Chapter 6
Learning and Teaching Biotechnological Methods Using Animations

Hagit Yarden and Anat Yarden

Rationale

It was recently suggested that school science should play a major role in the development of a citizenry that is capable of dealing with the scientific developments and changes in the vital field of biotechnology and their influence on our everyday lives (Steele & Aubusson, 2004). Biotechnology can be defined in the broadest sense as any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use. Biotechnology is also an aspect of science in which its content is rich with opportunities for applying the knowledge, understanding, and attitudes gained from the study of science to everyday life (Lock, Miles, & Hughes, 1995). Indeed, the importance of biotechnology education has been recognized in a number of international curriculum frameworks around the world (Dori, Tal, & Tsaishu, 2003; Falk, Brill, & Yarden, 2008; Steele & Aubusson, 2004). Although biotechnology education has gained significant recognition, less has been published about how to effectively teach and learn this aspect of science.

One of the most problematic issues to comprehend while learning biotechnology concerns the methods involved (Falk et al., 2008). Molecular biology methods are completely unfamiliar to most students because these methods are remote from the everyday lives of the students' who usually have no opportunity to experience them hands-on in the school laboratory (Olsher & Dreyfus, 1999; Steele & Aubusson, 2004). In addition, the methods are based on the understanding of molecular

H. Yarden
Department of Education in Technology and Science, Technion Institute of Technology, Haifa 36006, Israel
e-mail: hagit_y@oranim.ac.il

A. Yarden (✉)
Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel
e-mail: anat.yarden@weizmann.ac.il

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processes which are known to be an intellectual challenge for high school students (Falk et al., 2008; Marbach-Ad, 2001). According to Malacinski and Zell (1996), students' difficulties in understanding molecular concepts and processes are especially attributed to the emphasis on minute details and abstract concepts. Indeed, even though teachers regard this topic as important and interesting to students, most of them choose not to teach it, due to its subject matter difficulties (Steele & Aubusson, 2004). Thus, there is a strong need for a more concrete and accessible means of demonstrating and visualizing the course of action and applications of molecular processes.

Multimedia instructional environments in general, and animations in particular, have a great potential for improving the way people learn (Kelly & Jones, 2007; Mayer & Moreno, 2002; Stith, 2004; Williamson & Abraham, 1995). When an animation simulates real processes which include, for instance, motion, it allows learners to execute virtual experiments that would be costly, dangerous, or otherwise not feasible in a school laboratory. The idealization of complex laboratory experiments, as in simulations, is helpful in reducing errors and focusing students' attention on particular abstract concepts or isolating variables that are normally combined (Hennessy, Deaney, & Ruthven, 2006).

The studies presented in this chapter aimed to identify the cognitive as well as the pedagogical factors involved in using animations while learning and teaching biotechnological methods in high school. Specifically, we aimed to (1) explore how the use of animations affects high school students' comprehension of biotechnological methods and (2) characterize the pedagogical characteristics of enacting animations in class while teaching biotechnological methods. This chapter is divided into two parts; each part focuses on one of the above two aims, and a general discussion follows.

How the Use of Animations Affects High School Students' Comprehension of Biotechnological Methods

Cognitive Basis of Learning Using Visualization Tools

In designing multimedia presentations involving animations, instructional designers base their decisions on theories of how students learn from words and pictures. Those theories are relevant for learning and teaching in general, and they appear to be most relevant in biology education in particular. One of those theories is the cognitive theory of multimedia learning (Mayer & Moreno, 2002) which is based on three fundamental assumptions. According to the first assumption, the dual-channel assumption (Paivio, 1986), humans have separate channels for processing visual and verbal representations. Therefore, information encoded in both channels will be better remembered than information encoded in only one of the channels. Because pictures, whether they are dynamic or static, may be coded both visually and verbally, they are more likely to be remembered than words. There is a strong empirical evidence that learning outcomes are improved by presenting the learner with verbal and pictorial information in a coordinated fashion (Hoffler & Leutner, 2007). In biology education, where we are dealing with phenomena that are for the most part abstract, the integration between verbal and concrete pictorial information seems to be most significant.

