Jiang, B. et al. (Eds.) (2025). Proceedings of the 33rd International Conference on Computers in Education. Asia-Pacific Society for Computers in Education

# From Roof Cracks to Wound Healing: How Structure-Behavior-Function Analogy Shapes Students' Reasoning in Complex Biology System

**Meera PAWAR, Rajashri PRIYADARSHINI & Sahana MURTHY**
*Indian Institute of Technology Bombay, India*
***meerapawar19@iitb.ac.in***

**Abstract:** Complex biological systems, such as Human Body Systems, require a holistic understanding of how structures interact dynamically to produce functional outcomes. The Structure–Behavior–Function (SBF) framework offers a lens for capturing such reasoning by emphasizing the interconnected roles of system components, their mechanisms, and purposes. To support students in developing this form of reasoning, this study employed an SBF-based analogical story that compared the biological process of wound healing to the repair of a cracked roof. This study explores how an SBF-based analogical story, of repairing a cracked roof comparing with wound healing shapes students' reasoning about biological systems. Thematic analysis revealed key reasoning strategies students employed while interacting with the analogy. They mapped characters and roles across domains, gradually shifting from surface level similarities to identifying deeper behavioral and functional equivalences. Students compared the systems at both whole and part levels, demonstrating their ability to reason about interdependent system elements. To organize their understanding of biological processes, many developed schemas, such as distinguishing between temporary and permanent repairs. Furthermore, students were able to identify and critically evaluate the limitations of the given SBF-based analogical story, reflecting a deeper, more critical engagement with the analogy rather than relying on straightforward one-to-one mapping.

**Keywords:** Structure-Behavior-Function Framework, SBF- Analogy, Complex Biology Systems,

## 1. Introduction

Students at the secondary level frequently encounter difficulties in making sense of complex biological systems. These systems involve multiple interacting components, dynamic behaviors, and emergent properties that operate across different spatial and temporal scales (Hmelo & Azevedo, 2006). However, many students tend to rely on linear, part-by-part reasoning, which makes it difficult for them to grasp the interconnected and dynamic nature of biological phenomena and systems such as that of the human body (Assaraf, et. al, 2013). Building on this, a further challenge lies in helping students make sense of unobservable, micro-level phenomena and understanding how these relate to structure, behavior, and function (Hemlo & Pfeffer, 2004). Students have shown difficulties in reasoning about complex biological systems particularly about underlying mechanisms. One way to promote a meaningful understanding of such systems is through the Structure-Behavior-Function (SBF) framework, which helps students in systematically organizing their thinking about complex systems (Hmelo, 2007).

According to the constructivist learning theory, learning is supported when students can connect new concepts to familiar knowledge (Brock, 2024). In this context, analogies are commonly used as scaffolds to make abstract and unfamiliar ideas more accessible through acquiring relational schema (Gray & Holyoak, 2021). Analogical tasks have been proved to foster students' reasoning skills as well as their critical and creative thinking skills. Despite the widespread use of analogies in biology education, most emphasize only on structural and functional aspects, typically through visual or verbal formats (Rule & Furletti, 2004).

Combining pedagogical potential of analogies and explanatory power of SBF framework, we developed a technology-enhanced learning environment called BioAnalogica, featuring analogical stories designed explicitly around the SBF framework. These stories are intentionally aligned with biological target concepts such as, incorporating SBF elements along with narrative structures. The targeted complex biological system for this article is the human immune system. SBF based analogical story of roof crack repair was developed for the process of wound healing.

While our previous work focused on the design and learning outcomes of this intervention, the present study focuses on students reasoning process. This research article aims to investigate how analogical stories designed on SBF framework shapes students' reasoning about complex biological systems. With specific question, "*How does an SBF-based analogical story facilitate students' reasoning about the biological process of wound healing?"* By exploring how learners mapped elements of the analogical story to biological concept, we aim to uncover the underlying cognitive processes that shaped their SBF reasoning. we conducted a study in which 25 students engaged with the SBF based intervention. This paper contributes by highlighting key processes that students used the story to reason about wound healing.

