

GolgiQuest: Transporting, Sorting, and Modifying Life's Proteins:

A Hands-On Learning Experience Exploring Protein Transport, Sorting and Modification

Rylee R. Jacobson

The University of North Carolina at Chapel Hill

EDUC 915 Introduction to the Learning Sciences

Dr. R. Keith Sawyer

December 6, 2024

GolgiQuest: Transporting, Sorting, and Modifying Life's Proteins:

A Hands-On Learning Experience Exploring Protein Transport, Sorting and Modification

In primary and intermediate schools, educators often emphasize experiential learning and hands-on lessons to enhance and develop students' scientific thinking skills. While students are taught specific scientific phenomena and standards, these are often easily represented in real-world examples such as the lifecycle of a butterfly or the categorization of rock types. As students transition into upper middle and high school science classes, they are confronted with increasingly complex concepts in courses such as biology, chemistry, and physics. It becomes more difficult to provide physical examples. Instead, students are tasked with transitioning from concrete to abstract reasoning. This transition can be challenging and often deters students from exploring the sciences. There are, however, opportunities for educators and learning professionals to create real world embodied analogies that can draw upon particular aspects of concrete experiences or processes in scientific phenomena. These analogies can act as a vehicle to develop the higher order thinking required to understand difficult concepts. We can then offer additional enrichment by grounding these analogies in abstraction in simulation, deepening student learning and cognition as they practice abstraction. In this paper, I aim to create a learning experience incorporating these ideas and ground them in research from experts in the learning sciences. To address these challenges I have outlined, the experience applies the theory of embodiment, helping students connect physical, interactive tasks to abstract knowledge. Students will explore a museum featuring exhibits that mimic the biological processes of each organelle within an animal cell. By incorporating the principle of abstraction as simulated action, the design further bridges the gap between abstract cellular processes and tangible experiences. My learning experience is designed as a focused exhibit within this larger museum,

centering on the Golgi apparatus and its critical roles in modifying, packaging, and sorting proteins within the cell. It will be titled “GolgiQuest: Transporting, Sorting, and Modifying Life’s Proteins”. The analogy of a shipping warehouse serves as an embodiment tool by translating an abstract concept into a real world logistic system. Students move through three distinct stages: Receiving Dock (Cis Face), Modification Station (Lumen), Sorting Hub (Trans Face).

Foundations of the Learning Experience

The Target Learner

This learning experience is designed for ninth through twelfth grade students studying biology. These students need assistance conceptualizing the abstract processes that occur within the human cell. Additionally, they need to build an understanding that the cell is composed of multiple organelles, each with a designated function. Together, they are responsible for processes that support all forms of life. This is foundational knowledge that will support future learning in biology, such as the hierarchical nature of multicellular organisms and the systems of specialized cells within organisms.

The Value Proposition For The Learner

The value proposition of this learning experience is its ability to bridge the disconnect between abstract biological processes and tangible understanding. Students gain an enhanced conceptual understanding that can be challenging. Instead of relying on the digital visual simulations, such as video animations, that are often used within secondary biology classes, students gain a clear, practical understanding through an embodied experience. Students will also naturally gain critical thinking and problem-solving skills by practicing the higher order thinking

needed to interact with the experience. Finally, students will also be in an environment that fosters collaboration, movement, and teamwork, which makes the experience more enjoyable and encourages further exploration of the sciences.

The Intended Learning Outcomes

This experience is designed to deepen students' understanding of the role of the Golgi Apparatus and cellular processes. They will have the following cognitive outcomes. Students will identify the cis face, lumen, and trans face regions of the Golgi and their respective roles in transporting, sorting, and modifying proteins. Students will synthesize their knowledge of the Golgi Apparatus with other cellular organelles to understand their interdependence. They will recognize the parallels between cellular logistics and real world systems such as shipping and delivery. In addition to cognitive outcomes that increase knowledge and understanding there are also expected behaviors. These include the demonstration of the ability to categorize, modify, and sort objects, apply problem-solving skills, and practice collaborative teamwork by engaging in group tasks. Finally there are anticipated affective outcomes, such as students feeling more confident in understanding and applying abstract biological concepts, increased curiosity and interest in cellular biology and related sciences, and enjoy the collaborative and interactive nature of the experience, fostering a positive attitude toward STEM learning.

