Development and Preliminary Evaluation of ProSynX: An Educational Card Game for Teaching Protein Translation

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ABSTRACT

Teaching protein translation is challenging due to the abstract and complex molecular processes involved. This study aimed to develop and evaluate ProSynX, an educational card game designed to facilitate student understanding of protein translation. Guided by the ADDIE instructional design model, the game was created to transform abstract concepts into an interactive and engaging learning experience. A structured usability questionnaire, reviewed by subject-matter experts, was used to evaluate students' perceptions across four dimensions: design, organization, playability, and usability. The study involved 169 undergraduate biology education students at Universiti Pendidikan Sultan Idris, selected through simple random sampling. Expert validation indicated strong content validity, and a pilot test confirmed high internal consistency (Cronbach's Alpha = 0.93). Descriptive analysis showed positive student perceptions, with mean scores ranging from 3.53 to 3.62 on a 4-point Likert scale. Students reported that ProSynX reinforced learning, encouraged peer discussion, and enhanced conceptual understanding of protein translation. The findings suggest that ProSynX is a practical, low-tech, and pedagogically sound supplementary tool for teaching molecular biology. Its accessibility makes it suitable for diverse educational contexts. Future studies should explore its application to other genetics topics, assess long-term learning outcomes, and consider digital enhancements to further increase engagement.

Keywords: Game-based learning, Genetics, Educational card game, ProSynX, Protein translation

INTRODUCTION

Protein translation is a fundamental yet challenging concept in genetics education. It involves intricate biochemical processes that many students find difficult to grasp, often leading to persistent misconceptions (Guzman & Bartlett, 2012). Students frequently struggle to connect genetic information with the molecular entities involved, such as ribosomes and proteins (Duncan & Reiser, 2007). The differences between prokaryotic and eukaryotic translation mechanisms add further complexity (Dangkulwanich et al., 2014). Moreover, the intangible and dynamic nature of molecular processes, including transcription and translation, makes them especially challenging to teach and learn (Newman et al., 2018; Williams et al., 2020).

Traditional lecture-based and textbook-driven instruction often fails to provide students with a coherent and integrated understanding of these processes. Prior studies have shown that students retain fragmented knowledge and struggle to synthesize molecular details into meaningful conceptual frameworks (Revell & Wainwright, 2009; Debs et al., 2019). A needs analysis conducted at Universiti Pendidikan Sultan Idris (UPSI) revealed that many biology education students identified genetics, particularly protein translation as one of the most difficult areas of the curriculum. This underscores the need for supplementary teaching strategies to enhance understanding and engagement.

Several active learning approaches, including inquiry-based learning, collaborative projects, and problem-based tasks, have been employed to address conceptual challenges in science education. These methods promote engagement and student-centred learning (Freeman et al., 2014; Kay et al., 2019). However, their effectiveness in teaching sequential and abstract molecular processes remains limited. Digital animations and simulations

provide useful visual representations but require technological infrastructure and may reduce opportunities for hands-on or peer-interactive learning. Thus, there is a need for low-cost, accessible tools that can encourage repeated practice, collaborative interaction, and conceptual reinforcement. Game-based learning (GBL) has emerged as a promising strategy to enhance motivation, participation, and teamwork in science education. In particular, educational card games have shown potential for helping students engage with abstract content by structuring it into interactive and repeatable activities that promote peer discussion and self-directed learning (Gutierrez, 2014; Singh et al., 2021). Despite these benefits, relatively few studies have explored the use of card games to address advanced genetics topics such as protein translation.

To address this gap, the present study introduces ProSynX, an educational card game designed to support student learning of protein translation. ProSynX provides opportunities for students to revisit and sequence molecular steps in an interactive, guided format, thereby complementing conventional instruction. Specifically, this study aimed to (i) develop ProSynX as a card-based learning tool for protein translation, (ii) to determine undergraduate students' perceptions of ProSynX in terms of design, organization, playability, and usability. By addressing a well-documented area of student difficulty through a low-tech, collaborative tool, this study contributes to expanding the repertoire of instructional strategies for teaching molecular biology.

