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Edu-tainment in STEM: Exploring the Feasibility of Television-based Educational Games in Engineering Education

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Abstract

In the contemporary landscape of STEM education, a significant challenge lies in ensuring student engagement and facilitating the understanding of complex engineering concepts. Traditional teaching methods are passive and often struggle to sufficiently engage the young generation of students. While passive learning is important for understanding and remembering concepts, it is not efficient for developing high-level skills, such as applying, analyzing, and evaluating the material. The active learning approach, where students learn by engaging with the content, is beneficial for the development of high-level skills in students and has been shown to improve learning and retention. Interacting with the content better engages students which help them improve their concentration and deepens their learning. Hence, visions for engaging instructional methods such as game-based learning need to be explored for STEM education. The young generation of students are habituated to television and video games; therefore, an opportunity exits to integrate popular media-based themes with educational content to create enriched learning experiences. This paper presents a novel approach of game-based learning: the Television Media-based Educational Game (TMEG). Conceptually, TMEG provides a framework to embed the educational content within an engaging narrative inspired by a popular TV series, aiming to enhance both student engagement and learning. TMEG incorporates 3D models, animations, and visuals that are tailored to introduce different engineering principles. The game's narrative is crafted to mirror themes from a TV series, selected based on student interests, creating a relatable and immersive learning environment.

This study developed a prototype game for an introductory Materials Science and Engineering course. This process consisted of two steps: First, a student survey was conducted to identify the TV series that is popular among the students. This provided the backdrop of the game. The survey also identified the course concepts that students find challenging, which formed the educational content of the game. Second step focused on the technical development of the game using the TMEG framework. Unity game engine was used to develop the game that embedded the identified educational content within the selected TV series-based theme. The game used game tasks, animations, videos to deliver the educational content within the game narrative. The outcomes of this research could lay a foundation for the future development of innovative and engaging educational games and extend the reach of such pedagogical strategies across various STEM and non-STEM fields.

1. Introduction

The U.S. undergraduate engineering programs are experiencing a decline in enrollment [1]. This trend weakens the United States' longstanding leadership in global engineering and STEM fields, which has been declining over the past decade [2]. While the engineering workforce is evolving, there's an increasing emphasis on diversifying and expanding the appeal of undergraduate engineering programs. Addressing this challenge requires a shift towards more engaging and

diverse educational approaches in engineering education. This shift is not only essential for maintaining the country's competitive edge in these fields but also for adapting to the evolving needs and interests of a new generation of students. Hence, there is a growing recognition of the need for more engaging teaching strategies and learning environments to inspire and engage a broader range of students in engineering disciplines. Innovative learning technologies, such as digital game-based learning environments, are integral to addressing this need by inspiring interest through intellectual engagement among the young generation of students. Moreover, engineering undergraduate students must graduate from their programs with technical knowledge, critical thinking, and problem-solving skills to succeed in today's rapidly advancing and highly competitive STEM fields. Traditional lecture methods, while fundamental, are limited in maintaining student motivation and engagement, given that studies have shown students' attention wanes significantly after just 10-20 minutes of passive listening [3]. In contrast, active learning strategies, which involve students in tasks and activities promoting critical thinking and analysis, have shown promise in improving learning outcomes and retention [4-6]. These methods are not only pedagogically beneficial but also cater to students with varying learning preferences [7]. The active learning approach has been shown to improve learning and retention by promoting critical thinking and analysis. When students are actively engaged in learning activities or tasks, it potentially facilitates them to construct knowledge and hence deepens their learning [4-6]. There are ethical as well as pedagogical benefits of active learning as different delivery modes can support students with different learning needs [7]. There is growing evidence that student motivation [8] and engagement [9] play a critical role in learning [10] to the extent that student engagement has been used as a proxy for quality of learning [11]. Hence, visions for active learning approaches aimed at enhancing engagement need to be explored for higher education [12-13].

Research in the area of game-based learning suggests that educational games are effective in facilitating learning processes and enhancing knowledge transfer. These games, traditionally distinct from commercial games and termed 'serious games', need to balance educational content with entertainment to be truly engaging for students [14-18]. The concept of 'play' is fundamental to games, and emphasizing this aspect can lead to more effective and engaging educational experiences. Another important cultural phenomenon influencing today's youth is the prevalence of television series, largely due to the rise of streaming services like HBO, Netflix, Amazon Prime, and Hulu. These platforms have seen significant revenue growth, indicating the widespread popularity of TV series [19]. TV series are not just entertainment; they play a role in shaping perspectives and ideas, comparable to other forms of human interaction [20]. Recognizing the emotional connection viewers often develop with TV series, there is potential to use their engaging elements - compelling storylines, relatable characters, thematic depth, and cultural relevance - in educational contexts [21-27].

