MAKING SENSE OF BIOLOGICAL PHENOMENA THROUGH INQUIRY OF MATHEMATICAL REPRESENTATION AND INTERACTIVE TECHNOLOGICAL TOOLS

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This study aims at exploring how interrogative processes may foster making sense of biological concepts that related to the phenomena protein synthesis such as positive transcription factors, enzyme, DNA, mRNA destroyer, as they are learned in a multiple representational environment that consists of biological simulation and mathematical representation. Five pairs of high school students which they 17 years old participated in this study, which was guided by the logic of inquiry approach and the variation theory. We analyzed the data by identifying the students' questions through their engagements with the digital tool and the students' transitions between mathematical representation and biological simulation. The results indicated that the digital tool supports the students in posing several kinds of questions, and the answers to these questions support the students in making sense of the biological knowledge embodied in the digital tool.

Keywords: digital simulation, logic of inquiry, mathematical representation, questioning, variation theory.

INTRODUCTION

Educational committees and STEM proponents suggest that knowledge should be accessible to students through a combination of several topics in context. Inquiry-based learning (IBL) is one of the strategies that STEM educators recommend implementing in educational settings. IBL is a vague concept and no consensus exists among scholars about its definition. Keselman (2003) defines IBL as a strategy in which students follow methods and practices like those of professional scientists in order to construct their knowledge. Pedaste, Mäeots, Leijen and Sarapuu (2012) define inquiry-based learning as a process of discovering, formulating and testing hypotheses by conducting experiments and/or making observations.

Artigue and Blomhøj (2013) observe that inquiry-based learning has only recently been applied to mathematics education. To conceptualize the term inquiry-based learning, they refer to Dewey's work, which conceives inquiry-based education as a way of supporting students' development of habits of minds that promotes learning and introduces a vision of inquiry as a process that incorporates the determination of the object or a problem to be inquired . In the inquiry-based learning introduced by Dewey, students create their own scientifically oriented questions, give priority to evidence in responding to questions, formulate explanations from evidence, connect explanations to scientific knowledge, communicate and justify explanations.

Even though no consensus exists among scholars about the definition of inquiry-based learning, it seems that questioning is one of the fundamental components of any definition of inquiry-based learning. Questioning and discussion began approximately 2,000 years ago with Socrates, who strove to engage intellectuals in solving the political, medical, religious and philosophical problems of the day (Gross, 2002).

Recent research studies also highlight the value of questioning as an important teaching and learning tool (e.g., Walsh & Sattes, 2016). Several studies focused on the questions asked by teachers and the role of these questions in stimulating thinking styles. For example, Joseph (2018) investigated the types of questions teachers ask to stimulate student discussion and critical thinking in elementary and secondary school classrooms. The findings reveal that teachers tend to ask low-level cognitive questions that require information, rather than higher-order questions that stimulate classroom discussion. Chen et al. (2017) investigated the various roles that early elementary school teachers adopt when questioning to scaffold dialogic interaction and students' cognitive responses for argumentative practices over time. Their findings indicate that teacher questioning serves different functions in promoting students' conceptual understanding.

In a study conducted by Chin and Chia (2004), they examined how students are inspired to ask questions, identified the types of questions students ask, and determined how asking questions helps junior high school students construct their knowledge. They found that the observations, curiosity and issues raised during previous lessons inspired the students to ask questions. The results show that 'what is' questions require basic information and basic data collection, 'how' questions seek explanations and tend to focus on cause-effect relationships, and 'what if' questions encourage students to raise hypotheses.

