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Enhancing Systemic Understanding of Complex Biological Phenomena through SBF Analogical Stories

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Abstract: Understanding complex biological systems requires learners to reason about how structures interact dynamically to achieve functional outcomes. Yet students often describe biological processes in superficially overlooking the causal mechanism and interdependencies that define systemic behavior. The Structure–Behavior–Function (SBF**)** framework offers a powerful lens for supporting such reasoning by making visible the roles of system components, their interactions, and purposes. This dissertation investigates how SBF based analogical stories accessible across mobile and classroom environments can foster systemic reasoning in biology education. This research will be done in three different phases, phase 1 focuses on design and development of SBF based systemic analogical stories as an intervention and study how these supports students SBF reasoning compared to piecemeal analogies. Phase 2 focuses on training teachers for co-designing with AI guidelines to develop SBF based systemic analogies and Phase 3 implements these teacher-developed digital analogies in authentic classroom settings, examining technology integration and ubiquitous learning opportunities.

Keywords: Structure-Function-Behaviour, Complex Biological Systems, SBF based Analogical Stories, Biology Education

1. Introduction

Everyday relevance of human body systems emphasizes the need for learners to reason about biological processes as interconnected systems rather than isolated facts. Students at the secondary level face persistent difficulties in making sense of complex biological systems, which involve multiple interacting components, dynamic behaviors (Hmelo & Azevedo, 2006; Assaraf et al., 2013). Addressing this challenge requires scaffolds that foreground systemic and mechanistic reasoning rather than superficial descriptions. The Structure-Behavior-Function (SBF) framework provides such a scaffold by helping learners organize their thinking around what components are, how they interact and why they matter in the give system (Hmelo-Silver et al., 2007). Studies show that SBF is most effective when combined with other approaches such as guided questions, simulations, or augmented reality, which enhance students' grasp of functions and behaviors (Gregorčič & Torkar, 2022).

Analogies have been studied to support students in learning complex abstract concepts by linking familiar context to new ideas (Gray & Holyoak, 2021). Yet most analogies in biology emphasize surface features, neglecting dynamic and systemic dimensions essential for understanding complex systems. When structured around SBF relations, story-based analogies have the potential to help students form mental schemas, critically evaluate mappings, and reason about biology as an interconnected system. This research addresses these needs by designing and developing SBF based systemic analogical stories delivered as digital animated narratives enriched with interactive reflection spots. These stories provide access across pace, time context and location as these can be used for reasoning in both classroom and self-directed settings.

For these interventions to reach authentic classrooms, however, teachers must be equipped not only with analogical materials but also with training on how to design and adapt them. Research shows that teachers often face challenges in creating analogies that are accurate, developmentally appropriate, and systematically linked to learning goals (Harrison & Treagust, 2006). Gen-AI have been used as co-designer in many contexts. So scaffolding teachers' ability to design analogies with Gen-AI as a co-designer, reflect on their limitations, and integrate them into inquiry-oriented lessons is effective method for scalability of these SBF based stories. Gen-AI will be explored as a co-designer supporting teachers in constructing systemic analogical stories by suggesting mappings, refining narratives, and flagging design gaps. In the third phase of this research these designed SBF based systemic analogies by teachers will be implemented in the secondary grade classrooms via platforms such as Moodle or webpage which is easily accessible to investigate how they are implemented in practice, what affordances and constraints arise during implementation. Through these three phase research we aim to contribute theoretical insights into SBF based systemic reasoning, practical design principles for scaling systemic analogical instructions in biology education.

2. Literature Review

2.1 SBF Reasoning in Complex Biological Systems

The Structure-Behaviour-Function framework is a useful tool for understanding how people understand complex systems (Hmelo-Silver & Pfeffer, 2004). Structure-behavior-function (SBF) theory is a way of representing complex systems that take into account the system's components, their function in the system, and the mechanisms that enable their functions. This representation can help people to understand how complex systems work and to reason about their functional and causal roles (Hmelo-Silver et.al., 2007). For example: In the system of an aquarium structures refer to system elements (e.g., fish, plants, and a filter are some elements that comprise an aquarium). Behaviors refer to how the structures of a system achieve their purpose. These are the interactions or mechanisms that yield a product, reaction, or outcome (e.g., filters remove waste by trapping large particles, absorbing chemicals, and converting ammonia into harmless chemicals). Finally, functions refer to why an element exists within a given system, that is, the purpose of a component in a system (Hmelo-Silver et.al,2007).

2.2 Analogies in learning Complex Biology Systems

Gentner's Structure-Mapping Theory (SMT) explains how analogies support learning by enabling students to build on prior knowledge (Gentner, 1983). In this framework, the familiar concept is the source (or base analog) and the new concept is the target (Glynn et al., 2007). SMT emphasizes that analogies map relational structures rather than surface attributes, which is critical for reasoning about complex systems. The systematicity principle further ensures that mapped relationships form a coherent, logical structure in the source domain and can be systematically applied to the target. Analogical reasoning, therefore, involves a multi-step cognitive process, attending to relevant information, extracting relationships, and mapping elements across domains to make inferences and identify general principles (Trey & Khan, 2008).