METHOD

Research design

This study adopted a developmental research design to create and evaluate an instructional tool for teaching protein translation in genetics. The development process followed the ADDIE instructional design model, which consists of five phases: analysis, design, development, implementation, and evaluation. In the analysis phase, a needs assessment was conducted among undergraduate biology education students (Semesters 1–5) at Universiti Pendidikan Sultan Idris (UPSI). Students were asked to identify courses they found most difficult to understand. Genetics received the highest number of responses, highlighting protein translation as a key area of difficulty. This finding, supported by previous research, informed the study objectives and justified the selection of protein translation as the target subtopic. During the design phase, a conceptual framework was developed based on the needs analysis and supported by cognitive and constructivist learning theories. These theories emphasize active participation and reinforcement for long-term learning. The initial visual layout and card components were designed using Canva to ensure clarity, thematic consistency, and learner engagement. In the development phase, graphics and instructional content related to protein translation were selected, refined, and printed on high-quality Ivory cardstock. Each card represented molecular components and steps of the translation process in a simplified format. The finalized ProSynX card set was then prepared for expert review and classroom use (Figure 1).

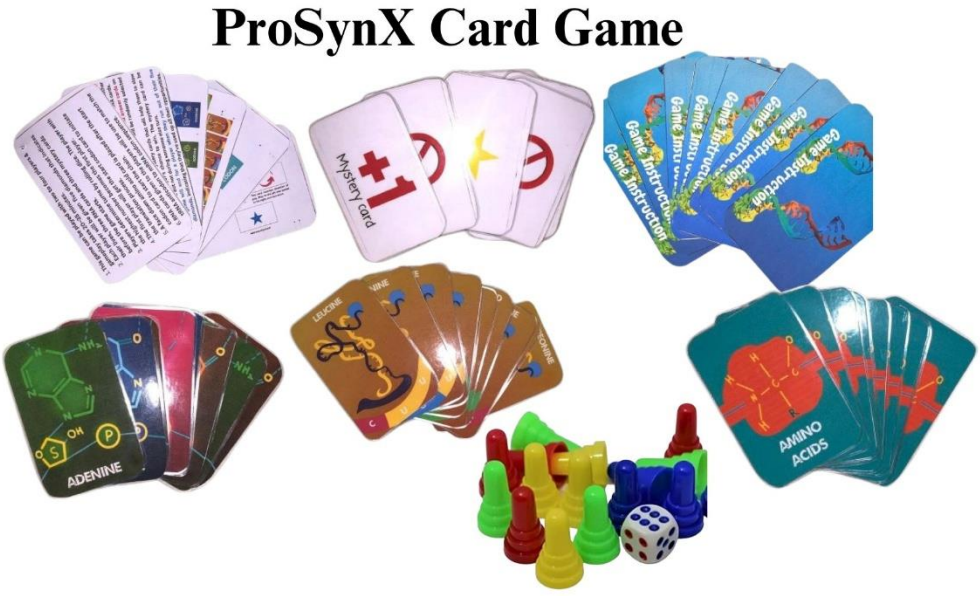

FIGURE 1. ProSynX card game set

The implementation phase involved validation of both the card game and the evaluation instruments. Two subject-matter experts in biology education assessed content and face validity. Quantitative validation employed Cohen's kappa coefficient and the Content Validity Index (CVI). Reliability of the usability questionnaire was further examined through a pilot test with 30 students, and internal consistency was analyzed using Cronbach's Alpha. Finally, in the evaluation phase, undergraduate students tested ProSynX and provided feedback via a structured usability questionnaire. Before completing the instrument, students were given time to review a user manual and an instructional video explaining gameplay. This stage aimed to assess the perceived usability of the card game in terms of design, playability, organization, and overall effectiveness as a teaching aid.

