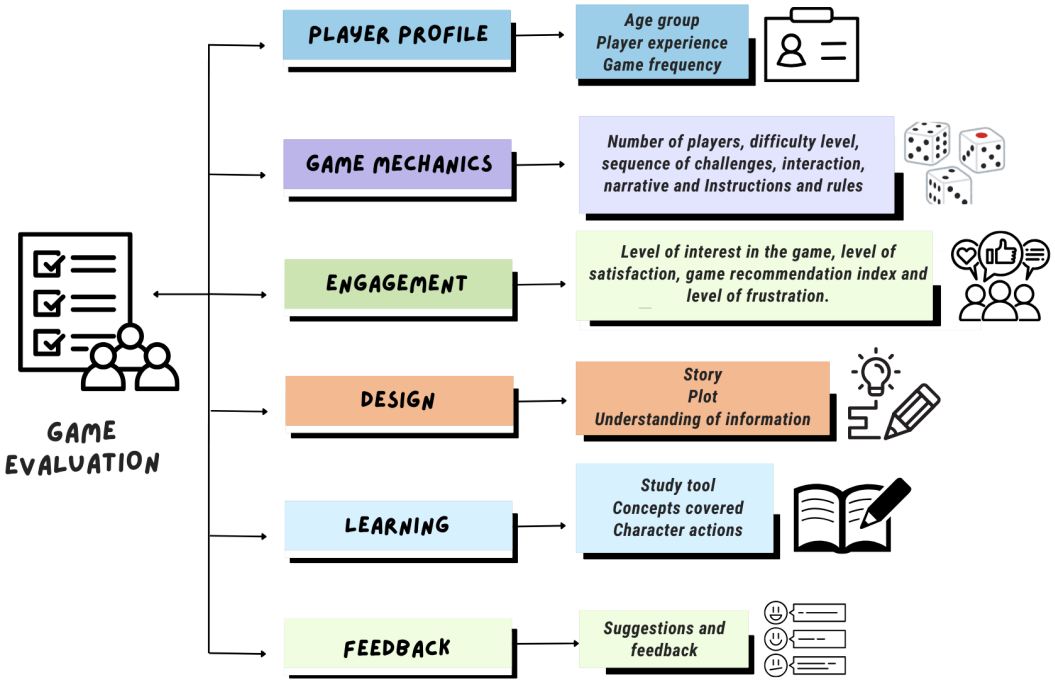


Figure 7 Prototype evaluation structure. Source: Prepared by the authors.

Regarding the difficulty level, this result does not in itself represent a shortcoming of the game, since in "Termópolis - Deserto de Sadhi" the proposed problems were intentionally designed with an intermediate difficulty level. This was done to encourage students to work collaboratively in solving the challenges encountered throughout the game, thereby contributing to a better understanding of the classroom content. However, this approach may render the game unsuitable for individual use. Another potential limitation of the game lies in the fact that the problems and challenges were developed and tested exclusively by professors and students from the chemical engineering program. Therefore, further investigation into the game's effectiveness with students from other undergraduate programs, such as those in the exact sciences, as well as its expansion to other knowledge domains like the natural sciences, remains necessary.

Table 6 Evaluation of the prototype's game mechanics.

Evaluation of the game Termópolis - Game mechanics						
Questions	**1**	**2**	**3**	**4**	**5**	**Mean**
What is the difficulty level of Termópolis Volume 1?	0	0	45,5%	45,5%	9,1%	3,6 ± 0,7
Does the game introduce new challenges at an appropriate pace?	0	18,2%	9,1%	36,4%	36,4%	3,9 ± 1,1
To what extent does Termópolis encourage interaction between players?	0	0	0	0	100,0%	5,0 ± 0,0
Is the game's story text easy to understand?	9,1%	0	0	27,3%	63,6%	4,4 ± 1,2
How effectively does the game's text immerse you in the Termópolis universe?	0	0	18,2%	9,1%	72,7%	4,6 ± 0,8
How would you rate the overall story of Termópolis?	0	0	9,1%	18,2%	72,7%	4,6 ± 0,7
How clear are the instructions and rules in the gamebook?	0	0	9,1%	36,4%	54,5%	4,5 ± 0,7

Source: Prepared by the authors

Table 7 Evaluation of the engagement provided by the prototype.