The second assumption is the limited-capacity assumption (Baddeley, 1997) which postulates that only a few pieces of information can be actively processed at any one time in each of the two separate channels (for processing visual and verbal representations). This assumption goes together with the cognitive load theory (Sweller, 1994) in that the working memory's capacity sets very narrow limitations. This aspect is particularly relevant in biology education where there is a burden of diverse concepts and processes, most of which are totally new to the learners (Yarden, Marbach-Ad, & Gershony, 2004), as well as a requirement to generate large conceptual frameworks (Trowbridge & Wandersee, 1996). In this situation, cognition in general and memory in particular are faced with a considerable challenge. Hence, there is a need for tools that will assist in reducing the inherent cognitive load as well as relieving the limited organic capacities for processing information.

The third assumption, the active-processing assumption, states that meaningful learning (Ausubel, 1968) occurs when the learner engages in active cognitive processes such as selecting relevant material, organizing it into a coherent representation, and integrating it with existing knowledge (Mayer, 1996; Wittrock, 1974). This active processing is most likely to occur when the learner has corresponding pictorial and verbal representations in his/her working memory simultaneously, and thus this theory predicts that multimedia presentations, such as narrated animations, are most likely to lead to meaningful learning.

According to the information delivery theory of multimedia learning (Mayer, 1996), the computer is an information delivery system for learners. When the information is presented in words (such as narration), the learner stores the information in his or her memory. According to this theory, adding multimedia (such as animation) to the verbal information should have no effect on what is learned if the pictures contain the same information as the words. Thus, according to this theory, multimedia presentations should not result in better learning than single-medium presentations. However, in a mixed situation with learners who favor visual presentations and others who favor verbal ones, a multimedia presentation might be equally effective in delivering information to both groups of learners. We are most familiar with students' multiplicity of learning styles (Tobias, 1990); therefore, tools such as animation, which can be effective for visual as well as verbal learners, could be extremely valuable.

In distinguishing between static and dynamic visualizations, multimedia may be a relatively new technology, but the addition of images to text in order to facilitate learning has a much longer history. Pictures can be used to accompany texts in order to improve their comprehensibility and memorability (Large, 1996). However, Tversky and Morrison (2002) found no advantage of animations over static graphics in 20 primary studies that they reviewed. In contrast, a more recent meta-analysis indicated a statistically significant advantage in favor of animations over static pictures (Hoffler & Leutner, 2007).

Obviously, there are some significant differences in the interpretation of information from dynamic versus static displays, which are not consistently in favor of the dynamic ones. Some of those differences can be explained from the perspective of the cognitive load theory (Sweller, 1994). For example, when viewing an animation, "one views one frame at a time, and once the animation or video has advanced beyond a given frame, the previous frame is no longer available to the viewer" (Hegarty, 2004, p. 346). This situation may place a heavy demand on the working memory, especially in cases when information presented earlier in the animation should be integrated with information that is presented later. In contrast, when viewing a static display, viewers can reinspect different parts of the display as often as they wish (Ainsworth & van Labeke, 2004). An alternative point of view is that the ability to introduce each step independently in animations reduces the clutter of static illustrations, in which all of the steps are shown at once (Stith, 2004). Individual differences, such as spatial ability (Yang, Andre, Greenbowe, & Tibell, 2003) or prior knowledge (ChanLin, 2001), can also influence whether static pictures or animations are superior within a specific domain. In the case of low prior content knowledge, learning from molecular representations can be a difficult process (Cook, 2006). Students who have little or no knowledge of the domain depend heavily on observable phenomena to construct understanding (Seufert, 2003), that is, they use what can be easily observed. For that reason, some educational practices favor the use of dynamic visuals over static illustrations because they provide the learners with a ready-made, explicit, and dynamic representation of the phenomena (Williamson & Abraham, 1995). On the other hand, static displays require the learner to construct a dynamic mental model using the static information provided. For instance, students who are expected to learn about changes in matter or motion using static visuals have reported that they had to visualize those changes using static information, whereas when learning from dynamic visuals, the corresponding changes were apparent (Ardac & Akaygun, 2005). Still, students with low levels of prior knowledge may have difficulty extracting information from complex animations. Blissett and Atkins (1993) reported that individuals with less prior knowledge or lower achievers tended to find the learning demands confusing when animation is used.

