Designing and Developing Science Tabletop Games: Engaging Senior High School Students as Designers to Foster Design Thinking Skills

JONG Jingping

New Taipei Municipal Jinhe High School, New Taipei City, Taiwan

porphyrin@jhsh.ntpc.edu.tw

Abstract

Design thinking is a human-centered, cross-disciplinary approach to problem-solving that emphasizes an iterative process for developing effective solutions. This study investigated a school-based course that integrated design thinking into science tabletop game development, aiming to cultivate 11th-grade students' design thinking skills and support them in creating their own science tabletop games. Using a five-stage framework—empathy, define, ideate, prototype, and test—students took on the role of designers, incorporating key chemistry concepts, along with biology, physics, and earth science into engaging game mechanics. The students' design thinking skills, encompassing the skills required across the stages of design thinking, were assessed using a semi-structured questionnaire. Results from a paired-sample t-test revealed significant improvements across all categories. Students described the course as challenging and rewarding, reporting growth in creativity, teamwork, communication, and problem-solving. Furthermore, 95% of participants recommended the course to their peers. The teacher facilitated the design thinking process by linking activities to students' tabletop game experiences, designing stage-specific tasks, and providing worksheets for guidance and progress tracking. These findings highlight the potential of integrating design thinking into science tabletop game design to foster innovation and create more engaging, interactive, and cross-disciplinary learning experiences.

Keywords: design thinking, tabletop games, design thinking skills, students as designers

Introduction

Student learning often relies on established thinking models, which serve as a foundation for analogical reasoning in similar situations. Design thinking is a practical process embodying a creative thinking model based on divergent and convergent thinking (Stanford d. School, 2010). In this process, designers confront problems from a human-centered perspective, developing final products or proposing effective solutions through a cycle of prototyping and iteration.

A tabletop game is a genre of game played on a flat surface, such as a table or board, typically involving physical tokens or cards. Science tabletop games are designed around scientific concepts or topics, aiming not only for entertainment but also to facilitate the acquisition of scientific knowledge through their core design and mechanics. Research indicates that such games can provide students with alternative pathways for engaging in science learning (Cheng et al., 2019; Ladachart et al., 2022).

However, the existing literature has predominantly focused on the outcomes of playing these games, such as the impact on students' learning of specific concepts and their motivation (Cardinot & Fairfield, 2019; Lin et al., 2019). Less attention has been paid to positioning students as active agents in the game design process itself. Granting students the opportunity to participate directly in the planning and creation of science games holds the potential not only to cultivate their design thinking skills but also to foster their creative abilities.

Therefore, the purpose of this study is to investigate the process of empowering students to become the primary designers of their own edutainment science tabletop games. By engaging in this authentic design experience, students can navigate a complete problem-solving cycle and, in doing so, manifest their creativity.

Literature Review and Theoretical Framework

Design thinking and related research

Design thinking is a human-centered problem-solving strategy that emphasizes a developmental process of empathy, collaboration between team members and designers, experimentation, and iterative refinement. It involves understanding and defining the problem, generating ideas, prototyping solutions, and then testing and improving them based on user feedback. The goal is to develop innovative and effective solutions that meet the needs of users (Stanford d. school, 2010; Tu et al., 2018; Yu et al., 2024).

A primary focus of design thinking is the gradual establishment of effective problem-solving strategies through a process of divergent and convergent thinking. Many researcher have developed diverse strategies to help learners master the design thinking process (Sung & Kelly, 2019; Stanford d. school, 2010). Sung and Kelly (2019) identified that design thinking includes steps such as analyzing the situation, defining the problem, modeling ideas, designing prototypes, predicting outcomes, questioning unexpected results, and managing the design process. Zhu et al. (2025) implemented a six-stage design thinking model to improve elementary students' innovation skills through two science projects. The process guided students through discover, focus, imagine, prototype, try, and reflect & share stages, moving from initial knowledge acquisition to hands-on creation and evaluation. The results found that students' design thinking skills, particularly after the second intervention, increased significantly.