This study aims at harnessing the elements of digital games and TV series to develop Television-based educational game (TMEG), specifically designed for STEM students. By doing so, the study aims to create an engaging and motivating learning environment that is effective in conveying complex concepts. This approach is particularly suited to address the diverse backgrounds and learning abilities of students, providing them with access to learning content in a manner that resonates with their experiences and interests.

2. Approach

The study specifically focused on an introductory materials science and engineering (MSE) course, which serves as a common foundational class for students in materials, mechanical, aerospace, industrial, chemical, and electrical engineering disciplines. This course was strategically selected due to its diverse student population, encompassing a wide range of engineering majors and academic standings, from freshmen to seniors.

This study followed a commonly accepted Instructional System Design (ISD) approach to design and develop TMEG as detailed below.

2.1 Analysis: This step focused on identifying the functional requirements of the game. In this step, an exploratory student survey was conducted with undergraduate MSE students to gauge student interests in game-based learning and to identify the challenging topics that could potentially be covered using TMEG. The survey also focused on identifying popular television series among students. This survey was given to the junior and senior undergraduate students who had completed the introductory materials course in the previous semesters. The survey included open ended questions such as "*What are the concepts that you found challenging to grasp from the course?*" and "*What are your three most favorite TV series?"*. Authors experience in teaching this course was also leveraged to identify concepts which are generally difficult for students to grasp and can be taught through game-based learning. The exploratory survey helped in exploring the student interests that was used in selecting the game characteristics, such as overall theme, narrative, avatars, visuals, and assessment mechanics. This also helped in developing the learning objectives of the game. Authors acknowledge that gender and other biases can inadvertently be perpetuated into game design when interests are collected from an inherently imbalanced population. It is crucial, therefore, to consciously consider these biases during the design process to ensure a more inclusive and representative educational tool.

2.2 Design: This step focused on designing the virtual game. The findings from step 2.1 helped in designing the instructional content and characteristics of the game. First, the backdrop of the game including the characters and the narrative were designed based on the student interests identified in step 2.1. The following elements were designed based on the top TV series identified from the survey.

- Genre (science fiction, thriller, fantasy)
- Historical context (ancient, modern, futuristic)
- Visual aesthetics (realistic, abstract, cartoonish)
- Thematic Elements (mystery, adventure, romance, or ethical dilemmas)
- Setting and World-building (urban landscapes, natural settings, dystopian worlds, or outer space)

The game narrative was created using the story mapping technique [28], which enabled the story creation in terms of theme and character development. Story mapping captured the story's central premise, structure, and elements of transformation and how the story's essential components incorporate into the overall flow of the narrative [29-30]. Then strategies for incorporating the instructional content were developed considering a) the core educational value of the Material Science concepts is not compromised and b) a smooth integration of instructional content with the overall theme of the game is achieved. Finally, the assessment structure that was designed to

evaluate student learning of these concepts through TMEG. Different assessment mechanisms such as informal feedback throughout the game (e.g., game scores), performance-based rewards (coins), and comprehensive assessment (quiz at the end of the game) were used.

2.3 Development: This step focused on the technical development of the game using Unity 3D game engine. First, the game environment was developed based on the design finalized in the previous step. Different virtual elements and relevant characteristics (avatars, terrains, visuals, motion effects, sounds) were modeled and added to the game environment. Then the instructional content was embedded in the game narrative as per the strategies designed above. Prebuilt models, effects, animations and visuals were used throughout the game to convey various educational concepts and enhance the overall game graphics. The game included a character (avatar) that students will use to navigate different levels of the game.

3. Television Media-based Educational Game (TMEG)

Conceptually, TMEG consists of three integrated components. The first component, ***Foundational Inputs***, combines the educational content from Materials Science and Engineering with game elements inspired by popular TV series. This includes incorporating real-world engineering concepts and pairing them with engaging narratives and rewards typical of TV series narrative. The second component, ***Game Cycle Process***, conceptualizes the mechanism of learning when students play the game. The game cycle is an iterative process and involves repeated judgment-behavior-feedback loops. Repeating the game cycle over time can lead to user judgments such as increased interest, enjoyment, and involvement. These reactions reinforce the learning of concepts and their correct application. Finally, these behaviors result in system feedback on the player performance in the game context. Student performance in the game (i.e their judgments and behavior) is regulated by comparisons of feedback to standards or goals. The third component, ***Educational Outcomes***, focuses on the results of student interaction with the TMEG. This component envisions the game as a medium for students to immerse themselves in learning, using the game narratives to anticipate, acquire, and apply knowledge. The expected outcomes include enhanced learning satisfaction, deeper understanding of content, and skill acquisition.

The following subsections discuss different elements of TMEG.