From the cognitive load perspective, the preference of the visualization format can be conflicting. Although dynamic visuals may reduce the load of cognitive processing by directly supporting the construction of a mental model, their transitory nature may cause higher cognitive load because learners have less control of their cognitive processing (Lewalter, 2003). In addition, although animations can provide learners with explicit dynamic information that is unavailable in static graphics, the inclusion of a temporal change in visual displays introduces additional information-processing demands (Lowe, 2003).

Even though there is no obvious cognitive advantage to dynamic over static media, dynamic media are considered to have enormous potential for instruction (Hegarty, 2004). In the next part of this chapter, we attempt to determine what conditions or what learning terms may enable dynamic visualizations to be effective in learning biotechnological methods.

Examples of Animations of Biotechnological Methods

At the molecular level, biotechnological methods are completely invisible and intangible to students. To demonstrate the mechanisms behind those methods, we developed animations which accompany a textbook which we developed in genetic engineering (Michael & Yarden, 2007). Each animation introduces, sequentially, the procedure of the biotechnological method being demonstrated—using restriction enzymes to digest DNA, cloning a gene into a plasmid, creating a DNA library, and the polymerase chain reaction (PCR) (Falk et al., 2003; Yarden & Yarden, 2007).

One of the most helpful and effective features of animations is their interactive use (Hegarty, 2004; Stith, 2004). Stopping, starting, and replaying an animation can allow reinspection, focusing on specific parts and actions. Animations that allow close-ups, zooming in, alternative perspectives, and speed control are even more likely to be facilitative to learners (Tversky & Morrison, 2002). Thus, two alternative versions were developed for each animation: a continuous version, showing the whole procedure of the biotechnological method continuously, and a sequential version, showing the process gradually, or step by step. The animations were divided into steps according to the way in which the various biotechnological methods are carried out in the laboratory, that is, whenever a new stage is encountered such as heating, a new step is demonstrated in the animation. In addition, the steps were selected according to transitions from macro to micro perspectives and vice versa.

Each animation includes a written text which appears in close proximity to the animation and describes what is being shown—according to the spatial contiguity principle (Mayer & Moreno, 2002). In addition, each animation is accompanied by components of active learning in the form of computerized tasks—according to the cognitive theory of multimedia learning (Mayer & Moreno). The tasks are aimed at identifying students' attention to key issues in the biotechnological methods being demonstrated as well as to understanding the symbols and images which appear in the animations themselves. Those animations were used as a context to the study that is described in the following sections.

Students' Comprehension of PCR Using Animation and Still Images

In our study (Yarden & Yarden, 2010) using pre- and post-intervention questionnaires, we identified the differences between a group of students (12th graders, biology majors; $n = 90$) who used the PCR animation in order to visualize the PCR method and a comparison group ($n = 83$) who used equivalent still images to visualize the PCR method. We found a statistically significant advantage for the animation group over the still images group using a t test, $t\ (171) = 4.64$, and $p < 0.0001$. Since no significant differences were found between students' prior knowledge, we concluded that the use of the PCR animation as a visualization tool provided an advantage to learners of the PCR method. In addition, regression analysis indicated a positive correlation between students' prior knowledge and their understanding of the PCR method in the still images group ($R^2 = 0.412$). Students with a low prior content knowledge achieved low scores in the post-intervention questionnaire, while students with a high level of prior knowledge achieved high scores in the post-intervention questionnaire. In contrast, for the animation group, the level of students' prior content knowledge seemed to have no noteworthy effect on their success in the post-intervention questionnaire, namely, on their understanding of the PCR method ($R^2 = 0.091$). Thus, prior content knowledge was found to be an important factor for students who learned PCR using still images, whereby low prior knowledge could serve as an obstacle to learning the PCR. In contrast, the same variable had no noticeable effect on students who learned PCR using animation.

