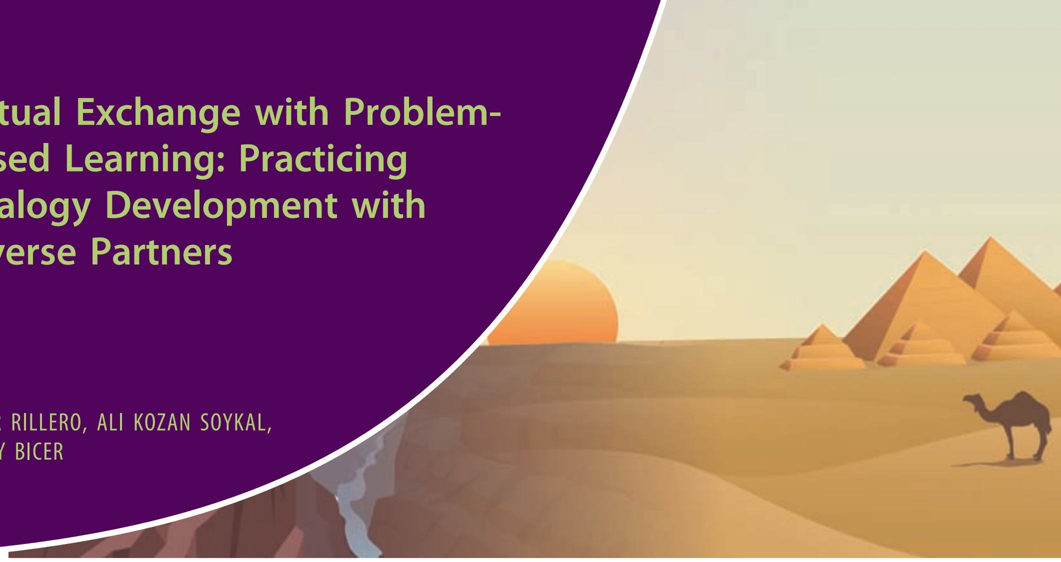
FEATURE ARTICLE

Virtual Exchange with Problem-Based Learning: Practicing Analogy Development with Diverse Partners



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Abstract

Problem-based learning via virtual exchange affords opportunities for students to learn biology while developing abilities to learn about and work with diverse others. We describe an activity using these methods, with goals for students to develop useful cell structure analogies, analyze how analogies are not perfect representations of target concepts, practice working with diverse others, deepen cell structure knowledge, and learn about people from another culture. We explain the framework for the activity and share student evaluation data. The activity had U.S. and Egyptian high school girls compare their Phoenix and Cairo homes, create an imagined combined home, construct an analogy for how cell structures and organelles are like parts of this home, and then analyze their analogy to see where it breaks down. The activity does not require special materials, only internet access through a computer or mobile phone and access to Google Docs. Students used critical and creative thinking, first to construct their analogies and then to analyze those analogies. Evaluation data suggest that students learned from the activity, enjoyed it, and appreciated the opportunity to work with someone from a different culture.

Key Words: *science education; secondary education; biology education; analogies; cell organelles; diversity; problem-based learning; virtual exchange; women and science.*

○ Introduction

In a longitudinal analysis of 25 million articles, Adams (2013) concluded that we have entered a new age of research – an age of *international collaborations*. Several researchers have concluded that the impact factor of an article is greater when the coauthorship is international (Adams et al., 2007; Schmoch & Schubert, 2008; Freeman & Huang, 2014). In science and in life, young people need to learn to work with diverse others, solving problems to achieve goals. This article describes an approach for international collaboration with problem-based learning (PBL) using a *virtual exchange* biology activity.

> *"A virtual exchange is an educational program that uses technology to bring diverse students together for collaborative problem-solving."*

Problem-Based Learning & Its Benefits

In PBL, a problem is posed before information on how to solve it is made available – in other words, student exploration precedes explanations (Loyens et al., 2008). We operationally define the method as follows: *Problem-based learning is an instructional approach where learners grapple with meaningful problems and collaboratively work toward their resolution.*

PBL started in medical education, suffused professional education, and has seeped into K–12 schools, with potential to achieve new science standards in states and countries (BouJaoude, 2012; NGSS Lead States, 2013; McConnell et al., 2018). Research suggests that PBL has many benefits, including improvements in problem-solving skills (Hmelo-Silver, 2004); cognitive engagement (Rotgans & Schmidt, 2011); academic learning, retention, and skill development (Jensen, 2015); critical thinking (Iwaoka et al., 2010); creativity (Ozdemir & Dikici, 2017); communication (Koh et al., 2008); self-directed learning (Koh et al., 2008; Loyens et al., 2008); biology research skills (Berry, 2017); working with others/teamwork skills (Koh et al., 2008; Brown et al., 2013); coping with uncertainty (Koh et al., 2008); and multicultural groups working together (Brown et al., 2013).