## 2. Related Work

### *2.1 SBF Reasoning in Complex Biological Systems*

Knowledge about complex biological systems requires students to comprehend different levels of organization: macro (system, organ) and micro (cell, molecules) and the interactions between them (Snapir, et. al 2017). Understanding how the human body functions requires reasoning about the roles of individual parts (such as cells, tissues, and organs, for example, white blood cells, lymph nodes, and skin in the immune system), the mechanisms by which they interact (such as how white blood cells identify and attack pathogens through processes like recognition, signaling, and phagocytosis), and the purposes they serve (for instance, protecting the body from infections and maintaining internal balance or homeostasis) (Assaraf, et. al, 2013). Structure-Bheaviour-Function framework gives a way to reason about such complex systems in terms of its structures, their functions and how they achieve its function (Hmelo & Azevedo, 2006).

Studies show its effectiveness when paired with complementary pedagogical approaches, for instance, Jordan et al. (2013) found that combining SBF ontology with guided questions and simulations enhanced students' understanding of system dynamics and knowledge transfer. Hmelo and Pfeffer (2004) observed that experts rely on integrated SBF representations, unlike novices who focus on static features, highlighting the framework's role in fostering expert-like reasoning. Additionally, SBF-based instruction combined with augmented reality has improved students' ability to visualize and connect multilevel biological elements (Gregorčič, & Torkar, 2022). These findings highlights SBF's potential in designing and analyzing effective biology learning interventions.

### *2.2 Analogies in learning Complex Biology Systems*

Dedre Gentner's Structure-Mapping Theory (SMT) provides a fundamental framework for understanding how analogies support learning by helping students connect unfamiliar concepts (targets) to familiar ones (sources) (Gentner, 1996; Glynn, et al., 2007). A core principle of SMT is that learners tend to transfer coherent systems of relationships rather than isolated features, allowing the structural essence of the base domain to be meaningfully applied to the target. This relational focus is especially critical for reasoning about complex systems, where underlying mechanisms and interactions are more important than superficial similarities.

Salih (2010) highlighted the potential of analogical to improve their reasoning abilities as well as their critical and creative thinking. Rule and Furletti (2004) introduced “form and function analogy object boxes” to teach high school students about human body systems by pairing physical objects (e.g., smoke detector, camera lens) with body parts (e.g., nose, eye) based on shared structural features and functions. Through hands-on activities, students explored similarities, differences, and generated new analogies. While effective in highlighting structure and function, the approach largely overlooked the behavioral dimension, critical for understanding dynamic system interactions. When it comes to teaching the human immune system, many existing interventions, such as game-based learning (e.g., *Humonology*) (Cheng, et. al, 2014), simulations, and classroom activities, frequently rely on metaphors and analogies drawn from defense, combat, or warfare. These analogies tend to be ad hoc and are rarely grounded in the SBF framework. In addition to lack in robust design of these analogies, a persistent challenge in analogical reasoning lies in supporting students to attend to these deeper structural and behavioral correspondences. Younger learners, in particular, often struggle due to focus on perceptual features (Richland et al., 2006).

One of the study shows, Han and Kim (2019) used a physical analogical model, comprising a syringe and balloon to explore students' SBF reasoning about the respiratory system. Their study demonstrated that such models can support a shift from understanding surface-level functions to reasoning about underlying behaviors and mechanisms. However, this analogical model lacked a system level perspective, dynamic progression and multi-level organization important for holistic view of the system. These studies emphasize the value of bringing in SBF reasoning in supporting students’ understanding of human body systems and highlights the instructional value of thoughtfully designed analogies to scaffold for multi-level, systemic understanding. Supporting students in developing SBF reasoning requires explicit scaffolding that helps them identify system structures, understand dynamic behaviors, and relate these to functional outcomes. Designing learning experiences, such analogies around the SBF framework can offer this structured support, guiding students to reason more effectively about complex systems (Pawar, 2024).