Using the conceptual status framework (Hewson & Lemberger, 2000; Tsui & Treagust, 2007) for analyzing students' discourse while learning about the PCR, we also found that the use of the animation was advantageous in understanding the mechanistic aspects of the method compared to students who learned using still images. Students from the animation group and from the still images group had reached the kind of understanding reflected by the conceptual status of intelligibility, indicating that they knew what the concepts of PCR mean and they could represent them using images, language, or examples. However, the next level of understanding—which is reflected by holding the plausibility conceptual status—appeared to be available only to the students who watched the animation. As expressed in their conversations, the students who used the animation were able to understand the causal relationships between different molecules in the PCR method, as well as the ontological function of those molecules. Regarding the third and highest conceptual status of fruitfulness, it appeared that neither group reached this level of understanding: They did not reveal significantly in their conversations that they had found the concepts of the PCR method useful in solving problems or in suggesting new possibilities and directions (Yarden & Yarden, 2010).

Students' Comprehensions of Restriction Enzyme Digestion of DNA Using Animation

In an additional study (Yarden, 2010), concept maps were used as a tool for identifying students' (12th graders, biotechnology majors, $n = 38$) understanding of the process of restriction enzyme digestion of DNA using animation. Students were asked to construct concept maps before and after watching an animation from a written list of eight concepts, namely, DNA, restriction enzyme, restriction site, nucleotides, sticky ends, DNA strands, phosphodiester bonds, and palindromic sequence. Students were instructed to think about as many connections as possible between those eight concepts, to draw lines between any two concepts, and to write

Table 6.1 Analysis of students' propositions in their pre-watching and post-watching concept maps

	Sample B1[a] ($n = 15$)			Sample B2[a] ($n = 23$)		
Factors that were tested	Pre-watching concept maps	Post-watching concept maps	Significance of the difference between the paired maps[b]	Pre-watching concept maps	Post-watching concept maps	Significance of the difference between the paired maps[b]
Average number of propositions	10.66	16.4	($p < 0.0001$)	5.21	7.43	($p < 0.0001$)
Average percent of correct propositions	84.66	90.2	($p < 0.0001$)	81.91	92.91	($p < 0.0001$)
Average percent of structural propositions	61.26	56.06	($p < 0.0001$)	75.21	65.47	($p < 0.0001$)
Average percent of functional propositions	38.74	43.94	($p < 0.0001$)	24.79	34.53	($p < 0.0001$)

[a]Samples B1 and B2 represent two 12th grade classes from two different high schools
[b]The Wilcoxon signed rank statistical test was used to test whether the differences identified between the pre-watching and the post-watching maps in each subgroup are significant. A *t* test was not used here because of the small sample size

on the line a sentence which reflects a proposition between those two concepts. After the students had watched the restriction enzyme animation, they were asked to build another concept map from the same eight given concepts.

As can be seen in Table 6.1, the number of propositions was significantly greater in students' post-watching concept maps than in their pre-watching maps. A closer look at the nature of the propositions in both student samples reveals that besides the significant increase in the number of propositions between the pre-watching and the post-watching maps in general, there was also a significant increase in the percentage of the correct propositions in students' post-watching concept maps in both groups. Thus, as reflected in the accuracy of the propositions made in students' post-watching concept maps, it seemed that watching the animation demonstrating restriction enzyme digestion of DNA had made this biotechnological method clearer and more coherent to the students,