Different instructor roles can present implementation challenges (Abdelkhalek et al., 2010), which can be reduced by education about the approach (Dole et al., 2016). Primary and secondary school implementations have additional challenges. Good problems for K–12 PBL can be difficult to derive (Jonassen & Hung, 2008). In postsecondary education, PBL can focus on a specific profession. For example, vast amounts of patient-with-symptoms cases provide authentic PBL experiences for future health professionals. Since K–12 experiences cannot prepare students for one specific profession, they typically require a more general focus. Further, "the constraints in a K–12 setting such as large class sizes,

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short class periods, and full and fixed schedules by teachers and students make it especially difficult to use PBL in a K–12 classroom" (Liu, 2005, p. 160). There is a need to explore ways of making PBL more viable in classrooms.

Virtual Exchange

Many lives have been enriched by physical travel and interactions with people from diverse parts of the world in physical student exchanges, which offer significant benefits. For example, in Dwyer (2004), participants reported overwhelmingly that their exchange programs "continue to influence my perspectives on how I view the world" (95%), "enabled me to learn something about myself" (98%), "influenced me to seek out a greater diversity of friends" (90%), and "enabled me to tolerate ambiguity" (p. 17). Such benefits have led universities to consider exchanges as high-impact educational practices (Kuh & Schneider, 2008). Expenses and logistics, though, can make physical exchanges difficult. Only 10% of the U.S. population with an undergraduate degree participated in a study-abroad experience (Institute of International Education, 2017). In countries with lower incomes and challenges for international travel, such as Egypt, the rate is lower (Clark & Al-Shaikhly, 2013).

Virtual exchanges provide advantages of physical exchanges but at far less cost and with fewer logistical problems. Our operational definition of the approach is as follows: *A virtual exchange is an educational program that uses technology to bring diverse students together for collaborative problem-solving.* The technology in a virtual exchange can feel natural for young people (Eubanks, 2006).

○ Methods

The "Cai-Nix and Cell Organelles" activity is a virtual exchange for biology PBL, with goals for students to develop useful cell structure analogies, analyze how analogies are not perfect representations of target concepts, practice working with diverse others, deepen cell structure knowledge, and learn about people from another culture. Students from two all-female high schools in Phoenix, Arizona, USA, and Cairo, Egypt, participated in a voluntary before-school program. Groups of four students were created, such that two students were from the American school and two students were from the Egyptian school, as shown in Figure 1. The activity was conducted in English, which is the language of science and mathematics instruction in the Cairo school.

Cai-Nix and Cell Organelles was the first of five activities. The second activity was a forensic-type investigation, requiring cooperation between international partners as they explored blood type, clothing fragments, and handwriting. The third investigated behavior, blood pressure, eye dilation, and results of a urine test to determine why a student has not been focusing in class. The fourth activity had students select a fruit common to both countries and create a frequency distribution, then compare the histograms between the two countries. The final activity had students compare typical diets from their cultures for chlorophyll consumption and then analyze graphs of wavelength versus absorption of chlorophyll. The authors developed the first two activities and then the cooperating teachers developed three more activities.

Pre-Launch

Prior to the launch, teachers create groups and e-mail group members so they can initiate communication and introduce themselves to their overseas partners. The students are given access to the activity sheet in Google Docs. The assigned document can be viewed and downloaded at https://tinyurl.com/VEPBL. Google Docs promotes student interaction through simultaneous and asynchronous work that can be accessed by computer or mobile phone.