Population, Sampling, and Procedures

The study population comprised 300 undergraduate students enrolled in the Bachelor of Education (Biology) program at UPSI. Eligible participants were those in Semesters 3–7 who had previously completed the Genetics course in Semester 2. A simple random sampling method was applied to ensure equal representation. Based on Krejcie and Morgan's (1970) sample size determination table, 169 students were selected.

Each participant received three materials: (1) a user manual detailing the rules and objectives of the game, (2) an instructional video demonstrating gameplay, and (3) a structured usability questionnaire. These materials were distributed digitally via Google Forms. Students were required to review the manual and video before engaging with the game and subsequently completing the questionnaire.

Instruments, Validity, and Reliability

Two instruments were employed in this study: (i) a content validity assessment form and (ii) a structured usability questionnaire. The questionnaire consisted of two sections. Part A gathered demographic information, while Part B evaluated four dimensions of ProSynX: design (7 items), components and organization (4 items), playability (4 items), and usability (4 items), for a total of 19 items. Responses were rated on a four-point Likert scale (1 = Strongly Disagree, 4 = Strongly Agree).

The content validity of the research instrument was performed by two experts' biology lecturers specializing in genetics before the pilot study was initiated. Feedback from these experts was incorporated to refine both the tool and the instrument. A pilot test with 30 students was then conducted, and the analysis confirmed strong internal consistency (Cronbach's Alpha = 0.93), which exceeded the minimum threshold suggested by Johanson and Brooks (2010).

Data Analysis

Data were analyzed using the statistical software SPSS 29.0 for analysis. Descriptive statistics including frequencies, mean, and standard deviation were calculated to examine students' perceptions of the ProSynX card game across four constructs: design, organization, playability, and usability.

RESULTS AND DISCUSSION

Validity and Reliability of Instruments

As shown in Table 1, the instrument achieved strong content validity as assessed by two subject-matter experts in biology education. The Content Validity Index (CVI) values were also high, at 1.00 for Expert 1 and 1.00 for Expert 2, resulting in an overall CVI of 1.00. These results exceed the minimum threshold of 0.70 recommended for high-quality instructional instruments (Abu Bakar Nordin, 1995), confirming that the items were appropriate for evaluating the ProSynX card game. In other words, both experts agreed that the questionnaire effectively captured the intended constructs of design, components and organization, playability, and usability.

TABLE 1. The CVI of all the items (n= 19)

Construct	Item No.	Item	Expert 1	Expert 2	I-CVI	UA	S-CVI/Ave	S-CVI/UA
Design	1	The size of the cards used in the game is appropriate.	1	1	1	1	1.0	1.0
	2	The images printed on the cards are appropriate and represent the topic.	1	1	1	1		
	3	The terminology on the cards is useful for players to handle.	1	1	1	1		
	4	The materials used to produce the cards are durable (Ivory Card).	1	1	1	1		
	5	The font size used on the box and cards is clear.	1	1	1	1		
	6	The font type used is easy to understand.	1	1	1	1		
	7	The game cards are compact and easy to carry anywhere.	1	1	1	1		
Components and Organization	1	The instructions provided in the ProSynX game set are clear, concise, and easy to understand.	1	1	1	1	1.0	1.0
	2	The learning materials in the game cards help illustrate abstract concepts.	1	1	1	1		
	3	The ProSynX game is suitable for the comprehension level of Bachelor of Biology Education students.	1	1	1	1		
	4	The duration needed to play this game is sufficient.	1	1	1	1		
Playability	1	The game rules provide equal conditions for all players to ensure fairness.	1	1	1	1	1.0	1.0
	2	The game provides opportunities for healthy competition and cooperation.	1	1	1	1		
	3	The game rules provide flexibility in decision-making during play.	1	1	1	1		
	4	This card game is enjoyable to play.	1	1	1	1		
Usability	1	This card game encourages players to explore more deeply the subtopic of translation.	1	1	1	1	1.0	1.0
	2	Playing this card game is a very productive use of time.	1	1	1	1		
	3	The ProSynX card game is suitable as a teaching aid during lessons on protein translation.	1	1	1	1		
	4	I would recommend this card game to Biology Education undergraduates for learning the subtopic of translation.	1	1	1	1		