After classifying the propositions that students had written in terms of structural versus functional type of propositions, we observed a significant decline in the number of propositions with a structural nature between the pre-watching and the post-watching concept maps of both groups. Accordingly, there was a significant increase in the number of propositions that were classified as functional. Within the pre-watching concept maps, structural propositions—such as "restriction site is composed

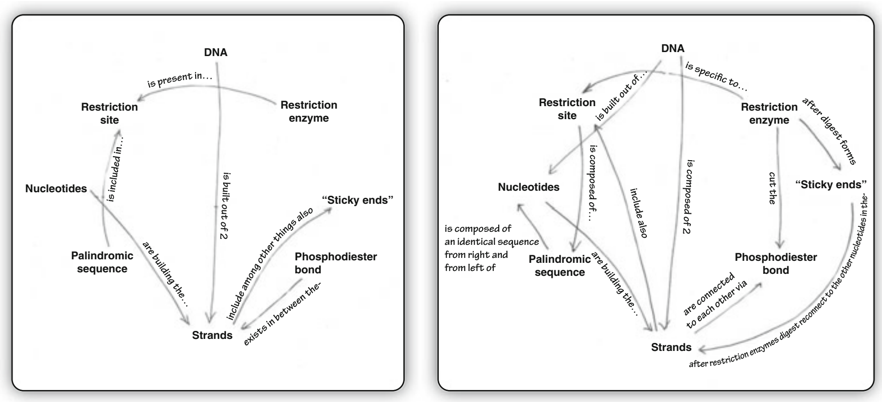

Fig. 6.1 An example of student's paired pre-watching (*left*) and post-watching (*right*) concept maps (subsample of Sample B2)

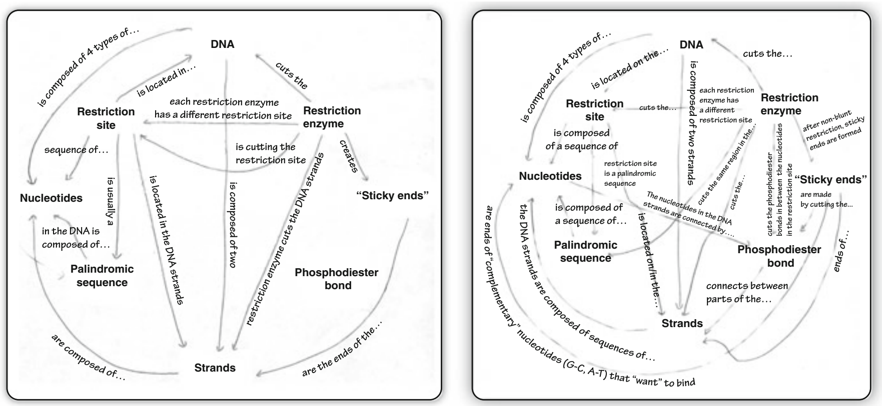

Fig. 6.2 Another example of student's paired pre-watching (*left*) and post-watching (*right*) concept maps (subsample of Sample B1)

of nucleotides," or "palindrome sequence is inside the DNA strands"—were most common. In the post-watching concept maps, most of the propositions dealt with the functions or configuration through action of molecules such as "the restriction enzyme cuts the phosphodiester bond" or "sticky ends are being configured as a consequence of a graded digestion by the restriction enzyme." Two examples of paired pre-watching and post-watching concept maps are shown in Figs. 6.1 and 6.2.

As can be seen in Fig. 6.1, there are more propositions and more correct propositions, as well as more propositions that can be classified as functional in the post-watching concept map, compared to the paired pre-watching map. For example, it can be seen that the concepts sticky ends and phosphodiester bond are more connected to other concepts in the post-watching concept map. In the pre-watching concept map, those concepts appeared in the propositions—"[strands] include among other things also [sticky ends]" and "[phosphodiester bond] exists in between the [strands]" (structural nature of propositions)—whereas in the paired post-watching concept map, they appeared in new propositions such as "[restriction enzyme] cuts the [phosphodiester bond]" or "after restriction enzyme digest reconnect to the other nucleotides in the [sticky ends]."