In the context of understanding complex biological systems, there has been limited exploration of how students develop Structure–Behavior–Function (SBF) reasoning. This study reorients the focus toward the process of SBF reasoning itself, using analogies not as the primary object of analysis but as a medium to support and reveal how learners identify structures, interpret dynamic behaviors, and relate them to system functions. By emphasizing SBF reasoning and examining how it unfolds through analogical support, we gain a deeper understanding of how students make sense of biological complexity and develop coherent system-level explanations.

## 3. Method

This research uses a qualitative research approach to understand how this SBF based analogical story helps students in reasoning about complex biology process. This is based on our previous work in which we designed and employed an SBF-based analogical intervention (BioAnalogica) involving roof crack repair story to explain the wound healing process carefully designed on the basis of SBF framework (Human Immune System) to secondary school students.

### *3.1 Participants*

All participants were recruited through teachers, coaching centers, social media, and word-of-mouth during school vacations, limiting access to regular classrooms. Total 27 Grade 9-10 CBSE students from Maharashtra voluntarily joined, this grade was selected for their familiarity with basic biology (e.g., blood clotting, immunity) but not detailed wound healing mechanisms.

They had no formal exposure to S-B-F framework before the intervention. Before participation, informed consent was obtained from parents, and verbal assent was collected from students at the time of the study.

### *3.2 Materials*

The instructional material used was animated story based videos of wound healing and roof crack analogy. Story content was reviewed by biology education researcher and two high school biology teacher for scientific accuracy and age-appropriateness. Figure 1 shows a few of the scenes from these both the videos.

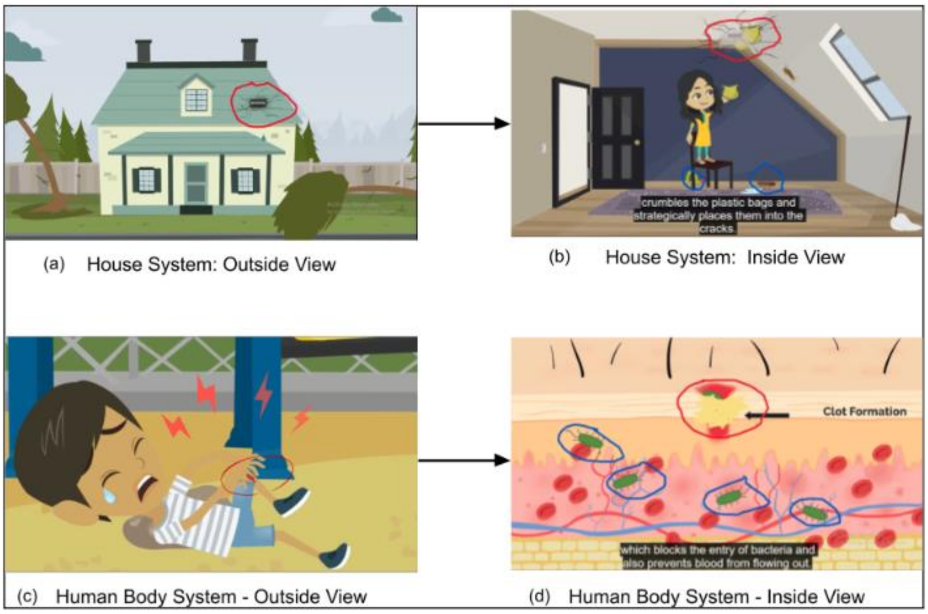


*Figure 1*: Visual representation of the SBF-based Roof Crack story (a, b) and wound healing process (c, d).

All the four visuals are as follows:

(a) Outside view of the analogy (Systemic view): A cracked roof on a house represents structural damage visible at the system level, analogous to a skin wound
(b) Inside view of the analogy (component view): Red circles indicate plastic patches applied internally to stop leakage (representing blood clotting), while blue circles depict insects entering through the crack (representing microbial invasion).
(c) Outside view of the human body (systemic view): A visible wound on the skin corresponds to the cracked roof, highlighting the structure and damage in the target domain.
(d) Inside view of the body (component view): Red circles show clot formation, and blue circles indicate bacterial entry at the wound site.