The Stanford d. school proposed a five-step, non-linear process for design thinking that includes: empathize, define, ideate, prototype, and test (Stanford d. school, 2010). These steps are described as follows:

- **Empathize**: Focus on understanding the user's needs, which can be achieved through methods like questionnaires and direct observation.
- **Define**: Synthesize the information gathered during the empathy phase to articulate a problem statement and confirm the user's core needs.
- **Ideate**: Brainstorm innovative solutions or product concepts from various perspectives.
- **Prototype**: Begin to implement the proposed solutions or create tangible prototype products based on the ideas generated.
- **Test**: Have users test the solutions or prototypes to gather feedback for improvement and refinement.

At its core, design thinking emphasizes a holistic mindset and balances three essential elements: desirability (creating a suitable product for the user), viability (ensuring the product can be profitable or sustainable), and feasibility (confirming that the innovative idea can be realized with current technology). Design thinking is not only applied in general product design and science education (Ladachart et al., 2022) but also in developing strategies for sustainable development (Shapira et al., 2015). Many studies have applied d. school model into innovation of product. Samadhiya and Agrawal (2022) applied the d. school's five-phase design thinking framework to innovate a traditional handloom used by weavers in India, addressing key usability and productivity issues. The research demonstrated how the design thinking process could be effectively implemented for a traditional product. The findings indicate that the resulting redesigned loom was successfully adopted by the weavers, and the study confirm that design thinking is a valuable methodology for technological intervention and fostering stakeholder collaboration.

Science tabletop games and related research

Science tabletop games are defined as tabletop games that incorporate scientific concepts or their mechanisms. Their purpose extends beyond entertainment, aiming for players to understand the relevant scientific content through gameplay (Cheng et al., 2019). For example, numerous commercially available tabletop games are related to scientific concepts like evolution. Research shows that players can construct a foundational understanding of concepts related to evolution while learning the game's rules (Eterovic & Santos, 2013).

The design of science tabletop games is similar to that of general tabletop games, primarily consisting of a thematic background, rules and procedures, physical components, and other secondary elements. The thematic background explains the game's narrative, making it easier for players to immerse themselves in a specific context. The rules and procedures include elements such as initial setup, use of objects, turn sequence, phase mechanics, and victory conditions. Physical components are the tangible objects that players interact with, which may include cards, a game board, chance or event cards, or dice (Cheng et al., 2019).

Research indicates that through participation in science tabletop games, students engage in immersive interaction in a gamified manner, which not only promotes their learning of scientific concepts but also enhances their interest and motivation (Cardinot & Fairfield, 2019; Lin et al., 2019; Jong et al., 2017; Peppler et al., 2013). Cheng et al. designed a tabletop game about water resource management where, through the game's mechanics and player interaction, players' attitudes toward resource management shifted from an initial profit-oriented perspective to one focused on the public interest. Throughout the process, players not only enhanced their knowledge of water resource management but also developed a better understanding of systems thinking, environmental responsibility, and public value (Cheng et al., 2019). Existing research has explored the use of design thinking to have adolescent participants design board games, through which they learn relevant scientific concepts and systems thinking (e.g., Parekh et al., 2021). Parekh et al. engaged teens in a workshop to design a board game about environmental issues. The research found that this hands-on process served as a powerful educational tool. By creating a game, students were prompted to model complex ecological interactions, which deepened their understanding of environmental importance and nurtured the development of their systems thinking skills (Parekh et al., 2021). However, these studies have primarily focused on the participants' acquisition of scientific concepts and motivation, with less emphasis on how to cultivate students into becoming proactive designers in order to develop their design thinking skills.

Research framework

The design thinking process includes the non-linear steps of empathize, define, ideate, prototype, and test (Stanford d. school, 2010). Through these steps, students can begin to devise solutions for specific problems. It is anticipated that after engaging in this process, students will gradually internalize these steps, forming a cognitive model that constitutes their design thinking skills.