In Fig. 6.2, it is also observable that there is an increase in the number of propositions from the pre-watching concept map to the post-watching concept map. On looking deeper into the nature of the propositions, it can be noticed that also here the concepts sticky ends and phosphodiester bond are more connected to other concepts in the post-watching concept map, with propositions whose nature can be classified mostly as functional, for instance: "[restriction enzyme] cuts the phosphodiester bond in between nucleotides in the restriction site." However, in the paired pre-watching concept map, the concept sticky ends appeared only in two propositions, and only one of them can be classified as functional ("[restriction enzyme] creates [sticky ends]").

Thus, the use of the restriction enzyme animation enabled the students to increase the number of propositions they could write between concepts in general and the correct ones in particular. Additionally, the use of animation while learning about restriction enzyme digestion promoted the students' understanding about the functional relationships between molecules that participate in this biotechnological method in terms of its mechanistic aspects in a way similar to the case of learning the PCR method using animation (cf. Yarden & Yarden, 2010).

The Pedagogical Characteristics of Enacting Animations in Class While Teaching Biotechnological Methods

The Role of the Teacher While Enacting Animations in Class

Using animations alone does not ensure learning. Animations are occasionally linked with unquestionable, sometimes simplified, models of a scientific process that give students the impression that every variable is easily controlled (Hennessy et al., 2006). It seems that students tend to attribute a great deal of authority to the computer and accordingly may develop misconceptions by taking animations and images of abstract concepts too literally (Wellington, 2004).

In some studies, students were reported to be engaged in unplanned, inefficient, and inconclusive experimentation while learning with simulations (de Jong & van Joolingen, 1998), and sometimes they missed essential features while watching animations alone (Kelly & Jones, 2007). Productive learning requires staged, structured tasks and systematic experimentation (Linn, 2004). Hence, it is most important to make implicit reasoning explicit to highlight any inconsistencies

(Hennessy et al., 2006). For students to be able to learn new concepts and processes which they encounter in a meaningful way, students must also relate new knowledge and information with concepts and claims they have already held (Ausubel, 1963). Since learning is viewed by this perspective as an accumulating process, it is also most important to construct the knowledge being learned gradually, as well as to organize it under main principles (Chi, Feltovich, & Glaser, 1981).

In view of the above perspectives about learning, it seems that the teacher plays a crucial role while learning from animations. There is a strong necessity for the teacher's coaching together with the software supports to address the students' learning needs and their interactions with each other to produce a robust form of support for students (Tabak, 2004). According to Soderberg and Price (2003), teachers should discuss and challenge students' own ideas as well as highlight the limitations of computer models themselves. The effectiveness of whole class instruction of animations might improve if teachers challenge and question the inconsistencies and contradictions between verbal explanations and the corresponding molecular representations (Ardac & Akaygun, 2005). In addition, connections should be made between students' lives and the subject matter being learned, between principles and practice, as well as between the past and the present.

The role of the teacher is also central in the dissemination of curricular initiatives (Barab & Luehmann, 2003). More specifically, the successful introduction of computer-aided instruction, as a tool for enhancing learning as well as teaching, depends on positive attitudes of the teachers (Dori & Barnea, 1997). Science teachers' beliefs affect their attitudes, and these attitudes affect their intentions to incorporate computer-aided instructional tools into class (Zacharia, 2003). Consequently, while examining the enactment of animations in class, it is important to study the teacher's perspective, namely, the teachers' perceptions, challenges, and recommended pedagogical strategies. In the following part, we describe the pedagogical characteristics of two teachers enacting animations for teaching the biotechnological methods in our study.

Enacting Biotechnological Methods Using Animations: Two Case Studies

In this study (Yarden & Yarden, 2011), we attempted to study two teachers' potential contribution to teaching biotechnological methods using animations in two exemplary case studies. Two biotechnology teachers, Ravit and Dora (pseudonyms), enacted several animations while teaching biotechnological methods in their classes. Our analysis revealed that the two teachers contributed to the enactment of animations in the following three aspects: establishing the hands-on point of view, helping students deal with the cognitive load that accompanies the use of animations, and implementing constructivist aspects of knowledge construction.

