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BioAnalogica: SBF-Based Analogical Stories to Enhance Understanding of Complex Biological Processes

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Abstract: Understanding complex systems is crucial, making it vital to strengthen high school students' grasp of complex biological processes. This study explores the design, development, and implementation of BioAnalogica, a Technology Enhanced Learning Environment comprising animated stories based on the Structure-Behaviour-Function (SBF) framework that use real-life analogies, like roof repair, to illustrate the human immune system's wound healing process. BioAnalogica was implemented with high school students as participants. Their understanding of wound healing was assessed through pre- and post-tests, interviews, and surveys. Findings show that students made improvements in understanding the mechanisms of wound healing, though their grasp of structures and functions did not change significantly. They responded positively to BioAnalogica, praising its clarity, connection to concepts, and engaging approach.

Keywords: Complex Biological Systems, SBF based – Analogical story, High school students, Interactivity

1. Introduction

Complex systems, seen in domains like science and engineering, consist of sub-components with hierarchical and dynamic interactions that are often difficult to intuitively understand, especially for novice learners. Students across various age groups face significant challenges when understanding complex biological systems, which require comprehension of multiple levels of organization, from macro (system, organ) to micro (cell, molecules), and their interactions. Students struggle with complex systems due to the intricate interconnections and multilevel organization, where mere memorization falls short. Contributing factors include a lack of conceptual understanding, reliance on rote learning, and limited use of technology in education (Hmelo-Silver et al., 2007,Doğru & Özsevgeç, 2018). The human immune system exemplifies a complex biological system, characterized by multiple interrelated components, dynamic interactions, hierarchical organization, and non-linear responses, making it difficult for students to understand (Cheng et al., 2014). Although analogical models, such as using syringes and balloons to teach respiration, have shown promise in improving comprehension by relating complex processes to everyday contexts (Han & Kim, 2019), they often fail to deeply connect with the target concepts and break down at superficial levels. Methods like the Structure-Behavior (Mechanism)- Function (SBF) framework provide a more structured approach, helping students visualize complex systems by their examining their structural components, functions, and how they work together. (Hmelo-Silver et al., 2007, Housh et al., 2022). However, current analogical models in immunology often lack deep relational mapping and fail to enhance students' higher-order cognitive skills (Gentner & Hoyos, 2017). This study presents the development of BioAnalogica, an interactive Technology Enhanced Learning Environment (TELE) that uses an SBF-based analogy of "Roof crack repair" to teach the "Wound healing process." Implementing BioAnalogica with 21 high school students showed no significant change in structure and function level scores, likely due to a ceiling effect. However, there was a significant improvement in understanding the mechanisms of how different structures together help wound healing. Most of the students reported enjoyable experience while interacting with BioAnalogica.

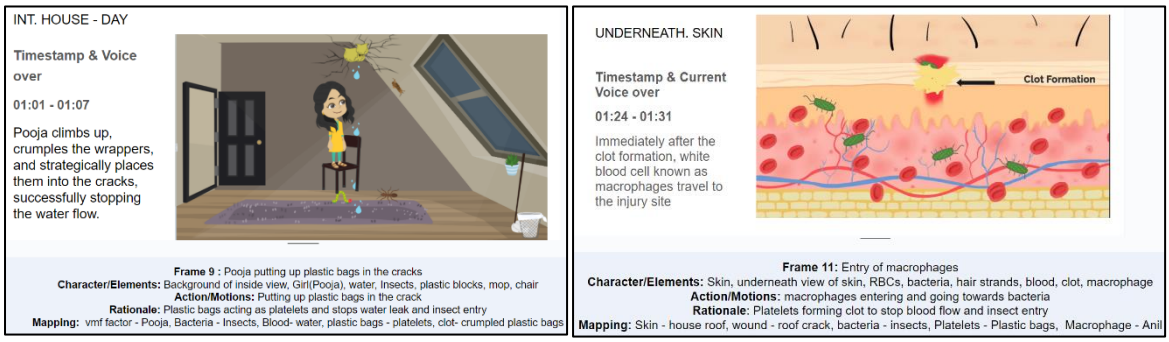
2. Design and Development of BioAnalogica