Educators believe that learners can acquire design thinking skills with the assistance of scaffolding (Razzouk & Shute, 2012; Stanford d. school, 2010). However, despite its widespread use, design thinking skills still lacks a single, unified definition (Aflatoony et al., 2018; Razzouk & Shute, 2012). Razzouk and

Shute (2012) proposed a hierarchical model that presents design thinking skills across dimensions such as use resources, iterate diagrams, and innovative design. Specific indicators within this model include identifying needs and goals, identifying resources and generating arguments, breaking down systems or creating innovative models, and testing, refining, and evaluating models to make decisions. Stempfle and Badke-Schaube (2002) suggested that the fundamental cognitive elements of design thinking are similar to general problem-solving skills, comprising generate, explore, compare, and select. Generation and exploration expand the problem space to create innovative solutions, while comparison and selection narrow the problem space to test and refine those solutions. Design thinking skills encompasses setting cognitive goals, considering user needs, generating innovative ideas, designing and implementing models, and continuously refining and evaluating those models.

In light of this, the present study, referencing the Stanford d. school's stages of design thinking (Stanford d. school, 2010) to conceptualize design thinking skills. These skills are defined as the learner's skills to complete effective and innovative solutions through the design thinking process. It is broken down into the following components: empathizing with others, defining the problem, ideating solutions, creating prototypes, and testing. This involves assessing how learners empathize with user needs, how they define a solvable problem from a wide range of user needs, how they use divergent and convergent thinking to find an innovative yet appropriate solution, how they then create a tangible prototype to visualize their ideas, and finally, how they test the effectiveness of the final product. This framework also serves as the basis for assessing students' design thinking skills (see Figure 1).

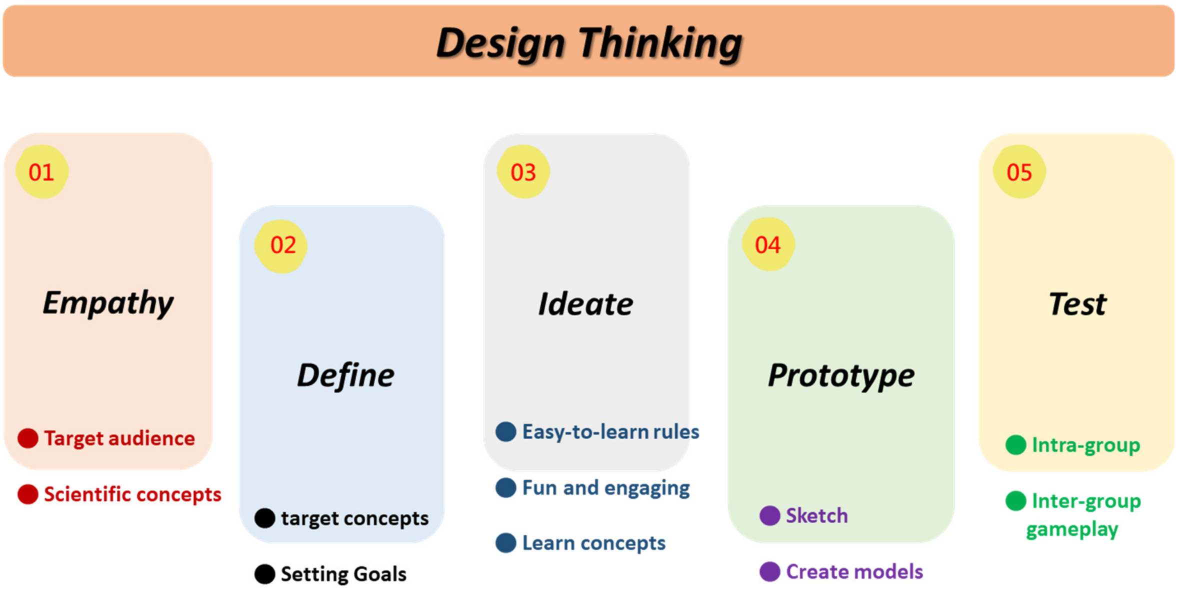

Figure 1. The theoretical framework of design thinking
(Adapted from Standford d. school, 2010)

The ideation phase of design thinking typically begins with divergent thinking to broadly gather ideas, followed by evaluation and review to form convergent thinking. Through this continuous process of refining ideas, innovative solutions are conceived. This process of divergence and convergence is precisely where creativity is manifested. In contrast, previous research has primarily focused on teacher-led initiatives, where educators design science tabletop games to facilitate student learning (e.g., Cheng et al., 2019). This course, however, positions students as the central agents, guided by the instructor to become the main designers. The goal is for them to experience the process of design thinking, and through continuous thinking, planning, designing, and creating, to produce a science tabletop game that elementary, junior, or senior high school students would be willing to engage with. By experiencing the steps of design thinking, students can cultivate their design thinking skills and thereby enhance their creative abilities.