Establishing the Hands-On Point of View

Analysis of class observations obviously showed that both Ravit and Dora often discussed with their students about how the biotechnological methods—both the rationale and the practical procedure behind various steps in the biotechnological methods that were introduced and demonstrated in the animations—are actually carried out in practice in the laboratory. They gave their students the hands-on point of view by making them aware of the existence of some steps skipped in the animations but are nevertheless important when performing the relevant biotechnological method in the laboratory.

Guided Watching: Help Dealing with the Cognitive Load

Both Ravit and Dora guided their students while watching the animations. Ravit, who tended to be more teacher centered, did this by leading her students' navigation through the animations. Dora, who tended to employ a more student-centered approach, supported her students on several occasions during the learning activity with the animations whenever they had misunderstandings. Both teachers focused their students' attention on important details in the animations and kept asking them different questions about objects in the animations which they were watching.

Ravit explained in an interview that by guiding students through watching animations, she was making the animations more comprehensible for her students:

> Look, I could sit, read a book, and let them watch the animation alone to the end. I believe that in that way they would lose some important points which they might miss because they did not notice them through all the details and changes in the animation.

In addition to the nature of animations, with their dynamic changes and intrinsic visual and cognitive load, Ravit explained that she was directing the students while they watched the animations because of the nature of the subject matter (the biotechnological methods) which is abstract and complex, and therefore, careful watching is needed, especially in animations on this topic in order to identify, for instance, fundamental differences between the structures of similar molecules.

Dora summarized in an interview the type of support she believed she had given her students:

> Focus is the key word here in order to cope with the visual load while they watch. The students could have looked over and over again at the different kinds of bacteria in the animation, but they really need my help to look for the five different plasmids, to focus on each of the plasmids and on its unique elements.

Implementing Constructivist Aspects of Knowledge Construction

Both Ravit and Dora implemented elements of constructivist teaching while using the animations in class, in keeping with the constructivist perspective of Ausubel (1963), for example, more effort should be made by the teacher to engage students more deeply and thoughtfully in any kind of subject-matter learning. Both teachers considered the animation activity as important in the construction of students' understanding of the biotechnological methods. For example, Ravit clearly established the animation activity on students' prior knowledge in biotechnology in order to make it more relevant and meaningful. Also both teachers made the animation activity more meaningful by connecting it explicitly to other activities in the students' learning sequence, such as laboratory experiences.

In her interview, Ravit stressed why she believed that it is so important to link the animation activity to other learning activities to which students have been exposed:

> It is most important to link the animation activity to the trip, to experiences we have had in the lab. Otherwise the student might say: "this belongs to the lab, this to the animation, there is no connection between them."

With different teaching styles, the two teachers tended to perform differently with regard to supporting students' understanding of biotechnological methods while watching the animations. Ravit, with her teacher-centered approach, supported her students by explaining and expanding on the meaning of concepts she believed are crucial for their understanding, and in her interview, she explained why conceptualization of the process that the students had just watched in the animation is so important: "The students are watching a process in the animation but they must know its name, the concept behind what is being demonstrated in the animation."

Whereas Ravit based her supporting efforts while enacting the animations on her own pedagogical and content knowledge, Dora based her supporting efforts on students' difficulties and misunderstandings to which they were exposed during the enactment of the animations. In response to the student's question, Dora discussed the process of plasmid replication beyond what was shown in the animation in order to make the processes in the animation more understandable for her students:

> Student: Dora, I don't understand. Why do we need the origin of replication in the plasmid?
> Dora: Why is it important that the plasmid replicate? Where does it replicate?
> Student: I don't know.
> Dora: In a test tube? Inside a living cell?
> Student: It can do that inside a cell.
> Dora: Only inside a cell. What is needed in order to replicate DNA?