2.3 Digital Storytelling as a Ubiquitous Technology.

Digital storytelling represents a transformative pedagogical approach that leverages narrative structure, multimedia elements, and interactive technologies to create immersive learning experiences (Lambert, 2013). These digital storytelling can be scalable and accessible for learning as it can be easily integrated into LMSs (Moodle, Canvas, Blackboard) and embedded across website, mobile apps and social platforms.

3. Research Goal

The main aim of this research is to enhance students Structure-Behavior-Function reasoning while learning complex biological systems through SBF based analogical stories. To achieve this, the first goal is to design SBF based analogical stories with ubiquitous technology, then followed by understanding of how SBF-based systemic analogical stories can foster systemic reasoning about complex biological systems. The study seeks to explore how such SBF based systemic digital analogical stories can be scaled through teacher professional development focused on educational technology integration and classroom implementation across diverse technological contexts.

4. Methodology

4.1 Development of BioAnalogica: SBF-based Analogical Stories

Phase 1 targeted the development of Intervention which considered process of wound healing, a complex biological phenomena involving coordinated cellular and molecular actions. To make this accessible, the everyday analogy of roof crack repair was chosen to make it more contextual for learners. Using the Structure–Behavior–Function (SBF) framework, elements of the analogy (e.g., characters, tools, and repair actions) were systematically mapped to corresponding biological structures, mechanisms, and functions (e.g., platelets, proteins, and skin restoration). Both analogy and concept narratives were developed as animated video stories with multimedia integration. Students active participation was done through H5P reflection spots where learners have to actively map across domains and articulate their reasoning. This intervention BioAnalogica, is capable of cross platform integration enhancing its ubiquity with access, pace and context.

In Phase 2, a two-day professional learning workshop will be organized for 10-15 secondary biology teachers to support them in designing SBF-based systemic analogical stories. On Day 1, teachers will be introduced to the SBF framework, analyze everyday systems, and engage with the wound healing–roof repair analogy to experience how systemic mappings work. On Day 2, teachers will be co-designing everyday SBF-based analogical stories that map their chosen biology topics, develop storyboards, and present drafts for peer feedback. Follow-up mentoring sessions will guide refinement of their designs. Data sources will include teachers' design artifacts, reflective notes, and interviews, which will be analyzed to derive and validate design guidelines for developing systemic analogical stories.

In Phase 3, teachers will implement their final refined analogical stories in their respective classrooms via suitable platform for their learners based on the availability and supportive technology. The data collected during this phase will be classroom recordings, students pre-post assessments, and access its ubiquitous nature for fostering learning anytime, anywhere with different topics, contexts.

4.2 Study Design

The study is organized into three phases. **Phase 1**, which is currently in its final stage of analysis, investigates students' reasoning with SBF-based analogical stories. It addresses two research questions: **RQ1**: *How do SBF-based systemic analogical stories support students' reasoning about complex biological systems?* **Phase 2** shifts focus to secondary school teachers and explores **RQ2**: *How do design guidelines for developing SBF-based analogical stories support teachers in creating stories for diverse complex systems?* Finally, **Phase 3** examines classroom implementation, with **RQ3**: *How effective are teacher-designed SBF-based analogical stories in fostering students' reasoning during classroom implementation?* Table 1 represents which constructs and data sources will be considered for each RQs.

Table 1. *RQs, Theoretical Constructs, Data collection*

RQ	Phases	Key Constructs	Data Sources
RQ1	Phase 1 (Students)	SBF Reasoning Process	Pre-Post test data, Interview data
RQ2	Phase 2 (Teachers)	Design strategies, support required , challenges faces	Teachers design artifacts, Workshop recordings, reflections and interview
RQ3	Phase 3 (Classrooms)	Implementation features, affordances and constraints	Classroom recording, students reflections, pre – post assessments

5. Findings and Conclusions

This study contributes in three key ways. First, the findings for RQ1 have shown that SBF-based analogical stories help students view wound healing as a connected process, linking structures, behaviors, and functions rather than treating them as isolated facts. Students developed mental schemas such as “damage–repair,” refined their mappings, and critically evaluated the analogies, demonstrating that embedding SBF relations in stories fosters deeper and more reflective understanding of complex biological systems. Second, the investigation of RQ2 will reveal how systemic and piecemeal designs of analogies differ in supporting students’ reasoning processes. Building on these insights, Phase 2 will contribute to design knowledge by generating guidelines for creating effective SBF-based analogical stories and identifying the kinds of scaffolds that may further enhance learning. Finally, Phase 3 will provide practical and contextualized evidence on the use of teacher-designed analogies in authentic classrooms. It will highlight both the affordances and challenges of systemic analogical stories in practice and offer implications for scaling systemic reasoning pedagogy in biology education across diverse classroom technological contexts. The research ultimately contributes to understanding how ubiquitous access to well-designed digital learning tools can transform biology education by making complex systemic reasoning accessible anytime, anywhere, while supporting teachers in becoming effective designers of technology-enhanced learning experiences.

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