Based on the literature review and discussion above, the primary purpose of this study is to develop a teaching module for science tabletop game design. The module emphasizes how to promote students' learning of design thinking elements within the design thinking framework, with the aim of cultivating their design thinking skills. The research questions are as follows:

1. What are the differences of 11th -grade students' design thinking skills before and after the teaching intervention?
2. How do 11^{th} -grade students refine their designed science tabletop games?
3. After the instruction, what are the students' perceived gains from and evaluations of the course content?

Methods

Participants and Context

This study employed a single-group, pretest-posttest design to investigate the development of design thinking skills in 79 eleventh-grade students from two classes (aged from 16-17) in New Taipei City. The intervention consisted of a teaching module that spanned 18 weeks, with two 50-minute sessions per week. Adopting the five-stage framework of empathize, define, ideate, prototype, and test, students assumed the role of designers. Their task was to create engaging tabletop games by incorporating key concepts from chemistry, biology, physics, and earth science into the game mechanics.

Instructional design and instruments

The primary instrument for this study was a pre-test and post-test questionnaire designed to measure students' design thinking skills. Student-generated data, such as design diagrams, presentation videos, physical artifacts, and written feedback, were collected as supporting evidence.

Design thinking skills questionnaire and the rubrics

A questionnaire assessing design thinking skills was developed based on the design thinking framework. The questionnaire uses a specific product or service as a central theme to measure students' familiarity with and proficiency in the design thinking framework before and after the instruction.

The questionnaire's dimensions align with the five stages of design thinking: empathize, define, ideate, prototype, and test. To ensure the instrument's quality, a two-stage validation process was conducted. First, the questionnaire was reviewed by three 11th-grade students from a non-participating class to ensure item clarity, with revisions made according to their feedback. Subsequently, the instrument was validated for content by two experts in science education. The complete questionnaire is provided in the Appendix.

A corresponding rubrics was developed to assess student performance across the previously mentioned five dimensions (Table 1). Each dimension is evaluated on three performance levels (0-2). For example, within the define dimension, level 0 indicates a non-response or an irrelevant answer; level 1 reflects the ability to describe one way of identifying the problem and its potential challenges; and level 2 reflects the ability to describe two or more ways. The rubrics were also validated by two experts in science education and revised based on their suggestions. To establish inter-rater reliability, the primary researcher and a second rater independently scored a sample of four questionnaires. After discussing and resolving initial discrepancies, they scored the remaining questionnaires, achieving an inter-rater agreement of 0.94.

Table1 The rubrics of design thinking skills

	Level 0	Level 1	Level 2
Empathy	No response or irrelevant answer	Identifies one user-related need connected to the product but lacks depth or clarity	Clearly identifies two or more user-related needs connected to the product, demonstrating an understanding of user perspectives.
Define	No response or irrelevant answer	Mentions the need for a new product but provides limited or unclear description of relevant constraints.	Clearly and thoroughly defines the problem, including its constraints and considerations based on user characteristics.
Ideate	No response or irrelevant answer	Briefly explains the brainstorming and narrowing process but does not clearly connect it to the defined problem.	Provides a detailed explanation of the brainstorming and idea-narrowing process, directly addressing the defined problem and user needs.
Prototype	No response or irrelevant answer	Sketches a simple diagram but does not highlight specific functional parts or explain how they meet user needs.	Creates a detailed diagram, identifies specific functional parts, and provides clear explanations of how they meet user needs and solve the defined problem.
Test	No response or irrelevant answer	Mentions the testing and revision process but fails to connect it to the problem definition or user feedback.	Clearly and comprehensively explains the testing and revision process, incorporating insights from problem definition and user feedback to improve the product.