These visuals illustrate the Structure–Behavior–Function (SBF) mapping between the analogy and the target system. Images (a) and (c) represent the systemic views (house and human body). In contrast, images (b) and (d) provide internal components and their roles. In visuals (b) and (d), the red circles indicate plastic bags (Structure) used to block the roof crack (Function), which are analogous to platelets (Structure) responsible for blood clotting (Function) in the body. The blue circles mark the structural mapping of insects entering the damaged house and bacteria invading the wounded body. The behaviors are mapped and showed as continuous actions and interactions between all the components.

### *3.3 Data Collection*

Each student participated in the study individually. The procedure began with a pre-test followed by watching an SBF based analogical story for approximately 5-10 minutes, then students interacted with the conceptual story of wound healing. This story included embedded reflection spot questions placed at logical transition points. These questions prompted students to map elements from the analogical story to the target concept and provide reasoning for the connections they made. After completing the concept story and reflection questions, students took a post-test. Total interaction with the intervention lasted for 30-45 minutes. This was immediately followed by a one to one semi-structured interviews lasting 15-20 minutes per session, to explore their reasoning in depth.

This study primarily focuses on qualitative analysis of student interviews to investigate how SBF-based analogies supported students' understanding of the wound healing process. While pre- and post-tests were conducted to assess conceptual gains, those results have been analyzed and published (Pawar, 2024) in a separate study and are not the focus of this paper. Sample interview questions included questions about the usefulness of the SBF story and the reasoning processes and approaches with it, such as, "How did the given analogical story help you understand wound healing?" and "Could you think of the differences between both the stories?". These interviews provided rich insights into students' reasoning strategies, analogical thinking, and metacognitive reflections, offering a deeper understanding of how analogies support conceptual learning in complex biological systems.

### *3.4 Data Analysis*

All interview recordings were transcribed, and any responses in vernacular languages were translated into English for consistency. Students' responses were segmented at the sentence level, which served as the unit of analysis. A qualitative thematic analysis approach was used with mixed coding (Clarke & Braun, (2017). The coding scheme was theoretically motivated by the Structure-Mapping Theory and the Structure-Behavior-Function (SBF) framework, which guided the identification of patterns in the student's responses such as Mapping phase of their reasoning. However, the majority of the codes emerged inductively from the data, capturing students' context-specific reasoning patterns. The initial phase of analysis involved one researcher (First author) conducting open coding of 30 responses. These codes were then reviewed by a second expert researcher (Second author) with experience in conceptual learning and thematic analysis. An iterative consensus-building process followed with 87.1% agreement, during which codes were refined, categorized and merged based on emerging patterns and meaning. These codes captured both students' analogical reasoning processes and their evolving understanding of the biological system. The codes were then grouped into four broader themes, which reflected the key mechanisms through which SBF based analogical stories helped students reasoning about the wound healing process. All the themes are explained with examples in detail in the findings section.

## 4. Findings

While mapping is a foundational strategy in analogical learning, the way students engaged in this process varied considerably in both depth and direction, revealing different underlying processes. These mapping strategies reflected how students interpret, prioritize, and adapt SBF elements from the analogy to the target biological system. The following subthemes detail the different approaches students used during this mapping process.

### *4.1 Students used chronological alignment, to understand system behavior, followed by role-based mapping to link structure and function*