Students Journey Through GolgiQuest

As students enter the exhibit they are transported into a large warehouse inspired environment. Students are immediately immersed in the hands-on learning experience. The space is divided into three distinct stations each representing a key stage in protein processing: Receiving Dock (Cis Face), Modification Station (Lumen), and Sorting Hub (Trans Face). The space includes elements like conveyor belts, wooden crates and color coded pathways to simulate the look and feel of a shipping warehouse. Bright colorful directional lights and signs help guide students through the workflow. Each station features tactile interactive elements such as computers, scanning devices, labeling tools, printers, etc. The stations are connected by a conveyor belt system. Large colorful and vibrant diagrams and digital displays of the Golgi apparatus can be seen throughout the exhibit. These include real transmission electron micrographs and illustrated images of the golgi apparatus to provide context for the interactive tasks. The space encourages teamwork by providing shared spacious work stations that facilitate movement and collaboration. A DALL.E 3 rendered image was created to provide a conceptual visualization of the learning experience (Fig1).

Figure 1

An interactive exhibit where students actively participate in hands-on tasks, simulating key processes of the Golgi Apparatus in a warehouse-inspired learning environment.



Before beginning the tasks students watch a video that provides an overview of the exhibit and a basic lesson on the Golgi apparatus and the processes that occur within its structure. Students are then split into smaller groups that are assigned to a station, all groups will have the opportunity to rotate through all three stages. This helps them understand that while there is order in the Golgi these processes are often occurring simultaneously because of the nature of a cell. Museum staff, teachers, and guardians are positioned throughout the exhibit to provide deeper instruction and scaffolding for students when needed. Students complete specific tasks at each station to represent tasks that are completed within the Golgi.

Receiving Dock (Cis Face)

At the receiving dock, representing the Cis face of the Golgi Body, students are directed by interactive display screens to unload small crates which are visibly labeled as “proteins” from larger shipping containers labeled as “vesicles”. Once the proteins have been unloaded, the students scan a barcode on the crate to log that the protein is ready for modification. They work together as a team to identify matching symbols in their digital log to create a categorized list that will be sent to the sorting station. As they complete this process they place the scanned crates on a conveyor belt where they are moved towards the Modification Station (Lumen) station.

Modification Station (Lumen)

At the modification station students scan the labels on incoming crates labeled “proteins”. Once the crate has been scanned they are given direction on tablets and/or computers that tell them specific stickers that need to be placed on or removed from the crates. These stickers are color and symbol coated to represent specific modifications such as, phosphorylation of oligosaccharides, removal of mannose residues and addition of N-acetylglucosamine, or the

addition of galactose and sialic acid. Once modifications have been completed. Students move the crates to a new set of conveyor belts where they are sent to the Sorting hub.

Sorting Hub (Trans Face)

At the sorting hub students are guided by interactive display screens to use the labels and stickers as a guide to sort the crates into larger shipping containers similar to those from the receiving dock. These shipping containers are color coded and labeled as “exocytotic vesicles”, “secretory vesicles”, and “lysosomal vesicles”. Students are informed that each of the containers are destined for different locations within the cell.

Reflection

After students have the opportunity to experience all stations they are brought back together for a guided group reflection. Museum staff lead them by asking guided questions such as “What role does the Golgi Apparatus play in the cell, and how did the tasks at each station represent its functions?” or “Can you think of other systems (biological or real-world) that function like the Golgi Apparatus?” Finally, students are led to the next exhibit.

The Science and Innovation Behind the Design

Embodiment in Learning

Embodied learning posits that cognition is not only a mental process but suggests learning is shaped by our bodily experiences. Moreover, it argues that cognition is not solely constrained to the mind but is interwoven with how we move, interact with physical objects, and engage with our physical environment. According to embodied cognition theories, we can develop a deeper understanding of complex, abstract, or symbolic concepts by transposing them into the tangible world. In this way learners can develop understanding by physically engaging

with the phenomena they are studying. As addressed earlier in this paper, this approach can be invaluable in science education where complex processes such as those in cellular biology require learners to shift from concrete observable phenomena to abstract and invisible systems. The design of *GolgiQuest: Transporting, Sorting, and Modifying Life's Proteins* aligns with this approach by providing an interactive, embodied environment that connects the abstract process of transporting, sorting, and modifying proteins to concrete actions.