Activity Launch

During the launch, the teachers engaged students by telling them that they will deepen their understanding of cell organelles, develop

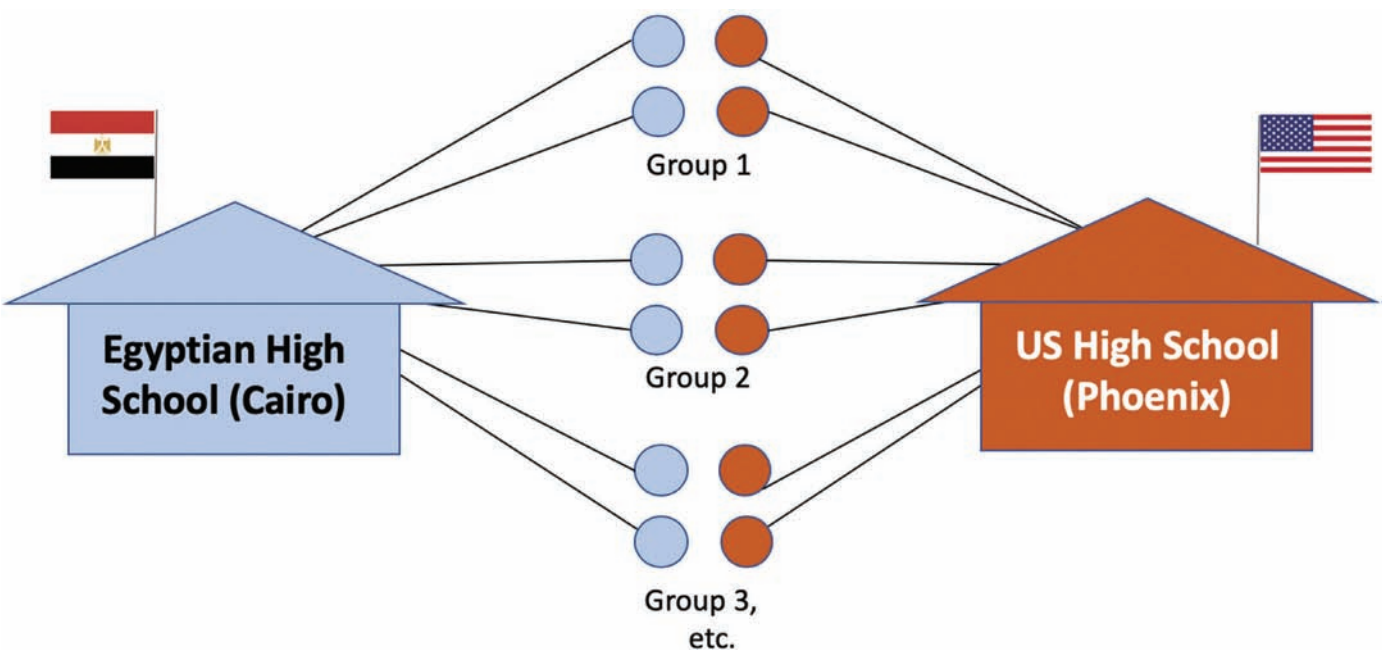

Figure 1. Group formation for the activity with two students from each country.

the ability to create their own analogies, and learn about the homes of their international partners. Teachers prompt students to open their assigned activity sheet in Google Docs and type their names in spaces that have a school abbreviation and student number. To distribute the work and communicate in the shared document, these codes are placed by prompts and questions indicating which student should type the response.

The Egyptian school launched first (Figure 2), and the U.S. school launched later the same day. In the morning, there was excitement as the teacher described the goals of the activity, which were reinforced in the activity document as follows:

> Cells are the basic building blocks of life. An analogy is a common way to learn about cell structures and organelles. Analogies that compare and contrast cell structures and organelles to other more familiar things, such as a factory or a school, are common. This activity is about building a similar analogy. However, there is a twist. The analogy should compare a Cairo-Phoenix (Cai-Nix) home and a cell.

With the objective established, the procedure was described:

> First, have a discussion about your homes. Try to understand how Phoenix and Cairo homes are similar and different. Then create a description of a combined Cai-Nix home. Next, build your analogy. Your analogy should be for a minimum of seven organelles or cellular structures. For each organelle/structure, state the analogy in the Cai-Nix home and explain why your group chose this part of the home as being analogous to the organelle/structure.

Student Work on the Activity

After the launch, students worked on the shared-activity document and communicated in their preferred modes, including WhatsApp, e-mail, and Instagram. We encouraged the first meeting to be synchronous. After the first meeting, most communication was asynchronous, due to time zone differences. Students followed the instructions in the activity sheet and asked each other questions about their homes.