Evaluation of Termópolis Game - Engagement						
Questions	**1**	**2**	**3**	**4**	**5**	**Mean**
Did the game maintain your interest throughout the gameplay session?	0	0	0	18,2%	81,8%	4,8 ± 0,4
How willing are you to continue playing future versions of the game until reaching the end of the story?	0	0	0	9,1%	91,9%	4,9 ± 0,3
Was playing the game an enjoyable experience? Would you recommend this game to a friend?	0	0	0	9,1%	91,9%	4,9 ± 0,3

Source: Prepared by the authors

In the engagement section, the results were quite promising, as can be seen in Table 7. For the players, experiencing "Termópolis - Sadhi Desert" was enjoyable, and most notably, they expressed interest in continuing to play other gamebooks in the "Termópolis" series and would recommend the game to their friends. These findings demonstrate the game's effectiveness in capturing players' attention, focus, and engagement.

Still within the engagement section, players were asked about instances of frustration during gameplay. Among them, 36.4% of students reported experiencing frustrating situations, primarily related to three aspects: the limited availability of in-game currency ("dobrões"), the high cost of using “dobrões" to obtain hints, and some confusion regarding when calorie expenditure tracking began.

In the first version of the game, registered with the “Fundação Biblioteca Nacional” (Registration No.: 914.007, Book: 1,783, Page: 269), these issues were properly addressed. To this end, the following improvements were implemented: the addition of a text alert to clarify when calorie expenditure tracking begins, the reduction of hint costs, and the inclusion of rewards at specific stages of the game. Furthermore, a checkpoint system was introduced, allowing the game master to periodically verify players' calorie and in-game currency (“dobroes”) counts, ensuring smoother gameplay.

Regarding the Design aspect, the evaluation once again showed excellent results, as presented in Table 8. The information on the cards and map was easily understood. Additionally, the game's key visual elements, the map and cards, successfully conveyed the atmosphere of the “Termópolis” kingdom to players, with the design receiving significant praise from participants.

Table 8 Evaluation of the prototype's design.

Evaluation of Termópolis Game - Design						
Questions	**1**	**2**	**3**	**4**	**5**	**Mean**
How do you rate the quality of the illustrations for each component of the game?	0	0	9,1%	18,2%	72,7%	4,6 ± 0,7
Do the visual elements of the game (map, coins, cards) convey the atmosphere and theme of the story?	0	0	0	9,1%	90,9%	4,9 ± 0,3
Was the information on the cards clear and easily understood?	0	0	0	27,3%	72,7%	4,7 ± 0,5
Was the information on the map clear and easily understood?	0	9,1%	0	0	90,9%	4,7 ± 0,9

Source: Prepared by the authors

Another positive aspect of the prototype's design concerned the font size on the cards as well as the physical size of the cards themselves. According to the students, 90.9% considered the font size adequate ("good"), while 72.7% rated the physical card size as good. On the other hand, 9.1% of students found the font size somewhat small, and 27.3% considered the card size small. The options "very small," "large," and "very large" were not mentioned by any students.

Table 9 Evaluation of participants' perception of learning facilitated by the prototype.

Evaluation of Termópolis Game - Learning						
Questions	**1**	**2**	**3**	**4**	**5**	**Mean**
Would you use Termópolis as a tool to study and help reinforce classical thermodynamics content?	0	0	9,1%	0	90,9%	4,8 ± 0,6
Are the characters' actions related to thermodynamics concepts?	0	0	18,2%	9,1%	72,7%	4,5 ± 0,8

Source: Prepared by the authors

Table 10 Evaluation feedback.

Evaluation of the Termópolis Game – Feedback (Suggestions and Criticisms)	
PARTICIPANTS' RESPONSES	
What did you like most about the game?	**What would you change about the game?**
The gameplay dynamics, the stories, illustrations, and visual elements.	I would add some kind of challenge that could give players the chance to earn more "dobrões".
The best part was the immersion it provided.	I would include cards featuring the game's characters (to enhance immersion a little).
I enjoyed the interaction and the encouragement to think in a relaxed way.	Remove the option to acess reference materials, this would encourage players to ask for more hints, formulas, and concepts, all costing "dobrões."
The design is very good, as is the writing of the text.	Add a note at the beginning stressing the importance of analyzing the cards carefully.
The gameplay dynamics.	Nothing.
The immersion in the game's story and the connection of challenges with classical thermodynamics concepts.	Nothing.
The story and the world of Termópolis.	Improve the descriptions of hints, making them clearer and more direct, as well as the problem instructions.
The interaction between participants and the game.	No suggestions.
The game's story is very interesting.	I would add more thermodynamics questions.
I liked the group interaction and the way it helped recall thermodynamics concepts, it's a fun and interactive way to review and practice them.	I would just add a way to earn more "dobrões" "lol", losing everything during the game is really frustrating, but the game itself is great! The cards look amazing!!
I enjoyed the theme; I felt engaged in the story.	I would like to have a reward system to earn more "dobrões" or a challenge to get extra ones.