In her interview, Dora revealed that after examining the animation with her students, she became aware of places in which they needed assistance to gain a meaningful understanding. Her presence at that point of the animation enabled her to support the students whenever they encountered concepts or objects which they found not so comprehensible.

Discussion and Conclusions

Learning from animations is not a simple task, even though it might appear to be so. Although animations can provide learners with explicit dynamic information, the inclusion of a temporal change introduces additional information-processing demands, and the transitory nature may lead to a cognitive load because learners have less control of their cognitive processing (Lewalter, 2003; Lowe, 2003). This chapter attempts to represent the complexity of viewing animations while learning biotechnological methods in terms of the cognitive and pedagogical factors involved.

Our first study (Yarden & Yarden, 2010) enabled us to show that animations do have a unique contribution in promoting biology majors' and biotechnology majors' conceptual understanding of biotechnological methods. Previous studies have already shown significantly higher understanding among students who used animations compared with those who used still images in their learning of molecular motion (e.g., Ardac & Akaygun, 2005; Williamson & Abraham, 1995). Animations can give an accurate and rich picture of the dynamic nature of molecules and molecular interactions which is often very difficult to understand (National Science Foundation, 2001). Our findings were also similar to those of Marbach-Ad, Rotbain, and Stavy (2008) who showed that computer animations are effective for learning molecular genetics, especially about the dynamic processes. We also have shown that prior knowledge is not an essential factor when learning using animation. The explicit, expert-like, dynamic representations of the phenomena in animations might explain why students depended less on their prior knowledge when learning with animations as opposed to when learning with static illustrations (Williamson & Abraham, 1995).

In addition to identifying the advantage that animations have on still images for visualizing biotechnological methods, we also found in our study (Yarden & Yarden, 2010) that the use of the animation gave the students an advantage in understanding the mechanistic aspects of these methods, namely, the ontological function of different molecules and the causal mechanism that invokes them. This advantage was also reflected while analyzing biotechnology students' concept maps, before and after viewing the restriction enzyme's animation (Yarden, 2010). According to Pallant and Tinker (2004), molecular dynamics tools help students develop more scientifically accurate mental models of molecular-scale phenomena. Our findings also implied that for such students' tasks, animations serve as a better alternative than the static visuals.

Due to the cognitive load involved, it was reported that students sometimes miss essential features when they watch animations alone (e.g., Hegarty, 2004; Kelly & Jones, 2007). Consequently, it seems that the teacher's role is important in structuring tasks and questions in ways that prompt students' thinking about underlying concepts and relationships being introduced in animations (e.g., Soderberg & Price, 2003) and guiding and helping them to reformulate their thinking when learning with animations (e.g., Parker, 2004). Indeed, in another study (Yarden & Yarden, 2012), we identified three aspects of the contribution of two exemplary biotechnology teachers—to the enactment of animations in class while learning biotechnological methods—(1) establishing the hands-on point of view, (2) helping students deal with the cognitive load that accompanies the use of animations, and (3) implementing constructivist aspects of knowledge construction.

Both teachers in our study (Yarden & Yarden, 2012) implemented elements of constructivist teaching while they used animations in class, namely, they established clearly the activity with the animation on students' prior knowledge as well as connected it explicitly to other activities on the students' learning sequence such as laboratory experiences. Constructivist teachers tend to explore how their students see any problem or issue they encounter in any learning situation and why their path toward understanding seems promising (Glasersfeld, 1998). Thus, the role of the teacher while enacting animations in class is critical in order to make learning of biotechnological methods meaningful.

The findings of our studies presented in this chapter might be usefully extended—beyond the context of visualizing biotechnological methods—to other diverse topics and biological processes that involve motion and interactions between different key factors. Such processes might include macroscopic interactions, for instance, in ecology, as well as molecular processes, which are not visible in the real world. These findings strengthen our assumption that students and teachers should work together in transforming knowledge while learning with animations.

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