Embodied Cognition and Its Role in Science Education

Research in embodied cognition suggests that a learners' understanding of abstract concepts is enhanced when they are able to interact with representations of the subject matter in their physical environment. Zohar and Levy (2021) argue that "embodied learning theory... provides learners opportunities to ground the studied phenomenon in concrete bodily experiences". The design of *GolgiQuest* applies this principle consistently. Hands-on tasks are designed to mirror the processes occurring within the Golgi Complex. Students are not simply moving boxes and adding labels just because. Every interaction in the exhibit is designed to reflect a very specific process. This enables students to experience the phenomena as dynamic systems instead of static concepts.

As Nemirovsky et al. (2012) suggest in their work on mathematical embodiment, "mathematical insights developed by an individual or a group are expressed in and constituted by perceptuo-motor activity". Similarly, the conceptual knowledge of the Golgi Body in *GolgiQuest* is articulated through physical actions of the group in addition to verbal explanations and diagrams. Students work in groups to "move" proteins through the stages of the Golgi process. Using their bodies the complete tasks that simulate the functions of the Golgi apparatus; identification is embodied as scanning, modification is embodied as labeling, etc.

Bridging the Gap: From Concrete to Abstract Reasoning

In secondary school and beyond one of the key challenges of science education is helping students transition from concrete to abstract thinking. As Lowell (1979) explains, "In science, the ability to reason in abstract terms is considered essential to the extension of knowledge".

However, the truth remains that all abstract concepts, specifically those related to scientific phenomena, can be difficult or even impossible for students to grasp without grounding them into concrete experiences. In *GolgiQuest*, the embodiment of cellular function is designed to allow students to engage with abstract biological phenomena in a concrete framework. This helps them develop the skills needed to transition to reasoning in abstract terms. For example the concrete task of adding or removing labels and identifiers from crates helps them conceptualize that a modification of a protein involves adding or removing a "molecular component" such as the simple hexose sugar mannose.

This physical engagement fosters the kind of learning that Zohar and Levy (2021) highlight in their work on embodied chemistry learning environments: "Embodied learning enables students to experience directly how the attractive and repulsive forces are changed, and how this affects the energy changes". *GolgiQuest* was designed in a similar fashion to allow students to engage directly with the process of modifying and sorting proteins.

The Power of Analogy and Metaphor in Embodied Learning

One of the primary ways *GolgiQuest* facilitates embodied learning is through the use of metaphor. Nemirovsky et al. (2012) explain that "understanding of mathematics is tied to a certain set of grounded metaphors. The shipping warehouse metaphor in *GolgiQuest* serves as the grounding framework that allows students to acquire the reason in a familiar experience that can be applied to abstract scientific concepts. The stages of the Golgi apparatus (Receiving

Dock, Modification Station, Sorting Hub) are represented by tasks within a simulated warehouse environment, where students manipulate crates, apply labels, and sort proteins. They can find commonalities between the real world concrete logistic system and the abstract system operating in the Golgi body.

Conclusion

The design of *GolgiQuest* endeavors to implement the insights gathered from these research examples as well as the greater study of embodied cognition. This experience uniquely combines innovative methods to make abstract cellular biology tangible and engaging. Physical tasks simulate Golgi functions. While the real world metaphor of a shipping warehouse provides a connection to a familiar logistical system. The life-sized, museum-style setup allows students a full range of motion to encourage them practice movement and collaboration within the space. In-depth exploration of the Golgi Apparatus develops connections that can be linked to broader cellular functions. By providing students with this experience we are positioning them with the opportunity to engage physically with abstract scientific phenomena. This is a powerful tool for enhancing their learning, improving their conceptual understanding, and helping them develop the skills needed to practice abstract reasoning in future scientific applications.

References

- Lowell, W. E. (1979). A study of hierarchical classification in concrete and abstract thought. *Journal of Research in Science Teaching*, 16(3), 255-262.
<https://doi.org/10.1002/tea.3660160313>
- Nemirovsky, R., Rasmussen, C., Sweeney, G., & Wawro, M. (2012). When the Classroom Floor Becomes the Complex Plane: Addition and Multiplication as Ways of Bodily Navigation. *The Journal of the Learning Sciences*, 21(2), 287–323.
<http://www.jstor.org/stable/23266407>
- Sawyer, R. K. (Ed.). (2022). *The Cambridge Handbook of the Learning Sciences* (3rd ed.). Cambridge: Cambridge University Press.
- Zohar, A. R., & Levy, S. T. (2021). From feeling forces to understanding forces: The impact of bodily engagement on learning in science. *Journal of Research in Science Teaching*, 58(8), 1203–1237. <https://doi.org/10.1002/tea.21698>