(Source: Prepared by the authors)

In the learning section, students' perceptions were evaluated regarding the prototype's capability and usefulness in fostering the teaching and learning process of classical thermodynamics. Once again, student reception of the prototype was highly positive (maximum score), with 90.9% of students stating they would use the prototype as a supplementary study tool (Table 9), while only 9.1% gave the prototype a median score (3 on a scale of 1 to 5, where 1 represents a very low evaluation and 5 very high).

In the final evaluation stage, within the feedback segment, students were prompted to list what they liked most and least about the game (Table 10). As positive aspects, students highlighted the design of game elements (map, cards, and narrative), the dynamics, interaction, and immersion provided by the game. On the other hand, participants pointed out the need for some adjustments, the main one being the need for more incentives in the game currency (the "dobrão"), for each overcome challenge. As previously mentioned in the engagement section, this and other adjustments were implemented in the first registered version of the game. Other improvement suggestions included creating character cards to enhance immersion and refining the description of hints and problem statements. These suggestions, along with the future development of a smartphone application, may be incorporated into a second version of the game.

5. CONCLUSION

In this study, an interdisciplinary team composed of professors and students from Chemical Engineering program at UNIFESSPA and Design program at UFMA employed Design Science Research and Design Thinking to develop an innovative serious game titled "Termópolis - Deserto de Sadhi". The objective was to create a tool to facilitate the teaching and learning process of classical thermodynamics concepts. The game's development was a complex process that involved the creation of the entire Termópolis universe, complete with its own story and narrative, as well as the design of all its components. The development stages were organized into ideation, artifact prototyping, and game evaluation.

The ideation phase of "Termópolis – Deserto de Sadhi" allowed the consolidation of the project's key characteristics based on findings from the empathy phase, aligning them with the target audience's needs and educational objectives. Structuring the programmatic content through game mechanics and dynamics aimed to promote an immersive and pedagogically relevant experience, encouraging active learning of classical thermodynamics. Additionally, the choice of a Steampunk aesthetic, with cartoonish and caricatured elements, reinforced the connection between the scientific theme and the playful narrative, creating a visually cohesive and appealing environment for players.

In the prototyping phase, materializing ideas into concrete elements, such as cards, maps, and the gamebook, highlighted the importance of iterative design and the validation of aesthetic and mechanical choices. The use of distinct colors for different game components, such as metallic and wood-toned cards and a warm-colored map, demonstrated a deliberate effort to employ visual language as a tool for immersion and thematic reinforcement. Thus, prototyping not only tested the game's feasibility but also refined its ability to engage players, establishing Termópolis as an educational tool.

The controlled experimental evaluation, conducted with the participation of an external member, proved highly productive and effective. Many of the errors detected in this phase were successfully corrected, such as the size of the cards and adjustments made to the map and narrative, which were

later well-received by students during functional testing. Another identified issue was the need to improve the clarity of problem statements. While most of these issues were resolved, a lack of clarity persists in one specific problem statement (the oil platform), as reported by a student during functional testing. Therefore, further adjustments will be necessary for the game's second version.

In the functional test, conducted with 11 students from the Chemical Engineering program at UNIFESSPA, the initial results exceeded the development team's expectations. The game is a tabletop RPG, a style with which the students were not very familiar, particularly as they belong to a generation more accustomed to digital games.

Despite this, the students' feedback at the end of the test was extremely positive, highlighting aspects such as the design of the game elements, the universe and narrative developed, as well as the interaction facilitated by the game. It is worth noting that in the suggestions and criticisms section, the game's story and narrative were positively mentioned multiple times. Thus, beyond visual elements, the presence of a cohesive and engaging story is necessary to ensure immersion in an educational game.

One notable point was the strong desire expressed by students to continue engaging with the Termópolis universe, as well as the high rate of game recommendations to friends. These factors demonstrate the significant engagement generated by the game among participants, indicating its potential as an auxiliary tool in the teaching and learning process of thermodynamics-related content.

Although the game has received highly satisfactory initial feedback, the Termópolis universe still has a long evolutionary path ahead. To expand its audience and attract new users, adjustments, improvements, and testing with students from other exact and natural science programs are necessary. To this end, the development team intends to continue refining the game.

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