Preliminary Evaluation of ProSynX card game

With regard to the design construct**,** Table 2 presents student perceptions of this dimension. The overall mean score for this construct was 3.62 (SD = 0.39), the highest among the four constructs. Scores across all items were consistently above 3.48, showing strong approval of the visual and physical aspects of the card game. The highest-rated item was "The font type used is easy to understand" (M = 3.70, SD = 0.47), followed closely by "The images printed on the cards are appropriate and represent the topic" (M = 3.69, SD = 0.47) and "The font size used on the box and cards is clear" (M = 3.69, SD = 0.47). Slightly lower ratings were given to "The materials used to produce the cards are durable" (M = 3.48, SD = 0.51) and "The terminology on the cards has useful features for players to handle" (M = 3.49, SD = 0.50), although these scores remained favorable. Overall, students perceived the design of ProSynX as visually appealing, accessible, and supportive of learning.

Table 2. Descriptive Evaluation of the ProSynX Card Game

Construct	Item No.	Item (Translated into English)	Mean (M)	SD (σ)
Design	1	The size of the cards used in the game is appropriate.	3.65	0.49
	2	The images printed on the cards are appropriate and represent the topic.	3.69	0.47
	3	The terminology on the cards has useful features for players to handle.	3.49	0.50
	4	The materials used to produce the cards are durable (Ivory Card).	3.48	0.51
	5	The font size used on the box and cards is clear.	3.69	0.47
	6	The font type used is easy to understand.	3.70	0.47
	7	The cards are compact and easy to carry anywhere.	3.66	0.49
Overall Design			3.62	0.39
Components & Organization	1	The instructions provided in the ProSynX game set are clear, concise, and easy to follow.	3.55	0.50
	2	The learning materials in the game help illustrate abstract concepts.	3.50	0.50
	3	The ProSynX game is suitable for the comprehension level of Biology Education undergraduates.	3.47	0.50
	4	The time required to play this game is sufficient.	3.60	0.49
Overall Components & Organization			3.53	0.44
Playability	1	The game rules provide equal conditions for all players to ensure fairness.	3.53	0.50
	2	The game provides opportunities for healthy competition and cooperation.	3.54	0.50
	3	The game rules provide flexibility in decision-making during play.	3.51	0.50
	4	The card game is enjoyable to play.	3.65	0.48
Overall Playability			3.56	0.44
Usability	1	This card game encourages players to explore the subtopic of translation in more depth.	3.65	0.48
	2	Playing this card game is a very productive use of time.	3.65	0.48
	3	The ProSynX card game is suitable as a teaching aid for protein translation lessons.	3.55	0.50
	4	I would recommend this card game to Biology Education undergraduates for learning the subtopic of translation.	3.59	0.49
Overall Usability			3.61	0.44

Turning to the components and organization construct, the overall mean was 3.53 (SD = 0.44), the lowest among the constructs, though still within the "agree" range. The highest-rated item was "The time required to play this game is sufficient" (M = 3.60, SD = 0.49), indicating that most students considered the duration of gameplay appropriate. "The instructions provided are clear, concise, and easy to follow" (M = 3.55, SD = 0.50) also received a strong rating, suggesting students could easily understand how to play. Slightly lower ratings were given to "The learning materials in the game help illustrate abstract concepts" (M = 3.50, SD = 0.50), while the lowest-rated item was "The game is suitable for the comprehension level of Biology Education undergraduates" (M = 3.47, SD = 0.50). These findings suggest that while the organization was generally effective, improvements could be made to ensure stronger alignment with student comprehension levels.

