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Enhancing Understanding of Complex Systems through Analogy-Based Video Scenarios

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Abstract: Biological education grapples with the challenge of teaching intricate systems, particularly the complex human immune system. Existing teaching methods often fall short of conveying these complexities effectively. Analogies and metaphors have proven successful in teaching complex biological systems across educational levels. We developed video scenarios connecting a wound-healing phenomenon with a real-life analogy, incorporating reflection spot activities for students to map elements based on structure, function, and behavior. Our study with high school students revealed significant improvements in their understanding of the wound-healing phenomenon through analogy mapping and reasoning. The study's contribution lies in an effective pedagogical and technological design for complex biological phenomena using analogies to enhance students' understanding of complex biological systems.

Keywords: Complex biology system, SBF framework, Analogical reasoning

1. Introduction

Biological education involves mastering complex, interconnected systems characterized by multilevel organization, diverse components, and dynamic processes, often posing challenges in understanding the relationships among facts (Hmelo-Silver et al., 2007). To comprehend such systems, it's crucial to learn their components, functions, and processes. The Human Immune system, a prime example of complexity, combines humoral and cellular interactions, frequently causing confusion among students (Su, Cheng, & Lin, 2014). While various teaching strategies have been explored, an educational card game using combat metaphors improved interest but lacked focus on cellular mechanisms (Su et al., 2014; Steinman & Blastos, 2002). Similarly, the Humanology Game integrated game features with immunology concepts, enhancing procedural knowledge (Cheng et al., 2014). These games employ metaphors or analogies, aiding students in connecting new concepts to familiar ideas.

Analogies and metaphors are valuable tools for teaching complex biological systems across various educational levels, including high school and undergraduate settings. Brown (2003) emphasized the importance of analogy as a universal learning mechanism at all ages. The structure-behavior-function theory posits that understanding any complex system involves analyzing its structures, functions, and how it achieves its purpose (Goel et al., 1996). Research has shown that even elementary school children can enhance their understanding of function and mechanism in complex systems through analogical modeling exercises, such as mapping respiratory system structures to the mechanism of human breathing (Moonhyun Han1 & Heui-baik Kim, 2017). This underscores the potential of analogies and analogous models for fostering learners' knowledge construction and reasoning skills related to the structure, mechanism, and function of complex systems. While strategies like card games and VR-based games use analogies or metaphors, they often focus on a superficial level rather than delving into the structure, behavior, and function aspects.

This study proposes a design of video scenarios based on the SBF theory and implements it in developing a wound-healing phenomenon from the human immune system and its corresponding analogy from a real-life situation, the water leakage process. The aim of this research was to investigate high school learners' ability to map the base analogy of “Water leakage at home” to the target concept of “Wound healing” as this is a new complex concept for high school students and understand their analogical reasoning through the SBF theory perspective.

2. Theoretical Framework

2.1 Analogy and Analogical Reasoning

Analogy and Analogical Reasoning Analogies involve comparing dissimilar concepts to uncover similarities, aiding comprehension of unfamiliar subjects. Gentner and Gentner (1983) argue that analogies enhance cognitive development by connecting existing knowledge to new concepts. This process involves relating the known (analog) to the unknown (target). Analogical reasoning is a multifaceted cognitive process involving steps such as identifying relevant information, extracting relationships, and mapping dissimilar domains for inferences and common principles (Trey & Khan, 2008). Mapping eases knowledge transfer from a source domain to a destination domain (Gentner 1983). Analogies assist in structuring concepts (Celik, Kirindi, & KOTAMAN, 2020). For instance, a bank robbery analogy helped students grasp hormone synthesis, transport, and mechanism concepts (Cardinali et al., 2022).