Instructional design

The instructional design is primarily based on the design thinking process, guiding students to develop a science tabletop game. The instructional process began with a one-week introductory phase where the teacher outlined the learning objectives and required deliverables while explaining the core concepts of design thinking. Following this, students moved into a three-week exploration phase to broaden their perspectives by playing various existing science tabletop games, with the objective of identifying different game mechanics. Subsequently, they worked in groups to discuss, brainstorm, and formulate an initial design plan. The development stage then commenced with a two-week period where each group presented their initial design direction, an interactive session that allowed the teacher and peers to provide crucial feedback for refinement. After incorporating this feedback, groups spent the next two weeks in further discussion and revision, during which the teacher provided timely technical assistance and monitored their progress. Once their plans were revised, students conducted a second presentation over another two weeks, allowing for a further round of peer and teacher refinement. With a well-refined concept in hand, students then entered a four-week creation phase to visualize their ideas and build their initial prototypes. This was followed by a two-week period of internal playtesting, where groups self-evaluated their game's flow and mechanics, identified areas for improvement, and made necessary revisions. Finally, the process culminated in a two-week showcase where the groups presented their completed products using a world café format, allowing students from different groups to rotate, play, and score each other's games.

Data collection

The data collected in this study were categorized into two types: qualitative and quantitative. The qualitative data included students' in-class design thinking questionnaires and the feedback questionnaires. The quantitative data were primarily derived by scoring the students' qualitative responses according to a scoring rubric, and these scores were then analyzed using a paired samples t-test on the pre-test and post-test results. Additionally, materials such as in-class tabletop game design worksheets, student presentation slides, and classroom video recordings served as supplementary data to provide supporting evidence for the teaching process.

Results

The instructional intervention significantly improved students' design thinking skills

To understand the differences in students' design thinking skills before and after the instructional intervention, the researcher scored student responses on a scale of 0, 1, or 2 according to the scoring rubric. A paired samples t-test was then conducted on the total score (maximum of 24) and on the individual constructs: empathize (max 4), define (max 6), ideate (max 4), prototype (max 6), and test (max 4). The results are summarized in Table 2. The findings indicate that there were statistically significant differences between the pre-test and post-test scores for the total score ($p = .000 < .05$), empathize ($p = .000 < .05$), define ($p = .001 < .05$), ideate ($p = .000 < .05$), prototype ($p = .000 < .05$), and test ($p = .000 < .05$).

Table 2. Paired samples t-test for design thinking skills (N = 79)

Item	Test	Mean (SD)	95% CI [Lower, Upper]	t-value	*p*	Cohen's *d*
Total Score	Pre	14.90 (3.68)	3.00, 4.46	10.18	.000***	0.93
	Post	18.63 (4.35)				
Empathize	Pre	2.01 (0.91)	0.62, 1.16	6.52	.000***	0.90
	Post	2.90 (1.07)				
Define	Pre	3.73 (1.32)	0.19, 0.70	3.42	.001**	0.34
	Post	4.18 (1.33)				
Ideate	Pre	2.23 (1.00)	0.63, 1.09	7.40	.000***	0.84
	Post	3.09 (1.04)				
Prototype	Pre	4.48 (1.46)	0.46, 1.09	4.85	.000***	0.55
	Post	5.25 (1.32)				
Test	Pre	2.44 (0.94)	0.54, 1.00	6.62	.000***	0.83
	Post	3.21 (0.92)				

Note: *$p < .05$; **$p < .01$; ***$p < .001$

In the pre-test, students were generally able to reach level 1 in each dimension, indicating that the 11th-grade students possessed a foundational level of design thinking skills. Among the five constructs, their initial performance was highest in prototype, showing that students were capable of conceiving a product based on their own ideas, creating a simple sketch, and explaining its innovative features. The lowest-performing construct in the pre-test was empathize, where students either described only one way to empathize with the audience or provided an irrelevant answer about who they intended to empathize with. In the post-test, the average score for each of the five constructs was nearly at or above level 1.5. Prototype remained the highest-performing area, while empathize remained the lowest, although both showed a statistically significant improvement compared to the pre-test. These results suggest that the instructional intervention was effective in enhancing the design thinking skills of students who already had a basic foundation.