In terms of playability, the overall mean score was 3.56 (SD = 0.44). Scores across all items ranged from 3.51 to 3.65, reflecting consistent satisfaction with gameplay. The highest-rated item was "The card game is enjoyable to play" (M = 3.65, SD = 0.48), suggesting that students found the game engaging and fun. This was followed by "The game provides opportunities for healthy competition and cooperation" (M = 3.54, SD = 0.50) and "The game rules provide equal conditions for fairness" (M = 3.53, SD = 0.50). Slightly lower but still favorable ratings were given to "The game rules provide flexibility in decision-making during play" (M = 3.51, SD = 0.50). These results indicate that ProSynX was perceived as enjoyable, fair, and motivating, though additional adjustments could further enhance decision-making flexibility.

Finally, with respect to usability, the overall mean score was 3.61 (SD = 0.44), the second-highest among the four constructs. Scores ranged from 3.50 to 3.65, demonstrating strong agreement among students that ProSynX was practical and beneficial. The highest-rated items were "The game encourages players to explore the subtopic of translation in more depth" (M = 3.65, SD = 0.48) and "Playing this card game is a very productive use of time" (M = 3.65, SD = 0.48). Slightly lower ratings were reported for "I would recommend this card game to Biology Education undergraduates" (M = 3.59, SD = 0.49) and "The game is suitable as a teaching aid for protein translation lessons" (M = 3.55, SD = 0.50). Overall, students regarded ProSynX as both effective and recommendable, though its role as a formal teaching aid could be further strengthened.

Among the four constructs, design received the highest overall mean score (M = 3.62). Students consistently valued features such as font clarity, card size, and visual relevance, indicating that aesthetic and carefully structured design elements played a central role in shaping their learning experience. This finding aligns with previous studies that emphasize the importance of visual clarity in simplifying abstract scientific concepts and sustaining learner attention (Gutierrez, 2014; Gilakjani, 2012). In addition, gamified tools that integrate high-quality visuals have been shown to reduce cognitive load and enhance engagement, further supporting the present results (Chen & Mokmin, 2024; Alvarado et al., 2024). The strong preference for design is particularly significant in the context of protein translation as a core molecular process in biology. Translation involves the stepwise decoding of mRNA into polypeptide chains by ribosomes, but its abstraction, invisibility, and sequential complexity make it difficult for students to grasp. Learners must mentally integrate spatial and temporal relationships among ribosomes, tRNAs, mRNA, and nascent polypeptides which interactions that cannot be directly observed. Without adequate scaffolding, this often leads to misconceptions and fragmented understanding. In this regard, the visual features of ProSynX likely provided students with concrete representations that reduced cognitive barriers, allowing them to better conceptualize the process of translation.

In contrast, components and organization received the lowest overall ratings (M = 3.53). While students generally agreed that instructions were clear and the duration appropriate, the lowest-rated item, "Game flow is logical" (M = 3.50), suggests that some learners found the sequencing less intuitive. Previous studies have highlighted the importance of structural clarity in educational games, noting that well-aligned rules and content provide essential cognitive scaffolding (Kordaki, 2015; Amabili et al., 2021). Similar organizational challenges have been observed in engineering and computing education, where unclear rules limited the educational value of card games (Haris et al., 2019; Hwang & Santolucito, 2021). One possible reason for the slightly lower ratings in this construct is the inherent complexity of protein translation, which involves multiple steps and interactions that are challenging to simplify without loss of accuracy. Balancing scientific concept with playability is a well-known challenge in educational game design, and in the case of ProSynX, this balance may have affected how students perceived the logical flow of the game. Refinements such as clearer rule summaries or guided demonstrations could help

address this issue and make gameplay more intuitive. Prior research shows that structural clarity in educational games which characterized by transparent rules and well-defined learning objectives can enhances student engagement (Gao et al., 2018). Greater engagement, in turn, is associated with higher motivation and improved learning outcomes, suggesting that strengthening the organizational features of ProSynX could potentially further increase its effectiveness.