2.2 Structure-Behavior-Function Framework

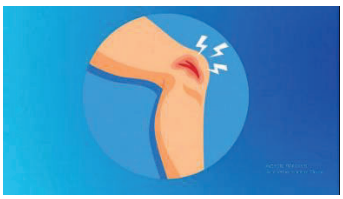
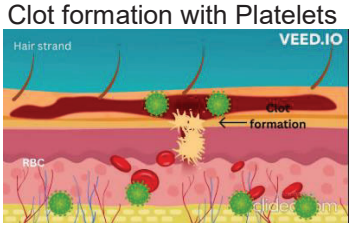
Structure-behavior-function (SBF) theory models complex systems, considering components, their functions, and enabling mechanisms. This representation aids comprehension and causal reasoning (Goel, 1996). Researchers used SBF theory and augmented reality (AR) to teach the circulatory system, yielding a better understanding (Gregorčič & Torkar, 2022). SBF is a valuable tool for comprehending complex systems (Hmelo-Silver & Pfeffer, 2004). We employ this framework to design video scenarios promoting analogical reasoning in students regarding the human immune system."

3. Design and Development of Scenarios

3.1 Designing video Scenarios

A wound-healing phenomenon from the human immune system was considered for the development of the scenario as it is a complex phenomenon that includes different types of blood cells, skin layers, proteins, and other factors that come together to perform an action. Its corresponding analogy was drawn from the day-to-day life routine i.e. water leaking at home. When water starts leaking, there is a mechanism to stop the leakage where different factors such as human factors, and other materials come into play. While designing videos for the analogy and scientific phenomena, mappings at structure, behavior, and function levels were considered. Table 1 shows elements from the water leakage scenario mapped to elements from the wound healing scenario. For example, Broken Skin from the wound healing phenomenon is mapped to Broken Roof from the analogy at the structure level. The clot formation process is mapped to plastic blocks stopping the leakage, this mapping is at the function level. Mechanism level mapping is done in the process of healing and stopping water leakage.

Table 1*: Design and Development of mapped elements in video scenarios*

Analogy video scenario elements (Water leakage)	**Complex phenomenon elements (Wound healing)**
Broken Roof 	Broken Skin 
Clot formation with Platelets 	Blocking of leakage with Plastic Blocks 

We created the wound healing video scenario in two ways: one without reflection spot activity and another with reflection spot activity using Edpuzzle's interactivity feature. The reflection spot activity includes multiple-choice questions in that the student has to map elements from the water leakage analogy to the wound healing concept, followed by reasoning for that mapping. There are a total of 5 mapping and reasoning questions. The analogy video scenario and the wound healing scenario with reflection spot activity were uploaded to the newly created 'Science Classroom' on the Edpuzzle platform (Mischel, L. J.,2019) - https://edpuzzle.com/open/cepbowi

4. Methodology

The purpose of this study is to determine whether students are able to identify and map the elements from the analogy water leakage scenario to the wound healing phenomenon scenario. Their analogical reasoning process will also shed light on how they grasp the target concept at the level of structure, function, or mechanism. This study is based on the following research question: “In what ways do analogy-based video scenarios help learners in their understanding of a complex system at three different levels (structure, function, and mechanism)?”

4.1 Participants and Procedure

In this study, a total of 12 students from grades 6 to 8 participated. They undertook two tasks: The initial task involved viewing a wound-healing scenario without reflection spot activity, followed by a pre-test questionnaire. In the subsequent task, students received instructions on using the Edpuzzle platform and were guided through the steps to complete the activity. During this phase, participants watched an analogy video scenario (Water leakage story) followed by a wound-healing phenomenon scenario. They engaged in a reflection spot activity to map elements and provided reasoning for each mapping. Following this, a post-test, similar to the pre-test, was administered, and a semi-structured interview concluded the study.

4.2 Data collection and analysis

Out of a total of 12 students, two students did not finish the activities entirely, while one student completed every activity except the pre-test. Thus, the data analysis of the reflection spot activity includes data from 10 students, whereas pre- and post-data include information from 9 participants. Throughout this study, four data sources were employed: pre-test, reflection spot activity questions, post-test, and interviews. The pre-test and post-test gathered data through a Google form, having open-ended questions like “Identify elements from the wound healing story" and "Describe or explain the wound healing process in proper sequence”.

Reflection spot activity data was collected in the form of MCQ and open-ended questions, for example, “*Which element from the analogy scenario is similar to the skin in this phenomenon scenario”* was the MCQ question followed by a question for reasoning “*In what aspects both the elements are similar*?”. A semi-structured interview was taken after students completed the activity. The questions for the interview were based on the responses students gave during the activity.