3.1 TMEG Instructional content (Educational element): The exploratory student survey identified Phase Diagrams, Crystal Structures, and Miller Indices as particularly challenging MSE topics. Out of these, Crystal Structures and Miller indices were chosen as the curriculum of the game due to their fundamental importance in understanding material structure and properties. The coverage of this curriculum, which spans basic definitions, types, and real-world applications, is outlined in Table 1. This curriculum aims to offer an in-depth exploration of Crystal Structures, facilitating a more effective and interactive learning experience within the gaming environment.

Table 1: TMEG curriculum

Topic	Details
Basic Definition and Importance	Introduction to crystal structures and their significance in MSE, with a focus on visualizing atoms in metals and ceramics.

Types of Crystal Structures	Exploring various crystal structures including FCC, BCC, HCP, Zinc blende, and perovskite with characteristics and interactive visualizations.
Lattice Parameters and Unit Cells	Examining lattice structures and parameters, understanding unit cells as the building blocks of crystal structures.
Calculation of Atomic Packing Factor and Density	Teaching how to calculate atomic packing factor and density from unit cells through interactive exercises.
Planar and Linear Densities	Studying planar and linear densities to understand surface and directional properties of materials.
Real-world Applications and Implications	Linking crystal structure knowledge to real-world applications in material science and engineering for game tasks.
Crystal Structure Analysis Techniques	Overview of methods like X-ray diffraction for analyzing crystal structures, including principles and applications.

3.2 TMEG Game characteristics (Entertainment element): In response to survey results indicating a preference for narrative-driven games and the popularity of TV series like "The Boys" and "Breaking Bad," the proposed game uniquely combines elements from both series into its theme and narrative. The game genre merges science fiction with drama and suspense, reflecting the complex and thrilling narrative styles of these series. It is set in a contemporary, high-tech laboratory environment, reminiscent of the advanced scientific landscapes depicted in both shows, providing a realistic yet challenging setting for Materials Science and Engineering concepts (Figure 1)

Figure 1: TMEG Game environment

Central to the narrative is a fictional female player character, crafted in the spirit of the themes from "The Boys" and "Breaking Bad." (Figure 2). Her role involves undertaking challenging missions that include solving problems, conducting experiments, and making decisions that have real consequences in the game world. A virtual guide in the form of player's superpower is available to players to provide hints and scaffold the learning throughout the gameplay. Players take on the role of a scientist, solving problems, conducting experiments, and making decisions that have real consequences in the game world. Visually, the game blends the gritty, realistic look of "Breaking Bad" with the more fantastical and vivid elements of "The Boys," creating an engaging and visually stimulating environment. The thematic elements of cutting-edge technology, and complex character dynamics from both series are woven into the game's narrative, enriching the storyline and enhancing the educational experience. This combination of genre, setting, visual aesthetics, and thematic elements in the game's design aims to capture student interest, offering an

immersive educational journey that bridges MSE education with elements of popular Television series.

Figure 2: TMEG Game protagonist, "*Dr. Sterling"*

3.3 TMEG Game Narrative (Edu-tainment)

The instructional content and the game characteristics identified above were integrated to develop the pilot game named "Crystalline Conundrums,". In this game, players step into the shoes of a brilliant young scientist named Dr. Ava Sterling, working in a high-tech laboratory that mirrors the complex worlds of "The Boys" and "Breaking Bad." The game's narrative weaves a story of discovery, strategy, and application of Materials Science and Engineering principles, specifically focusing on Crystal Structures.

Journey through the Game:
Dr. Sterling's quest begins with a mysterious challenge from an unknown benefactor. She is tasked with uncovering the secrets of revolutionary materials that could change the world of science. Each level of the game represents a different aspect of Crystal Structures, from basic concepts to real-world applications. Figure 3 shows some screenshots from the players journey in the game.

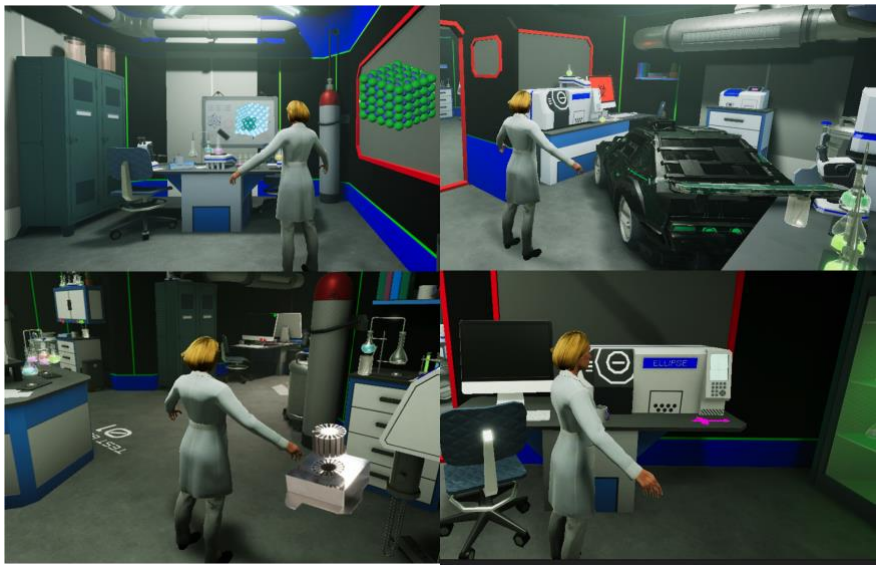

Figure 3: Screengrabs from the game

Game Tasks:

In "Crystalline Conundrums," players embark on a series of missions, each designed to align with the learning objectives. Table 2 provides an overview of each game task, along with a description and the specific learning objective it aims to achieve.

Table 2: Crystalline Conundrums Tasks

Game Task	Task Description	Learning Objective
Forging a Super Alloy Sword	Players must forge a super alloy sword, choosing the right crystal structure for the alloy (FCC, BCC, HCP).	Understand different types of crystal structures and their properties.
Repairing a High-Tech Futuristic Automobile	Diagnose and repair a high-tech futuristic automobile using knowledge of lattice structures and unit cells.	Grasp the fundamentals of lattice parameters and how unit cells form various crystal structures.
Creating a Lightweight Armor	Design a lightweight, yet strong armor, calculating atomic packing factor and density for materials selection.	Apply the concept of atomic packing factor and density in material selection.
Designing Electric Motor Core Lamination	Engineer the core lamination for an electric motor, requiring precise understanding of material directional properties.	Learn the importance of directional properties in materials for specific engineering applications.
Unraveling the Molecular Mystery	Use interactive X-ray diffraction to analyze diffraction patterns and uncover the structure of alien technology.	Learn and apply X-ray diffraction techniques to analyze and interpret molecular structures.
Developing a Nanomaterial	Synthesize a new nanomaterial for a high-tech application, integrating various crystal structure concepts.	Demonstrate the application of crystal structures knowledge in innovative material design.
Decrypting the Crystal Code	Enter a VR chamber to interact with a 3D model of an ancient artifact's crystal structure, manipulating atoms to unlock its secrets.	Enhance understanding of crystal structures through interactive 3D visualization and manipulation of atomic arrangements.

Narrative Progression:

As Dr. Sterling progresses through these tasks, she uncovers a larger narrative, involving corporate espionage, ethical dilemmas, and the potential for groundbreaking scientific advancements. The game tasks are intricately linked to MSE concepts, ensuring that players not only engage in an exciting storyline but also gain a deep understanding of crystal structures and their applications.

Culmination:

The game culminates in Dr. Sterling presenting her findings at a prestigious scientific conference, facing challenges from peers and integrating all she has learned to defend her work. This final stage tests players' overall understanding and application of the learned MSE concepts in a realistic, high-stakes environment.

4. Summary and conclusions

This study introduced a novel approach to STEM education through the development of a Television Media-based Game (TMEG), specifically targeting the topic of Crystal Structures in Materials Science and Engineering (MSE). The game, "Crystalline Conundrums," was designed in response to a survey that highlighted the challenges students face in understanding certain MSE topics through traditional instructional methods. By incorporating elements from popular TV series such as "The Boys" and "Breaking Bad," the game aims to increase engagement and comprehension among undergraduate students. The game is planned to be implemented in an introductory Materials Engineering course with over 120 students this fall, with an evaluation strategy that includes both qualitative and quantitative methods to comprehensively assess its impact.

The integration of the curriculum into an immersive narrative and interactive gameplay enables students to apply theoretical knowledge in practical, problem-solving scenarios. The tasks within the game are aligned with specific learning objectives, ranging from understanding basic crystal structures to applying advanced techniques like X-ray diffraction analysis. "Crystalline Conundrums" successfully demonstrates the potential of using popular TV series elements to make complex scientific concepts accessible and engaging for students. This approach could transform the way STEM subjects are taught, moving away from traditional lecture-based methods to more interactive and student-centric models. While television media-based games can be excellent tools to teach STEM concepts in engaging ways, it is recognized that the 'Crystalline Conundrum' has the potential to inadvertently foster a broader interest in gaming among some students. This extension beyond educational objectives underscores the need for a balanced approach in the implementation of edu-tainment methods in STEM education.

In conclusion, the development and implementation of TMEG like "Crystalline Conundrums" represent a promising direction for educational innovation in STEM fields. By aligning learning content with students' interests and leveraging the interactive nature of digital games, educators can provide more effective and engaging learning experiences. This study lays the groundwork for future research and development in this area, highlighting the potential for games to bridge the gap between entertainment and education in the realm of science and engineering.

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