Guidance, feedback, and iteration drove the refinement of student game designs

The science tabletop game design course was structured according to the stages of design thinking. As illustrated in the process diagram (Figure 2), although the students had experience playing tabletop games, they were initially unclear about how to design and produce a finished product. Therefore, the process began with students playing and evaluating various commercial science games to identify their strengths and weaknesses. This activity helped establish a foundational understanding of what a science tabletop game entails and the key elements to consider during the design phase.

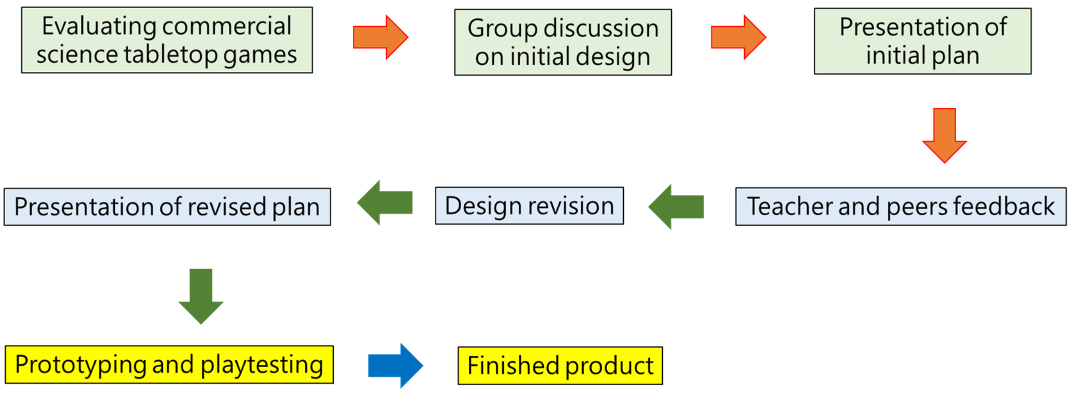

Figure 2. The process of students refining their designed science tabletop games

Following this, student groups began the design process, guided by worksheets and presentation prompts provided by the teacher. These prompts included guiding questions such as: "What is the core scientific concept?", "Why is this concept considered difficult to learn?", and "How can the game mechanics facilitate the learning of this concept?". This structured approach enabled students to develop a complete initial design.

During the initial presentations, peers provided feedback using structured forms, while the teacher also shared insights on the scientific concepts and game design to help students enhance their work. Subsequently, students revised their designs based on the feedback from the first presentation and then conducted a second round of sharing and revision. After two cycles of revision and confirming the integrity of their refined concepts, the groups began the physical production of their tabletop games. Finally, a world café format was used for the final showcase, where groups interacted with, playtested, and scored each other's games.

Students self-reported learning growth and evaluation for the course

Hardship, fun, and a sense of achievement Students described the game design process as a challenging yet ultimately rewarding journey that fostered a profound sense of achievement. The difficulty of creating a product from scratch was a common theme, with one student stating, "Making the tabletop game ourselves was super tiring" (A-25), reflecting the arduous process of translating scientific concepts into playable game mechanics. Despite this, the experience was also filled with enjoyment and collaborative spirit, as another student noted, "Although it was tough, we were full of laughter in the end" (B-03). This journey culminated in a strong sense of accomplishment, best summarized by a student who expressed, "I felt a huge sense of accomplishment after finishing. It was an unforgettable and rewarding memory" (A-33), highlighting the lasting, positive impact of seeing their creation enjoyed by others.

Teamwork The collaborative nature of the game design enhanced students' teamwork, teaching them to consider user needs while fostering internal team coordination. Students learned to approach the design from multiple standpoints, with one student noting that the process taught them "how to consider others' needs from different perspectives, how to make a team work together smoothly, and how to make our product better fit the theme" (A-17). This collective effort underscored the importance of coordination in joint problem-solving. As another student stated, "by cooperating and coordinating with my group members, we found the best solutions to problems, which also strengthened our team cohesion" (B-21). Ultimately, the project required students to work together closely to find solutions, thereby improving their skills to function as a cohesive and effective team.