The SBF theory served as the framework for the analysis of the data. In order to determine if a student's thinking was at the level of structure, behavior, or function, a grading rubric based on the SBF theory was developed, and students' responses were examined using this criterion. Table 2. shows a scoring matrix for the reflection spot activity, Mappings are graded based on answers to multiple-choice questions, and reasoning is examined to see whether any points from the structure, function, and behavior level descriptors are present.

Table 2. *Scoring rubric for reflection spot activity*

	Skin and Roof	**Mentioned at least one of the phrases or words from the description**	**Did not mention even a single word/phrase from the descriptors**
	Identification and Mapping	If done correctly (1)	If not done correctly(0)
Structure	1) Outer layer or a boundary 2) **Damage** or the **broken area** is similar in the skin and roof. 2) The roof is **like skin** and the **pipe is like a blood vessel** 3) Roof had a leakage similarly Skin was bleeding.		
Function	1) Skin **Covers/ protects** us similarly roof protects the house. 2) Roof had a pipe that had water similarly skin has blood vessels that have blood flowing in it. (**carrying water and blood)**		
Behavior/ Mechanism	1) Skin **prevents entry** of external bacteria from coming inside our body similarly roof is preventing rain or insects from coming inside the house.		

A score of "1" was assigned if these features were identified, while a score of "0" was given if they were entirely absent from the reasoning. For pre-test and post-test responses similar scoring rubric was developed on 3 scales. If the responses included most of the structures, their function, and the proper sequence of the wound healing process then it was scored “3”. If half of the structures, functions, or sequence were correct then it was scored “2” and if only a few things mentioned were a correct or completely incorrect sequence of the process then it was scored “1”.

5. Result and Findings

5.1 Understanding students' analogy mapping and reasoning

Analysis of individual students' analogy mapping and reasoning of reflection spots showed that all of the students were able to map the base analogy to the target concept with a high degree of accuracy. However, the reasoning varied for the structure-function behavior. Figure 1 below represents the reflection spot activity data of 10 students.

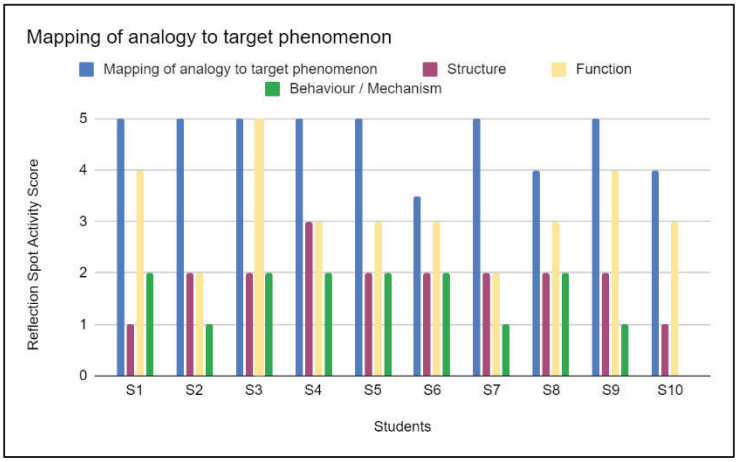


Figure 1: Reflection spot activity Scores

5.2 Analyzing Pre and Post-test Scores

A paired t-test was performed to evaluate if there was a difference between the learning gain from the pre-test to the post-test. The data was checked for normality assumption. The results showed that there was a statistically significant difference between the average of the pre-test (*Mean- 4.11, SD-1.27*) and post-test scores (*Mean –6.78, SD-1.92*) shown in Table 3., with a p-value of 0.0014 (< 0.01). The results of the paired t-test suggest that the use of analogy was effective in improving learning. The students who used analogy showed a significant improvement in their scores from the pre-test to the post-test.