After the initial sharing, a Cairo student is asked to write what a Phoenix home is like and a Phoenix student is prompted to describe a Cairo home. Students work together to create an imagined Cai-Nix combined home. They use this to develop and present their analogy. Afterward, students reflect on their analogy and describe areas where it is weakest. Teachers and the authors tracked student progress by tracking the progress on the shared documents and provided feedback and encouragement when necessary.

Debrief

Debrief sessions were held at each school. The teacher prompted groups to share the analogies developed, discuss challenges they had in completing the activity, explain the role of analogies in science, and describe what they learned about their international partners.

○ Results

The firsthand examination of the students' Google Docs sheets provided key insights, as did a survey containing an open-ended survey about student perspectives on the activity. It also contained one multiple-choice item and one free-response item used to help evaluate biological learning. Interviews also provided student perspectives on the activity.

Analogy Construction

Before constructing an analogy, students were asked to share information about their homes. They tended to see more similarities than differences between Cairo and Phoenix homes. Common

Figure 2. Launch day for the activity in Cairo, Egypt.

analogies developed, including the walls of the home being like cell membranes; drawers, closets, pantries, and refrigerators being similar to the vacuoles of a cell; trash cans as analogs for lysosomes; and parents as akin to the nucleus. Several groups saw the cytoplasm as like the floors of the house, whereas other groups saw cytoplasm as like the air in the house. Evidencing critical thinking, the students explained why they selected these analogies for the target concepts. The work suggested that the students had achieved the goals of developing useful cell structure analogies and deepening their cell structure knowledge.

The analysis showed many instances of the process leading to creative, useful analogies, such as the three analogies below:

> The microfilaments in the cell membrane are the planks of wood that make up the inside of the walls because they provide structural support.

> A centriole has a few commonalities with a clothing rack, the centriole organizes cell division in a cell. In the home, a clothing rack organizes the different sizes of clothes a person may have.

> The mitochondria provides [*sic*] the cell with energy as they break down food and convert it into ATP. The electricity supplies a house with all its energy to perform its daily functions such as heating and air conditioning. Therefore, mitochondria is [*sic*] like electricity in a house.

Examining Where Analogies Break Down

The last section in the activity sheet starts with an important understanding: "No analogy can ever be perfect – the analogue cannot be exactly like the target concept." After building their analogy, groups are asked to explain where their analogies break down. The analysis suggests that most students met the goal of analyzing how analogies are not perfect representations of target concepts. Here are three sample student responses:

> The cytoplasm in the cell helps the organelles to move freely and safely around and provides support to the cell. A house floor is like the cytoplasm because the cytoplasm in a cell allows the organelles to move freely and safely just like the floor of a house allows people to move in their house freely. The floor of the house is solid, but the cytoplasm is a liquid material so this difference lets the analogy be weak.

> The Mitochondria is [*sic*] to produce the cellular energy and to maintain the control of the cell cycle, but the power sources and sockets don't do more than distributing the energy from the main source of electricity without generating it nor controlling or affecting other things in [the] home, and that is not precisely similar to the Mitochondria's role which makes the analogy weak here.

> Second the nucleus are [*sic*] not like the sitting room because the Nucleus controls the cell while sitting room doesn't affect the house. Finally the vacules [*sic*] are not exactly like the refrigerator as the vacules [*sic*] also store wastes not only water and nutrients.

Student Perspectives

After the activity, 16 U.S. and 25 Egyptian students completed assessment questions. The responses were assessed on a Likert scale ranging from Strongly Agree (5) to Strongly Disagree (1). The items, percentage of agreement (both strongly agree and agree), means, and standard deviations across groups are as follows: "I enjoyed the activity" (U.S.: 81%, 4.25, 0.93; Egypt: 84%, 4.16, 0.80); "The activity was a good opportunity to practice working with others" (U.S.: 88%, 4.44, 0.73; Egypt: 88%, 4.28, 0.89); and "I learned from the activity" (U.S.: 75%, 4.13, 0.96; Egypt: 96%, 4.68, 0.56).

High percentages of agreement and high mean scores on all three items suggest that students had very positive feelings about the activity. There were no significant differences between the two groups for the first two items, but there was a significant difference on the third item, "I learned from the activity" ($F_{1,39} = 5.531$, $P = 0.024$). These results suggest that the Egyptian students had a significantly stronger feeling that they learned from the activity than the U.S. students.