Students, while mapping an analogical story to the concept, mapped similarities in different ways. Learners aligned elements of the analogy and target concept by mapping structures, assigning roles to characters, and recognizing sequence and system-level interactions, reflecting emerging SBF reasoning. For example, student, S1, when asked how the analogical story helped, he mentioned that, "*It helped me understand* ***as first Pooja put plastic bags to stop the rain coming inside****. That was the same as blood clot as platelets are put there. Platelets we can say that* ***platelets are the same as plastic bags****. Then we saw Anil removing all the insects just like how white blood cells did, then we saw the* ***plumber putting cement paddy, same as fibroplasm (Fibroblast) which put collagen***." This excerpt shows a stepwise mapping strategy, where the student first traces the chronological structure of the analogy, starting with the first event (*first Pooja put plastic bags- Character in the Analogy*), and then gradually connects each character (*plastic*) to its corresponding function (stop the rain) and then map these with the wound healing (*That was the same as blood clot as platelets are put there).* The transition from saying "the same as" to "we can say" reflected an emerging confidence in the relational alignment, moving from simply noticing resemblance to asserting equivalence from SBF perspectives. The character-role mapping represents structure-function mapping, and the overall chronological sequence describes the behavior of the system of how wound healing occurs stepwise.

Another mechanism observed was when students, while identifying the similarities, tried creating a hypothetical situation and extending the understanding of both analogy and transferring the same understanding to the concept. For example, S12 thought of a hypothetical situation of "what if?" By saying, "….*No, for the understanding it is fine, but I think when you put the plastic bag,* ***so then again when the rain comes, again the water would come out of it,*** *they might come out. But I* ***think it matches this thing very well, because even after like again, if we get wounded on the same place****, so that layer that has formed of platelet, that would get broken. So it is totally similar…".* This indicates that the student engaged in a deeper level of reasoning by constructing a hypothetical situation of dynamic behavior of the system, how the structures (Plastic bags) over time and changes their function (Again water would come) under different conditions within the analogue domain and extending it to the target concept. By imagining what might happen if the plastic bag were removed and it rained again, the student reasoned about the failure and recurrence of the damage, and mapped it to the biological event of re-injury and clot breakdown in the same wound area. This reflective process highlights not only structural and functional parallels but also an emerging awareness of dynamic, cyclical processes within the system, strengthening the mapping between the analogy and the target concept.

In another example, S11 remarked, "..*That story (Analogical story) gave me an idea of what is going to happen one after other, and understood steps …Because if, for example, the WBCs start working even before the bacteria arrive, and then the platelets come in afterward,* ***it won't make sense and the process won't work properly****."* Here, the student recognized the interconnectedness of the system components (Platelets, WBC) and the importance of their coordinated functioning. By emphasizing that a mismatch in the sequence would disrupt the overall mechanism, the student demonstrated an understanding of the system as a dynamic whole, where the correct temporal alignment of parts is essential for the intended function to emerge.

Through this manner, SBF-based analogical stories supported students' understanding of complex systems by helping them grasp system behavior through chronological and interconnected processes, learn structure-function pairing via character-role mapping, and learn dynamic behavior by reasoning through hypothetical scenarios.

### *4.2 Students shifted between macro-level and micro-level perspectives to map systemic functions and local mechanisms across the analogy and biological process*

Another important strategy employed by students while engaging with SBF-based analogical stories involved changing their levels of perspectives, either adopting a zoomed-out, (macro) view of the system as a whole or a zoomed-in, (micro) view focusing on local parts and interactions. This form of perspective shifting revealed the flexibility with which students approached the analogical mapping between the biological process of wound healing and the SBF-based analogical story. In the zoomed-out approach, students mapped broad systemic roles and processes between the analogy and the biological target. For example, when a student remarked, "*. It was explained that* ***the house is related to our body***,." they reflected a zoomed-out perspective, where the student approached the analogy by comparing entire systems rather than isolated parts or events. Instead of focusing on specific one-to-one mappings, such as platelets with plastic sheets or fibroblasts with cement, the student recognized a holistic parallel between the house and the human body.

Consider another example excerpt by S17, *"Because the roof , .. I mean,* ***the house was shown to be related to our body.*** *When the roof got damaged,* ***both water and insects entered the house****, ….and then later, Anil's father came".* In this example, we see that students first emphasize on the similarities of both analog (House) and target (Body) as a whole part as a system. An analogical system of the house was mapped to the body system, indicating a zoom- out perspective. After discussing the body and the house as whole systems, she shifted perspectives to examine what happens inside (*both water and insects entered*), focusing on how damage allows insects to enter and how they are removed (*Anil's father came)*, demonstrating a move from a zoomed-out to a zoomed-in view.