Table 3: *Paired t-test Statistics*

Scores	Mean	N	SD	SEM
Pre-test	4.11	9	1.27	0.42
Post-test	6.78	9	1.92	0.64

5.3 Correlation between reflection spot activity score and students' post-test performance

To check if the reflection spots and reasoning activity helped learners in answering the post-test questions, we performed a Pearson correlation test between scores on reflection spot activity and post-test scores. The variable reflection spot activity score and post-test score were found to be weakly correlated r (0.276) but statistically not significant *p (0.44).*

6. Discussion

In this article, we explored high school students' ability to connect the "Water leakage at home" analogy with the concept of "Wound healing" using video scenarios based on the SBF theory. Our findings indicate that these analogy video scenarios effectively enhance students' understanding of complex systems at three different levels: structure, function, and behavior.

Specifically, 70% of students successfully mapped elements from the analogy to wound healing, while 70% understood the structural aspects with 40% accuracy, 80% grasped the functional aspects with over 60% accuracy, and 60% comprehended the mechanisms with 40% accuracy. The significant improvement in learning from the pre-test to the post-test underscores the pedagogical value of using analogies (Cardinali et al., 2022). However, we noted a statistically non-significant low correlation between the reflection spot activity scores and post-test scores, possibly due to the small sample size, prompting further exploration of the causal relationship between activity performance and subsequent test results.

This study contributes by using the SBF framework to map real-world scenarios to scientific phenomena through video-based scenarios and reflection spot activities. While our approach showed promise, its generalizability is limited by the study's focus on a single analogy and concept. Future research should involve a more diverse range of analogies and concepts and include larger sample sizes for improved statistical power and result reliability. We intend to continue designing analogical scenarios based on the SBF theory, providing scaffolding for analogical reasoning and investigating the impact of different reflection questions on students' learning with analogies to gain further insights.

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References

Cardinali, C. A., Martins, Y. A., Prates, R. P., de Araújo, E. V., Costa Viana, F. J., de Sousa, M. E., ... & Nunes, M. T. (2022). The bank robbery analogy as a first approach for understanding basic concepts of synthesis, transport, and mechanism of action of hormones. *Advances in Physiology Education*, *46*(4), 724-727.

Celik, H., Kirindi, T., & KOTAMAN, Y. A. (2020). The effect of the computer-based analogy used in science teaching on learning outcomes. *Journal of Turkish Science Education*, *17*(1), 73-93.

Cheng, M. T., Su, T., Huang, W. Y., & Chen, J. H. (2014). An educational game for learning human immunology: What do students learn and how do they perceive?. *British Journal of Educational Technology*, *45*(5), 820-833.

Gentner, D., & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. *Mental models*, *99*, 129.

Goel, A. K., Gómez de Silva Garza, A., Grué, N., Murdock, J. W., Recker, M. M., & Govindaraj, T. (1996). Towards design learning environments—I: Exploring how devices work. In *Intelligent Tutoring Systems: Third International Conference, ITS'96 Montréal, Canada, June 12–14, 1996 Proceedings 3* (pp. 493-501). Springer Berlin Heidelberg..

Gregorčič, T., & Torkar, G. (2022). Using the structure-behavior-function model in conjunction with augmented reality helps students understand the complexity of the circulatory system. *Advances in Physiology Education*, *46*(3), 367-374.

Han, M., & Kim, H. B. (2019). Elementary students' modeling using analogy models to reveal the hidden mechanism of the human respiratory system. International Journal of Science and Mathematics Education, 17, 923-942.

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive science*, *28*(1), 127-138.

Mischel, L. J. (2019). Watch and learn? Using EDpuzzle to enhance the use of online videos. *Management Teaching Review*, *4*(3), 283-289.

Steinman, R. A., & Blastos, M. T. (2002). A trading-card game teaching about host defence. *Medical education*, *36*(12), 1201-1208.

Su, T., Cheng, M. T., & Lin, S. H. (2014). Investigating the effectiveness of an educational card game for learning how human immunology is regulated. *CBE—Life Sciences Education*, *13*(3), 504-515..

Trey, L., & Khan, S. (2008). How science students can learn about unobservable phenomena using computer-based analogies. *Computers & Education*, *51*(2), 519-529.