Evidence of Learning

Evaluation of the rich student analogies revealed deep understandings of cell structures and suggested that students worked well together. Two post-activity questions on the survey assisted in evaluating learning. The first asked students to name five organelles, with one point given for each correct response. The mean score was 4.95 (SD = 0.21). Some groups listed more than five organelles, but the maximum score was 5.

The second was a multiple-choice question focusing on analogies in science. The question was nuanced and delved into possible alternative conceptions, resulting in 58.5% of the students identifying the correct answer: "An analogy explains a scientific concept by comparing it to a more familiar idea. Analogies are not perfect. They break down at some point." The following two distractor items both had 19.5% of the students selecting them: (a) "An analogy explains a scientific concept by comparing it to a more familiar idea. Analogies are built to be perfect representations of scientific concepts" and (b) "An analogy explains a scientific concept by giving step-by-step descriptions. Analogies go into detail about the concepts they explain." A nonresponse was considered incorrect.

Interview Data

Interviewed students expressed positive opinions about their participation. There was evidence that students learned about their international partners. Several students commented on how friendly their partners were. According to one student, "I liked how we worked together and I appreciated knowing new people and new information." An Egyptian girl used the word *cute* to describe her U.S. partners. While the majority of the U.S. students were Christian and the majority of Egyptian students were Muslim, religion was not mentioned in interviews. In the activity, students also learned how their homes were different, a big difference being that Cairo students lived in apartment-style buildings while U.S. students lived in freestanding homes. A U.S. student wrote, "They all congregate in the kitchen like we do."

○ Discussion

Students seemed to appreciate the simplicity of the Cai-Nix analogy activity as they learned to work with their partners – one from the same school and two from another school, country, and culture.

A strong majority of students evaluated the activity as beneficial for learning, good practice in working with others, and enjoyable. The interview data also reinforced that students had positive attitudes regarding their participation. Students learned about differences between the two cultures but also realized how similar they are to each other. The data also suggest that students practiced working with diverse others, deepened their cell structure knowledge, developed useful cell structure analogies, and analyzed how analogies are not perfect representations of target concepts.

Analogies have important roles in science (Brown & Salter, 2010; Taylor & Dewsbury, 2018), and helping students construct their own analogies is an important goal. Simple analogies, statements that something is like something else, are the most common in science education (Curtis & Reigeluth, 1984) – such as analogizing an enzyme and substrate to a lock and key. In this activity, all the groups moved beyond the simple analogy, to the enriched analogy phase where they describe the conditions for the likeness.

Analogies have potential to cause misconceptions, which can be reduced if the analogy is analyzed for where it breaks down (Champagne Queloz et al., 2017); for example, enzymes are not rigid like steel locks, and their flexibility aids in their function. According to Gardner (2016), "by asking students to . . . point out where the analogy is not quite accurate (no analogy completely reflects reality), we get students to think more deeply about the scientific principle" (p. 512). In the "Teaching with Analogies" model (Glynn, 2007), as well as other teaching-with-analogies strategies (Brown & Salter, 2010), after an analogy is developed a key step is to reflect where the analogy breaks down. After this activity, only 58.5% of the students correctly answered the nuanced question about analogies, suggesting that the role and nature of analogies may need to be explicitly taught. This could be a topic that needs more attention in high school biology.

Working with diverse others, students exhibited critical-thinking abilities in their explanation of their analogies for cell organelles. Creativity was displayed in the development of novel analogs. Some researchers have suggested that critical thinking, innovation, and creativity are enhanced in a diverse group (Freeman & Huang, 2014; Rock & Grant, 2016). Future research could compare diverse groups to those with greater homophily to see if this is evident in science activities.

A virtual exchange can help students learn to work with different people. Students from large cities in two different countries productively worked together. Other virtual exchange matches can occur when there are differences across or within a country, such as between an urban and a rural school. An international school-matching system can be found at the website of the Stevens Initiative (https://www.stevensinitiative.org/ways-to-engage). Another productive approach to finding a partner school is to ask someone with a connection to a school to provide a virtual introduction.

○ Conclusion

The collected data, including our observations of student work, suggest that students were excited to participate in this virtual exchange activity to enhance biology education. They indicated that it was a valuable experience in learning to work with diverse others as they learned biology. PBL in a virtual exchange can be a very positive experience that does not need complicated or expensive materials and can therefore be replicated to enhance international connections.

○ Acknowledgments

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