Hence, in this way, the SBF based analogical story prompted students to shift perspectives first zooming out to understand the system as a whole and then zooming in to explore the interconnected parts and their functions aligned. This perspective-shifting reveals the flexibility with which students approached the analogical mapping between the SBF-based analogical story the and biological process of wound healing.

### *4.3 Through analogical abstraction, students constructed simplified models of wound healing, organizing their understanding around structural roles, behavioral sequences, and functional goals*

Another key theme that emerged was how students were able to make sense of the wound healing system by using the SBF-based analogical story. Through this, students formed a core idea or mental model of how the wound healing system works. For example, some students came up with a damage-repair model, where they understood the wound as a form of damage and the body's response as a repair process. Others talked about a temporary-permanent repair model, where the body initiates a quick, temporary fix followed by a more stable, long-term solution. These student-generated models suggest that learners were engaged in abstraction processes, moving beyond surface details to identify in-depth relationships. Rather than focusing only on visual or literal similarities, they recognized key structural, behavioral, and functional elements from the analogy and mapped them to the biological system. This shift indicates that the analogical story supported the understanding of how the system works both as a whole and at the level of individual parts. For example, when asked about the similarity between roof and skin, S13 explained "…*Because like after the* ***roof got damaged l****ike after that only the insects came inside and they tried to* ***fix it.*** *Okay. So like when* ***we get a wound,*** *the bacteria also comes inside and the cells, different cells* ***try to repair that****……".*

In this response, the student engages in a clear process of abstraction, moving beyond literal description to extract underlying relationships between the analogy and the biological system. She begins by identifying the structure-function relationship, linking the roof in the story to the skin in the human body. Both are recognized as protective barriers, and she understands that their function is compromised when physically damaged. Student then shifts to 1describing the behavior of the system: once the protective structure is breached, external agents (insects in the house and bacteria in the body) enter through the damaged area. This mapping reflects her ability to track cause-and-effect sequences, recognizing that the system's behavior changes dynamically after damage occurs. Finally, she refers to function again when she says "different cells try to repair that," pointing to the goal-directed actions that follow the intrusion. This shows her understanding that specific components of the biological system (e.g., immune cells and fibroblasts) are mobilized to restore the function of the damaged tissue. Here, student is not simply listing one-to-one correspondences between story elements and body parts. Instead, she is abstracting higher-level concepts such as protection, disruption, invasion, and repair, and using them to reason about the wound healing process

Another instance of abstraction and model development was observed when, students internalized the analogy as a “temporary and permanent repair” schema, in which early actions were seen as provisional fixes and later actions as more stable, long-term fixes. Instance of this can be seen in the excerpt of S11, “…*Then, Pooja realized that insects were entering from there, so* ***she stuck plastic bags over it, similar to how platelets arrive and temporarily cover*** *the wound…”.* In this response, the student exhibits an understanding of the wound healing process by distinguishing between immediate and long-term responses within the system. Student begins by describing the role of plastic bags and platelets as providing a temporary seal, indicating an awareness of the system’s initial, rapid response to damage aimed at preventing further damage to the system. Indicating understanding of dynamic and temporal (Temporary at the beginning) behavior of structural components (Platelets) while fulfilling their functions of repairing (Covering the wound). Then the student transitioned to long term fixes and identified structures plumber in analogy story and corresponding cells fibroblast in the body by saying “*After that, they called a plumber, and* ***he applied cement putty to provide a permanent fix*** *to the roof, restoring it to its original state. In biology****, this is like fibroblasts coming in and secreting a protein called collagen, which provides a permanent solution to the skin***”. This shows student’s ability to move beyond surface-level analogies and recognize the progression from a temporary function to permanent functions aligning with the underlying biological mechanism. By articulating this two-phase process, the student engages in abstraction, mapping not just events, but functional roles and temporal dynamics within the system. This explanation reflects an emerging systems perspective, in which structural components interact sequentially to restore working of the system.