Although much is known about the questioning processes of students and teachers in traditional science classes (e.g., Chen et al., 2017; Joseph, 2018; Watson, 2018), less is known about the role of questions asked by the students in the process of making sense of scientific concepts when they are taught in digital-rich environments, environments that display simultaneous simulations of biological phenomena and mathematical representations of the biological processes involved in the phenomena. In this study, we aim at shedding light on questions asked by students and exploring how these questions prompt students to make sense of biological phenomena, following the theory logic of inquiry which considering the inquiry as a process of asking questions and answering them is the way which students construct their knowledge, more details about this approach is described in the theoretical background. Our working hypothesis is that the use of these kinds of digital learning environments may prompt students to ask questions; answering these questions and use of the digital tool may foster making sense of biological phenomena. the questions research are :

1. How the interactive environment simulates the students to investigate the biological phenomena ?
2. What types of questions raised by the students during the inquiry process ?
3. How the students interpret the biological phenomena by using mathematical concepts ?

THEORETICAL BACKGROUND

In this study, we used a hybrid model proposed by Arzarello (2016) that was created by networking two theoretical approaches: logic of inquiry (Hintikka, 1999) and the variation theory (Marton et al., 2004). The former defines inquiry as an interrogative process, while the latter frames and defines the concept of learning. Below we briefly outline the main ideas of the two approaches and elaborate on the hybrid model called MVI (Arzarello, 2016). The researchers (Swidan, Arzarello, Beltramino, 2017) use the MVI model to bridge the gap between the formal world of mathematics and the real-life situations. The researchers noticed that using MVI model increase learning opportunities that encouraged a deep understanding of pre-calculus ideas. In our recent research we took the MVI to a biological phenomena.

The main idea behind the logic of inquiry approach involves seeking rational knowledge by questioning (Hintikka, 1999). Hintikka conceived the process of seeking new knowledge as an interrogative process between two players. The first player (the inquirer) has the role of asking questions, and the second player has the role of answering and is called the verifier (or oracle). The former is the seeker of knowledge who tries to prove a conclusion to be reached from prior experiences or even from theoretical premises. The latter is considered the source of knowledge.

The variation theory (Marton et al., 2004) defines learning as a change in the way something is discerned, i.e., seen, experienced or understood. According to this theory, meanings emerge as the learner focuses his awareness on the object of learning. In this case, some aspects of the object appear at the forefront of his attention. Yet, not all aspects are discerned at the same time or in the same way. In order to understand an object of learning in a certain way, various specific critical aspects must be discerned by the learners. To facilitate the discerned object of learning, Marton et al. (2004) proposed four interrelated functions (or patterns) of variation to be taken into account when designing educational tasks: (a) Contrast: "...in order to experience something, a person must experience something else to compare it with"; (b) Generalization: "...in order to fully understand what 'three' is, we must also experience varying appearances of 'three'..."; (c) Separation: "In order to experience a certain aspect of something, and in order to separate this aspect from other aspects, it must vary while other aspects remain invariant"; and (d) Fusion: "If there are several critical aspects that the learner has to take into consideration at the same time, they must all be experienced simultaneously" (Marton et al. 2004, p. 16).

Integration of variation theory and logic of inquiry is done by Arzarello (2016) and what he called MVI model, to implement the MVI model we should design educational situations that may promote inquiry processes. This model proposes that drawing students' attention to critical aspects, asking to vary them and observing their effects on the phenomena may foster students' inquiry processes. The main idea of MVI is creating challenging situations by varying some aspects of the phenomena (real-world or mathematical) while keeping the others invariant. Exploring various aspects of the same phenomena may lead the students to grasp the intended object of learning.

We find the MVI model suitable for serving as a theoretical basis for our study since it attributes to questioning a central role in constructing knowledge and also assumes that questioning is catalyzed when students are exposed to situations that are varied, which is the main feature of the digital tool used in this study. In the following section, we will elaborate on the features of the digital tool used in this study and the study's methodological issues.

METHODOLOGY

The simulation used in this study

In this study, we used the simulation Gene Expression Essentials (Version 1.0.5; Dalton, 2018). this interactive simulation of protein synthesis (SPS) , which consists of graphical and numerical representations (mathematical representation) and a simulation of biological phenomenon (Fig. 1). SPS allows the students to create different situations by varying some aspects of the phenomenon while keeping the others invariant. For example, SPS enables students to vary parameters (concentration, affinity, degradation, etc.) that affect protein production (right side parameters, Fig. 1) and see how varying these parameters affect the level of protein production.