Communication Students reported that the process highlighted the importance of communication, both for gameplay and for formal presentations. They learned that effective communication was essential for the game itself to function, with one student noting, "When explaining the rules and gameplay to the teacher or other groups, if they couldn't understand what you were saying, the game couldn't proceed. So, I think communication skills are very important" (B-21). Furthermore, students felt that the multiple presentation cycles enhanced their public speaking skills. As another student expressed, "Through so many presentations, I became better at maintaining my composure on stage...spoke clearly without stuttering, and could highlight the main points" (A-25). Thus, the course was perceived to build communication skills in both interpersonal and presentational contexts.

High recommendation rate and student satisfaction Student feedback questionnaires revealed that the vast majority of students would strongly recommend this course. The data shows that 95% of enrolled students (75 out of 79) would recommend that their junior peers take this course. Students were generally satisfied with the course content and learning outcomes, believing it had a positive impact on their learning and development. Students also rated the semester-long course on a scale of 1 to 10, with 10 being the highest. The average overall rating for the course was 8.01. This is a considerably high score, indicating a high level of overall student satisfaction. Among the ratings, two students gave a low score of 1. A closer look revealed their dissatisfaction stemmed from the large amount of time required for thinking and production.

Discussion

Fostering Interdisciplinary Skills Through Science Game Design

The development of a science tabletop game is a highly complex, interdisciplinary challenge. It requires students to set clear objectives, integrate relevant scientific concepts, and design engaging gameplay mechanics. Furthermore, the process involves iterative cycles of testing, refinement, and clear communication of rules to ensure the final product is both educational and appealing. This course provided students with the unique opportunity to navigate this entire product development cycle, offering them a meaningful and holistic learning experience.

To guide students through this complexity, the course was structured around the design thinking framework. The hands-on, collaborative process fostered a positive learning environment and, consistent with prior research (e.g., Tu et al., 2018), enhanced student interaction and communication. Students themselves reported marked improvements in teamwork and collaborative problem-solving as they worked to bring their ideas to fruition.

This study extends previous findings by demonstrating the unique potential of design thinking within a deeply integrated, product-development context. Rather than applying design thinking to a single academic discipline, the core task of creating a science game required a sophisticated synthesis of diverse skills. Therefore, this course serves as a practical model for a truly integrated, multidisciplinary learning experience, aligning with calls for design thinking to be taught as a comprehensive framework rather than a supplemental activity (Yu et al., 2024). The research provides a valuable case study on leveraging a complex design challenge to foster interdisciplinary collaboration and innovation.

Cultivating design thinking skills through science game design

Design thinking is fundamentally an interdisciplinary mindset. The process of developing products or innovative services requires the integration of cross-disciplinary skills, including empathizing with others' needs, reframing problems, continuously diverging and converging on ideas, visualizing concepts, and understanding that success is the result of continuous refinement. By using science tabletop game development as its core, this study allows students to experience the authentic process of product development.

The core objective of the present study is different from that of the research by Parekh et al. (2021), although both successfully utilize tabletop game design as an educational tool. Parekh et al. focused on game design as a medium to enhance understanding of a specific topic—environmental science—and to foster systems thinking. In contrast, the present study centers on cultivating the design thinking process itself, aiming to develop students into proactive innovators. Our research implemented and measured the formal five-stage design thinking framework within a school-based course, whereas the study by Parekh et al. used a workshop format.

Assessing design thinking skills for problem-solving, not product evaluation

This course utilizes the design thinking framework to cultivate students to create a science tabletop game. The process guides students to understand player needs, brainstorm rules, integrate scientific concepts, and iteratively prototype and test their games. This practical framework also fosters key skills, including teamwork and communication.