Dedre Gentner's Structure-Mapping Theory provides a foundational approach to understanding how analogies facilitate learning, by mapping relational structures from a familiar concept (the base, such as roof repair) to a new, complex concept (the target, such as wound healing) (Gentner & Hoyos, 2017). According to this theory, successful analogies require systematic relational mapping that captures the structural essence of the base domain and applies it logically to the target domain, aiding students in building on prior knowledge to comprehend new concepts. This relational mapping can be further understood through the Structure-Behaviour-Function framework. It offers a practical method for breaking down complex systems into their core components: structures (elements), behaviors (interactions or mechanisms), and functions (purposes) within the system (Hmelo-Silver et al., 2007). This study applies the SBF framework to map the wound healing process in the human immune system to the analogy of roof crack repair, ensuring that the structural, behavioral, and functional elements of the target concept align closely with those of the base analogy.

2.1 Design and Development of Interactive Stories

The design process began by selecting an appropriate analogy for the wound-healing process in the human immune system. The analogy chosen was "Roof crack repair," which aligns with the sequence of events and elements in the wound-healing process. This analogy was mapped to the target concept using the SBF framework, considering the complexity suitable for high school students. The structures, mechanisms, and functions in wound healing were systematically matched to those in the analogy story.

Storyboarding was a crucial step in constructing the narratives and scenarios for both stories. Once the mapping between the analogy and the target concept was finalized, the development of both the analogy story and the concept story was undertaken using the animation software "Vyond". The storyboards included details such as characters, actions, and voiceovers, all carefully mapped to align with the corresponding elements of the target concept. For instance, one scenario depicted clot formation by platelets in the concept story, while the analogy story illustrated roof crack blocking by plastic bags. These mappings were illustrated in frames in Figure 1 that detailed the timestamp, characters, and rationale behind the elements used. To enhance student engagement and understanding, the developed video stories were made interactive by incorporating reflection spot activities. These interactive elements were added using the Edpuzzle platform. Reflection spots were strategically placed within the concept video to guide students in making these connections.



1(a) *1(b)*

Figure 1 (a): Crack blocking in the Analogy Story (b): Wound Clotting in the Concept Story

3. Study and Findings

This research explored the impact of SBF-based analogies on students' understanding of complex biological concepts. The study addressed two questions: RQ1: How does the SBF-

based analogy affect students' understanding of complex biology? RQ2: What are students' perceptions of learning through BioAnalogica?

Using a mixed-methods approach, each student participated in a two-hour session, starting with a pre-test on wound healing, followed by an analogical story and an interactive conceptual story in BioAnalogica. The session concluded with a post-test and a perception survey. Open-ended responses collected from pre - and post-tests were analyzed with a SBF-based rubric, scoring students' understanding of structures, functions, and mechanisms involved in wound healing. These scores were then statistically analyzed to determine improvements in understanding. Upon completing interaction with BioAnalogica, students' perceptions regarding the analogy story were gathered using a Likert scale questionnaire. The statistical analysis of scores revealed mixed results across the structure, function, and mechanism levels. There was no significant difference between pre-and post-test scores at the structure and function levels, likely due to a ceiling effect observed in pre-test responses and semi-structured interviews. However, a statistically significant improvement was noted at the mechanism level, indicating that while students had prior knowledge of certain structures and their functions, their understanding of how these structures interact to facilitate wound healing improved as shown in Table 1 below. The perception survey results showed that BioAnalogica simplified complex concepts of wound healing, and most students enjoyed the experience and preferred analogical stories for future learning.

Table 1. *Statistical Analysis of pre-post responses to open-ended questions*

	Pre-test		Post-test				
Levels	Mean	SD	Mean	SD	*P*-value	SD	*z/t value*
Structure	5.19	1.83	5.33	2.51	0.631	2.08	-0.477
Function	4.09	2.28	4.05	2.04	0.940	2.87	-0.076
Behaviour	4.19	2.11	5.81	2.25	**0.015**	2.78	2.67

The study's small sample size in India and reliance on self-reported surveys limit the generalizability of the findings. Despite this, SBF-based analogical stories hold the potential to make complex processes easy and clear. Future research should explore and refine the design from structural and functional perspectives and with a larger and more diverse student population. Overall, BioAnalogica is a potential learning environment to support and investigate students understanding of complex biological phenomena.

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