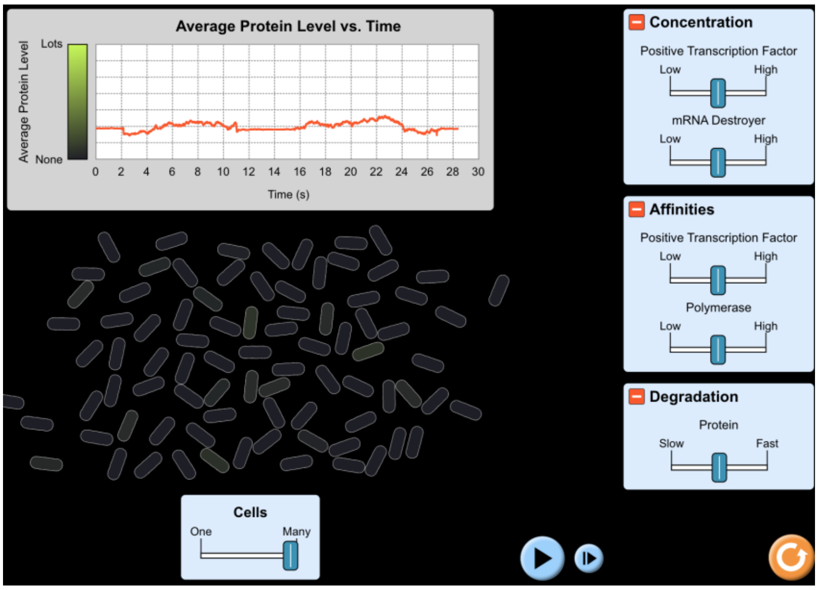

Figure 1. Mathematical representation (top left), cell simulation (middle left), factors affecting protein production (right).

Study design, data collection and analysis

We video-recorded the entire learning process of five pairs, 17-year-old students from an Arab high school in Israel who volunteered to participate in after-school meetings while working with SPS. To document the entire learning process, we used the task-based interview (Goldin, 2000) as the main tool for this study. The students learn in a science-oriented school and study biology at a high level, i.e., they were taught the subject from DNA to protein. In addition, these are 4 and 5 bagrut mathematics students which considered the highest level in mathematics learning in the Israeli curriculum.

The tasks given to the students were designed according to the theories that guided this study, at these tasks the student required to change some parameters and examine the influence of these parameters on the mathematical representation (graph) and the biological representation (color of the cell/s).

The procedure was conducted in a computer laboratory in the students' school whereby every two students shared one computer. The students were video-recorded and their corresponding computer screens were captured. After collecting the data, the task-based interviews were transcripted. We analyzed the data by divided the transcripts into episodes. We defined each episode as part of the transcript, which started with a question and ended with drawing a conclusion. Each episode was coded according to types of questions raised by the students, the biological knowledge the students constructed, the mathematical concepts the students used, and the transition directions between the mathematical and biological representations.

FINDINGS

The results show that a difference exists between the frequency of each question type: questions like 'what if' and 'why' have a higher frequency, 41 and 58, respectively; questions like 'when' and 'how' have a lesser frequency, 3 and 5, respectively (Fig. 2).

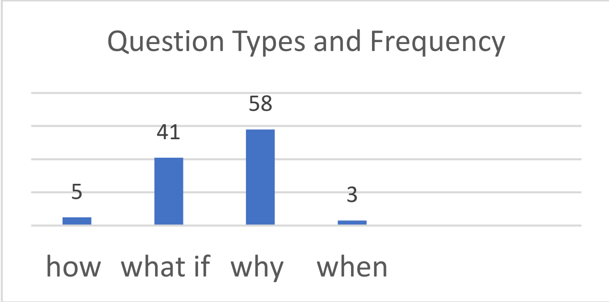

Figure 2. The frequency of each type of question.