Hence, in this way, the SBF-based analogical story facilitated students’ abstraction of the wound healing process by supporting model construction of system repair. It enabled learners to reason about the system’s sequential behavior and goal-directed functions, highlighting coordination among components during healing.

### *4.4 Students identified and evaluated mismatches in character roles, system dynamics, and underlying mechanisms between analog and target*

In this theme, we discuss how students demonstrated not only the ability to map similarities between the analogy and the biological system but also a critical awareness of where the analogy breaks down. Their reasoning extended beyond simple alignment to include identifying mismatches and limitations across structural, behavioral, and functional elements. This reflective engagement with the analogy indicates a process of evaluative thinking, where students monitored and questioned the accuracy of the mappings.

For instance, in one excerpt, a student S7 curious and grapples with the role of the character "Pooja," initially unsure how she fits into the wound healing process. Asks, “*Okay, so* ***what is Pooja supposed to be?*** *Hmm…”,* This question emerges from the student’s discomfort in not being able to locate a direct counterpart (Structure) for the character of Pooja in the wound healing concept, indicating active engagement with the structural elements of the analogy. The student kept thinking back and forth between the analogy and the target concept, and eventually attempts to bridge the gap by proposing a possible match for Pooja, by saying “***Maybe she could be the blood which brings the platelets***” this attempt to find a possible match goes beyond structural alignment and extends to the functional role, emphasizing the dynamic action of “bringing the platelets”. In doing so, the student refines the conceptual model of wound healing through reflective mapping of characters. This shows students transferred understanding of structures, their functions and place of action from analogical story to concept of wound healing.

By noticing these discrepancies and, dissimilarities, students demonstrated a critical understanding toward the analogy itself, rather than accepting it as it is. This reflective engagement suggests that their analogical reasoning was not limited to straightforward one-to-one mappings, but instead involved iterative evaluation, questioning, and refinement. The

SBF based analogical story supported this process by guiding students to examine how structures, their dynamic behaviors, and resulting functions correspond or fail to correspond across the analogical and biological domains. Such reflective awareness is especially important in learning complex biological systems, as it helps students recognize limitations in analogies and reduces the risk of misconceptions.

## 5. Discussion and Conclusion

The SBF-based analogical story played a central role in shaping how students' reasoning process to understand the complex biological process of wound healing. Rather than simply helping them find surface-level similarities by embedding structural elements, behaviors, and functions into a familiar, everyday narrative, the SBF aligned story provided a concrete way for students to follow the sequence of events, understand elements involved at each stage, and understand why those steps mattered. Rather than viewing the process as a disconnected list of biological terms, students were able to make sense of the sequence and purpose behind each event. They reasoned about who performs which function at each stage (like platelets being like plastic bags, or fibroblasts sealing the wound permanently), which shows they were thinking about the roles and functions of each part. This helped them see how the system behaves over time, not just what things are, but how the whole thing works as a process. This kind of mapping supports what Gentner (1983) refers to as systematicity, where learners are more likely to understand complex systems when they can align not just individual elements, but the relationships and sequences among them.

Another way in which SBF- aligned analogical story supported reasoning about wound healing process was by helping students in developing mental models or core ideas of the process by taking processes “Damage - Repair” and “Temporary - Permanent fix” ideas. These models were conceptually understood with the help of the narrative used in the stories. This supports what Gentner and Stevens (1983) and Hmelo-Silver et al. (2007) describe as analogical model-building, where learners use analogies not only to understand isolated ideas, but to build coherent mental models of a system. Another way this study extends previous research is in how students approached the mapping process itself. Rather than treating it as a fixed one-to-one match, many students revised their initial mappings based on deeper functional or behavioral understanding. For instance, when a student initially aligned a character with white blood cells but later re-evaluated and changed their mapping, they were not just engaging in analogical refinement, they were actively refining their understanding of how structures relate to functions within the system (Holyoak, 2012).