A fundamental difference from the study by Zhu et al. (2025) lies not only in the project's complexity but also in the assessment methodology. The present study immersed senior high school students in a complex product development challenge, requiring the integration of chemistry, biology, physics, and earth science into game mechanics. In contrast, Zhu et al. engaged elementary students with more structured tasks. Critically, our assessment focused on the students' problem-solving thought processes during the design tasks. In contrast, Zhu et al. evaluated the final product's attributes using a detailed rating scale with dimensions like novelty, technicality, and aesthetic. This distinction highlights our study's emphasis on cultivating the cognitive skills of a designer, rather than solely grading the output.

Balancing Challenge with Appropriate Scaffolding

The findings also showed that some students gave negative comments because of a large time demand for thinking and production. Such comments are important for pedagogical reflection. This apparent “difficulty” is not necessarily a defect in the design of the course but rather a testament to its authenticity. It simulates the messiness and difficulty of real-world product development and constitutes a kind of “productive struggle,” which is an essential element for project-based or STEM learning (e.g., Bolyard, 2024). The amount of work the students had to put in to go through the whole design process from the beginning was almost as great as the sense of fulfillment they described upon completing it.

But it is also a cautionary note to instructors to more effectively scaffold, but not “dumb down”, the challenge of the class. In future terms, the course could address this by possibly dividing the project into a series of smaller bang-for-the-buck milestones and/or dedicating more structured in-class time for hands-on production to decrease after-class demands. In addition, instructors can frame this challenge proactively early in the course, to convey that such struggles are an expected and valuable part of the innovation process. This would help temper student expectations and promote greater resilience.

Conclusion

This study demonstrates the successful implementation of an interdisciplinary course where senior high school students designed and developed science tabletop games. By providing a creative learning environment, the course effectively guided students in applying the design thinking framework to a tangible product development cycle, significantly enhancing their design-related skills.

Following the five-stage design thinking model—empathize, define, ideate, prototype, and test—students engaged in a comprehensive, iterative process. This course began with an analysis of commercial tabletop games and initial brainstorming, progressed through multiple cycles of peer and teacher feedback, and culminated in the production and playtesting of a finished game. The quantitative results confirm the effectiveness of this approach, showing significant improvements in students' design thinking skills across all five dimensions from pre-test to post-test.

Beyond these metrics, qualitative data from student feedback revealed a rich, multifaceted learning experience. Students described the process as both challenging and highly rewarding, fostering a strong sense of achievement upon completion. They reported significant growth in crucial skills, including teamwork and communication. The overwhelmingly positive student evaluations, with 95% recommending the course to their junior peers, underscore its value and impact.

The primary implication of this research is that it offers a validated, practical framework for integrating design thinking into the science curriculum. This model serves as an effective pedagogical strategy for fostering design thinking skills and applying scientific knowledge in an engaging, project-based manner. For future research and practice, the course could be enhanced by incorporating modules on the commercial aspects of product development. For instance, introducing topics such as market analysis, intellectual property, and the patent application process would further empower students, providing them with a more complete understanding of how a scientific concept evolves into a market-ready product. This would not only deepen their learning but also better equip them for future innovation challenges.

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Appendix

A group of passionate young individuals aims to design an innovative product or service. Please answer the following questions step by step.

(1) What is the planned "product or service to be developed"?
(2) Who are the intended "target users" for this product or service?
(3) Before designing, how will you "empathize" to identify the "characteristics of the target users"?
(4) Before designing, how will you ensure that the product meets the "needs of the target users"?
(5) Among the various needs of the target users, how will you "define the problem you want to solve"?
(6) During the design process, how will you ensure that the problem you aim to solve aligns with the "needs of the target users" rather than being based solely on your own imagination?
(7) During the design process, what kind of "difficulties or limitations" might you encounter?
(8) During the design process, what methods will you use to facilitate team brainstorming?
(9) During the design process, describe how you will "narrow down and refine your ideas."
(10) (a) Please roughly sketch a prototype of the initial product.
(b) Explain the specific functional components.
(c) How do the specific functional components meet the needs of the users?
(11) How will you "test and revise" the initial product to make the design more suitable for the target users' needs?
(12) How will you "respond to user feedback" to make the design more suitable for the target users' needs? Please provide examples.