Due to space limitations in this paper, we will concentrate on 'why' questions and how these questions foster the construction of knowledge. Sawsan and Hala is a pair of students who took a part in the research, the first episode illustrates how the students recognized factors affecting enzyme activity. We shed light on the relationship between the concentration of positive transcription factors with enzyme activity.

1 Sawsan: Why did these factors affect enzyme activity?

2 Hala: When the enzyme binds the positive transcription factor, these factors guide the enzyme from where it started; when the enzyme binds more positive transcription factors, the activity is greater.

3 Sawsan: Does it determine enzyme activity?

4 Hala: Yes.

5 Sawsan: How does enzyme activity affect DNA?

6 Hala: The DNA is like the substrate: when the substrate is higher, the enzyme activity is higher.

7 Sawsan: If we suppose that DNA is like a substrate, the concentration of positive transcription factors is high, and the mathematical graph is high until a certain limit.

The students examined the relationship between the concentration of positive transcription factors and enzyme activity. The students varied the concentration of the transcription factor parameter in the digital tool while keeping the other parameters invariant. In this way, the students separated this parameter from the others to observe how the concentration of positive transcription factors affects enzyme activity. The inquiry process was triggered thanks to the questions asked by Sawsan throughout the episode. Sawsan observed that the positive transcription factor parameter affects the graph. She observed the constant function graph when the parameter of the positive transcription factor was in the middle; the function increased when she set the parameter to high and decreased when she set it to low. Following these observations, Sawsan posed a 'why' question (line 1).

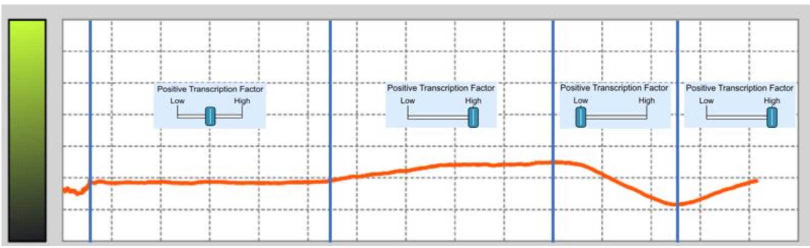

Figure 3. Graph reaction to the concentration of the positive transcription factor.

Following the ‘why’ question, the students drew a biological conclusion. They answered the ‘why’ question using the logic form of when-then twice. In this way, they recognized the proportional relationship between the concentration of the positive transcription factor with enzyme activity (line 2). In line 3, Sawsan, as an inquirer, continued questioning Hala. This time, she asked a clarification question (line 3). In line 5, Sawsan took the inquiry one step further by asking a ‘how’ question and introduced the DNA concepts into the students’ discourse. In line 6, Hala – the source of knowledge in this case – answered Sawsan’s ‘how’ question and elaborated on the relationship between DNA and enzyme activity. In line 7, Sawsan elaborated on Hala’s statement and connected between the DNA, the concentration of positive transcription factors and the graph. She described the relationship between the three elements qualitatively using the word ‘high.’

The second episode illustrates the ways the students recognize the effect of the concentration of positive transcription factors and molecules destroying mRNA on the amount of protein in the cell. By doing so, the students move between mathematical representations and simulation of the biological phenomenon.

18	Hala:	When the mRNA is low and the number of cells is low, the graph increases but the increment is not sharp. At first, it begins to rise and then it reaches equilibrium.
19	Sawsan:	Why is there an increase? I think that the concentration of molecules destroying a messenger RNA is like a substrate, it has a certain graph.
20	Hala:	Let’s try to set the mRNA to high when there are multiple cells. The graph decreases.
21	Sawsan:	Why? Because molecules destroy the transcript stand so the decrease occurs linearly.
22	Hala:	Let’s try to change the concentration of the transcription factors; the number of molecules destroying mRNA is low. When we have a single cell, the graph increases. Why does the graph increase when the concentration of transcription factors is low?
23	Sawsan:	Since the influence of molecules destroying mRNA is high, something is positive and the other is negative.
24	Sawsan+ Hala :	Let’s try to increase the number of cells to see if the number of cells affect the graph. The graph is straighter, the changes in the graph are not sharp, and when the cells are multiple, the line is completely straight.