This study provides insight into how SBF-based analogical stories help address the challenge of learners being distracted by irrelevant details in analogies. Unlike the findings by Richland et al. (2006), who reported that younger learners often become distracted by such details, students in our study acknowledged these aspects but were still able to engage effectively with the core ideas of the analogy. Notably, students did not accept the analogy uncritically; instead, they questioned its applicability—asking, for instance, “What is Pooja supposed to be?”. Such comments indicate that students were engaged in evaluation rather than merely searching for matches, consistent with Holyoak and Gentner’s framework. This engagement suggests that students were not only using the analogy as a learning scaffold but also thinking about how (Behavior) and why (Purpose/Function) it works (or doesn’t), a reflective process that signals deeper conceptual understanding and analogical maturity, especially for this age group.

This suggests that reflective reasoning about complex process through analogy can naturally emerge when analogies are designed to highlight structure, behavior, and function explicitly. Because the SBF framework makes these relationships clear, students could more readily detect misalignments at the level of function, behavior, or structure, whether within components or the entire system. These findings extend prior research in important ways. Previous studies have noted that analogies can sometimes lead to misconceptions if students overextend mappings (Glynn et al., 2007). However, in this study, students themselves identified potential misconceptions.

The strategies students used, such as chronological alignment, role-based mapping, and analogical evaluation, were strongly informed by the SBF-based design of the analogical story. By explicitly embedding structures, behaviors, and functions within a familiar narrative, the story made the biological system's dynamics more accessible. The sequence of events mirrored wound healing, encouraging students to reason about processes over time, while assigning roles to characters (e.g., Anil as WBC) supported functional understanding. The SBF framework's focus on causality and interconnections helped students build coherent mental models, refine their mappings, and critically assess the analogy's limits indicating that their reasoning was shaped by both the structure of the analogy and the underlying SBF design principles.

A key limitation of this research is that it focused on short-term reasoning gains without examining long-term retention or transfer of SBF-based understanding. Additionally, the study relied solely on interview responses; incorporating multimodal data such as drawings or think-a louds could provide richer insights into students' reasoning. Future research could explore how students apply these analogical reasoning strategies in new biological contexts over time to assess deeper conceptual understanding.

## Acknowledgements

We would like to thank the schools and coaching centre for allowing their students to participate in the research and Coaching centre and IITB for granting access to their premises to conduct this research. And my colleague Alekh for their support during the research.

## References

Assaraf, O. B. Z., Dodick, J., & Tripto, J. (2013). High school students' understanding of the human body system. Research in Science Education, 43, 33-56.

Brock, R. (2024). Constructivist approaches to learning and teaching science. In Learning to Teach Science in the Secondary School (pp. 131-141). Routledge.

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.

Clarke, V., & Braun, V. (2017). Thematic analysis. *The journal of positive psychology*, *12*(3), 297-298.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive science*, *7*(2), 155-170.

Glynn, S. (2007). The teaching-with-analogies model. *PUB TYPE*, 195.

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.

Gray, M. E., & Holyoak, K. J. (2021). Teaching by analogy: From theory to practice. *Mind, Brain, and Education*, *15*(3), 250-263.

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., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *The Journal of the learning sciences*, *15*(1), 53-61.

Hmelo-Silver, C. E., Marathe, S., & Liu, L. (2007). Fish swim, rocks sit, and lungs breathe: Expert-novice understanding of complex systems. *The Journal of the Learning Sciences*, *16*(3), 307-331.

PAWAR, M., VASUDEVAN, S., & MURTHY, S. (2024, November). BioAnalogica: SBF-Based Analogical Stories to Enhance Understanding of Complex Biological Processes. In *International Conference on Computers in Education*.

Richland, L. E., Morrison, R. G., & Holyoak, K. J. (2006). Children's development of analogical reasoning: Insights from scene analogy problems. *Journal of experimental child psychology*, *94*(3), 249-273.

Salih, M. (2010). Developing Thinking Skills in Malaysian Science Students via an Analogical Task. *Journal of Science and Mathematics Education in Southeast Asia*, *33*(1), 110-128.