Playability was rated positively (M = 3.56), with students particularly valuing the game's ease of understanding and overall enjoyment. The highest-rated item, "The card game is enjoyable to play" (M = 3.65), suggests that the competitive and interactive features of ProSynX fostered motivation and active participation. This finding is consistent with previous research showing that competition in educational games can stimulate engagement and support knowledge retention (Gutierrez, 2014; Lawsin, 2023). At the same time, competition may not equally benefit all learners, as some students prefer collaborative rather than competitive dynamics. A notable area of concern was the slightly lower rating for "Game duration is appropriate" (M = 3.54), indicating that the length of play may not have met the expectations of all students. Prior studies emphasize that game duration significantly influences learning outcomes: shorter sessions tend to sustain attention, while longer sessions allow for deeper exploration of content (Chu et al., 2011; de Sousa Silva et al., 2020). The mixed responses in this study likely reflect diverse student preferences and learning styles. This suggests that providing adaptable formats, for example, a shorter version for classroom activities and an extended version for review or group study could increase inclusivity and maximize the educational value of ProSynX.

In terms of usability, ProSynX was rated positively, achieving the second-highest overall score (M = 3.61), closely following design. The top-rated item, "The game encourages exploration" (M = 3.65), suggests that the game not only engaged students but also fostered curiosity and deeper engagement with the complex process of protein translation. Exploration is particularly valuable for abstract molecular topics, as it encourages learners to actively construct meaning rather than passively receive information. This finding is consistent with research demonstrating that playful learning activities promote peer interaction, critical thinking, and self-directed inquiry (Ismail et al., 2011; Campos da Silveira et al., 2021). By stimulating exploration, ProSynX may have provided opportunities for students to collaboratively unpack translation as a dynamic, sequential process. The strong usability ratings also highlight the advantage of its low-tech and accessible design. This feature is particularly relevant in resource-limited classrooms, where expensive digital simulations may not be available. Consistent with prior evidence that intuitive tools enhance inclusivity (Mavroudi et al., 2022), the accessibility of ProSynX increases its potential for widespread classroom adoption. At the same time, the item "The game is suitable as a teaching aid for revision" received a slightly lower rating (M = 3.55), suggesting that while the game was effective for exploration and discussion, it was less effective as a structured review tool. Exploration emphasizes discovery and meaning-making, whereas revision requires systematic reinforcement of content. This distinction indicates that ProSynX may need to be complemented with revision-oriented strategies, such as targeted quizzes, digital flashcards, or integration with existing review sessions, to maximize its instructional value.

CONCLUSION

This study highlights the potential of ProSynX as a valid and reliable educational tool for teaching the complex process of protein translation in undergraduate genetics. Student responses indicated high satisfaction across all constructs, including design, organization, playability, and usability. The results demonstrate that ProSynX transforms abstract molecular concepts into an accessible and engaging learning experience. By fostering active participation, peer interaction, and guided practice, the game encourages deeper conceptual understanding and supports the development of critical thinking skills. These features are particularly valuable in addressing common learning challenges associated with protein translation.

While this study demonstrated the potential of ProSynX as a supplementary instructional tool, several avenues for future research are worth pursuing. First, experimental and quasi-experimental studies with control groups are needed to move beyond perceptions and measure actual learning outcomes. Such designs would provide stronger evidence of whether the positive usability ratings observed here translate into measurable gains in conceptual understanding of protein translation. Longitudinal research could examine the sustained impact of ProSynX across multiple semesters or cohorts. Short-term usability feedback is valuable, but it does not capture

whether the benefits of using ProSynX persist over time. Investigating its long-term influence on student engagement, retention, and performance would help determine whether the game promotes lasting conceptual understanding, an important goal in science education. Finally, exploring digital integration, such as augmented reality or mobile applications, could improve the adaptability of ProSynX in hybrid or online learning environments. While the simplicity and low-cost nature of the physical game are strengths, digital features may increase interactivity, broaden accessibility, and appeal to tech-savvy students. At the same time, careful design would be needed to balance technological complexity with inclusivity, ensuring that digital enhancements do not create barriers in resource-limited settings.

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