Initially, the students separated the variables, varying the concentration of molecules destroying mRNA while keeping the other variables invariant. At this moment, the students discerned that the graph was increasing. This discrimination invited the ‘why’ question (line 18). Answering the question, the students came up with conjecture that the molecules destroying a messenger RNA were like a substrate. To verify their conjecture, they changed another parameter, the cell amount. After observing a decrease in the graph, they posed another ‘why’ question. Like in the first case, this time they also came up with a conjecture about the relationship between the mRNA destroyer and protein production (line 20), while again referring to the rate of change of the graph. They qualitatively described the rate of change of the graph: in line 18 they used word ‘sharp’ and in line 21 they used words ‘straight way.’ In line 22, the students fixed the number of cells and the mRNA destroyer, and varied only the transcription factor. Following this action, they posed, for the third time, a ‘why’ question in an attempt to explain the increment in the graph. To answer this question, they referred to the simulation of the cells. The light and dark cells caught their attention so they interpreted the increment in the graph by referring to the dark cells as negative and the light ones as positive (line 23). Generally, the students changed the number of cells and the concentration of molecules destroying the mRNA; these actions helped the students learn about how the mRNA destroyer affects the amount of proteins and make a comparison between the two cases. When the students changed the mRNA destroyer and concentration of positive transcription factors together, they fused the variables, i.e., they changed two aspects at the same time to explore their combined effects.

CONCLUDING REMARKS

This study aimed at exploring how high school students construct knowledge through an interrogative process while using digital and multiple representation simulation of biological phenomena. The results of the study showed that the digital tool has the potential of supporting students in posing questions and answering them. The micro analysis of the data attributes a central role to the linked mathematical representations and the biological simulation of the phenomenon in fostering the interrogative processes of the students. These interrogative processes were essentially triggered by the shape of the graphs and the parameters that affect the graph. In addition, the micro analysis highlights the dynamicity of the inquirer/oracle roles through the learning processes. This study showed how one student can play the role of the oracle (Hintikka, 1999) when being familiar with ideas that are discussed, and how the oracle becomes the inquirer when the same student encounters an unfamiliar situation.

The digital and multiple representation simulation tools foster the students to ask several kinds of questions. These questions help the students to explore by interpreting the mathematical representation of the biological phenomena and to recognize the biological knowledge that is simulated in the digital simulation. This insight is in accordance with Pedaste, Mäeots, Leijen and Sarapuu (2012), who argue that inquiry-based learning is a process of formulating hypotheses and testing them by conducting experiments and/or making observations.

According to Chin and Chia (2004), students raise questions as a result of observation and curiosity. In our research, we found that the students raised questions as a result of varying parameters in the simulation and after observing the graphical and biological representations. As shown in episode one, the interaction with the simulation results in asking a ‘why’ question, then the students draw a biology-related conclusion. Moreover, asking ‘how’ and ‘when’ questions help the students make sense of the biological concepts while drawing mathematical and biological conclusions. In addition, the design of the task, which takes into account the four principles of the variation theory, allows the students to raise questions. As shown in episode two, when the students vary some aspects while keeping the others invariant, they create a challenging situation that helps them ask ‘why’ questions, which leads them to explore the biological phenomena. For this reason, it seems that using the MVI model for designing tasks that prompt inquiry-based learning is a promising method. However, we recognize that the small number of students participating in this study and their background is one of the study limitations. To better understand the role of the MVI approach in fostering inquiry-based learning, further research is needed.

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