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Studying Biotechnological Methods Using Animations: The Teacher's Role

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Abstract Animation has great potential for improving the way people learn. A number of studies in different scientific disciplines have shown that instruction involving computer animations can facilitate the understanding of processes at the molecular level. However, using animation alone does not ensure learning. Students sometimes miss essential features when they watch only animations, mainly due to the cognitive load involved. Moreover, students seem to attribute a great deal of authority to the computer and may develop misconceptions by taking animations of abstract concepts too literally. In this study, we attempted to explore teachers' perceptions concerning the use of animations in the classroom while studying biotechnological methods, as well as the teachers' contribution to the enactment of animations in class. Thirty high-school biotechnology teachers participated in a professional development workshop, aimed at investigating how teachers plan for and support learning with animation while studying biotechnological methods in class. From that sample, two teachers agreed to participate in two case studies aimed at characterizing teachers' contribution to the enactment of animations in class while studying biotechnological methods. Our findings reveal marked teacher contribution in the following three aspects: establishing the "hands-on" point of view, helping students deal with the cognitive load that accompanies the use of animation, and implementing constructivist aspects of knowledge construction while studying using animations.

Keywords Animation · Biotechnology education · Cognitive load · Constructivist teaching

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Introduction

Recent advances in information technology and graphics have enabled the development of powerful visualization tools for scientific phenomena and abstract information. The enthusiasm for graphics of all kinds lies in the belief that they can promote comprehension and foster insights into abstract phenomena (Scaife and Rogers 1996). More specifically, animation's potential for promoting students' understanding of diverse disciplines in science has been discussed at length in the literature (Hegarty 2004; Hoffler and Leutner 2007; Tversky and Morrison 2002). By animation, we refer to a simulated motion picture depicting the movement of drawn objects (Mayer and Moreno 2002).

Instruction involving computer animations has been shown to be most effective at facilitating an understanding of processes at the molecular level (Ardac and Akaygun 2005; Barak and Dori 2005; McClean et al. 2005). Students who had viewed molecular-level computer animations were found less likely to demonstrate misconceptions than students who had not (Sanger and Greenbowe 1997). In another study, students who viewed animations illustrating the molecular processes of diffusion and osmosis were less likely to exhibit misconceptions and were less likely to have anthropomorphic views of matter (Sanger et al. 2001).

Similarly, in biology, students who viewed an animation on cell death scored significantly higher on the subsequent test than those who did not view it (Stith 2004). Similarly, students who viewed a three-dimensional animation of protein synthesis scored significantly higher in a follow-up test than the group that had not viewed the animation (McClean et al. 2005).

Molecular processes, such as protein synthesis and molecular biology methods, are known to be an intellectual challenge for high-school students (Bahar et al. 1999; Falk et al. 2008; Lewis and Wood-Robinson 2000; Marbach-Ad 2001). The methods are completely unfamiliar to most students because they are remote from their everyday experience, and the students usually have no opportunity to experience them hands-on in the school laboratory (Olsher et al. 1999; Steele and Aubusson 2004). According to Steele and Aubusson (2004), further research is needed to identify ways of promoting the effective teaching of biotechnological methods based on molecular biology processes, because even though teachers regard this topic as important and interesting to students, most choose not to teach it because of the significant subject matter difficulties. Animations that simulate processes such as biotechnological methods can allow learners to execute "virtual experiments" that would otherwise be dangerous, costly, or unfeasible in a school laboratory. The idealization of complex laboratory experiments, as they appear in animations and simulations, is helpful in reducing error and focusing attention on particular abstract concepts, or isolating variables that are normally combined (Hennessy et al. 2006; Newton and Rogers 2001). In our study, we used animations that we developed to support biotechnology majors' learning of biotechnological methods in the context of learning genetic engineering.

Theoretical Background

This paper is based on three theoretical frameworks. The first refers to the cognitive basis of learning using visualization tools (Mayer and Moreno 2002; Paivio 1986; Sweller 1994). The second refers to the teacher's essential role while enacting animations in class (Ardac and Akaygun 2005; Hennessy et al. 2006; Tabak 2004), by promoting meaningful learning (Ausubel 1963; Perkins 1993) while studying from multimedia environments in general (de Jong and van Joolingen 1998) and animations in particular (Soderberg and Price 2003). The third refers to the importance of studying the teacher's perspective while enacting animations in class (Dori and Barnea 1997; Hazzan 2003; Zacharia 2003), towards promoting their effective implementation. These three theoretical frameworks are discussed in detail below.

The 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 science education. One of those theories is the cognitive theory of multimedia learning (Mayer and Moreno 2002), which is based on three fundamental assumptions. The first is the dual-channel assumption (Paivio 1986), according to which 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. Since pictures, whether they are dynamic or static, may be coded both visually and verbally, they are more likely to be remembered than words. According to Hoffler and Leutner's (2007) meta-analysis, there is strong empirical evidence that learning outcomes are improved by presenting the learner with verbal and pictorial information in a coordinated fashion. In science 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 in this theory is the limited-capacity assumption (Baddely 1998), which postulates that only a few pieces of information can be actively processed at any one time in each channel. This assumption goes together with the cognitive load theory (Sweller 1994), in that the working memory's capacity sets very narrow limitations. This is particularly relevant in science education, where there is a burden of diverse concepts and processes while learning, most of them totally new to the learners (Yarden et al. 2004), as well as a requirement to generate large conceptual frameworks (Trowbridge and Wandersee 1996). In this situation, memory in particular, and cognition in general, 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 relievingthe limited organic capacities.

The third assumption, the active-processing assumption, states that meaningful learning 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 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. The value of endorsing meaningful learning, as opposed to rote learning, is well known in science education (Okebukola 1990).

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 that favor visual presentations and others that favor verbal ones, a multimedia presentation might be equally effective in delivering information to both kinds of learners. We are most familiar with students' multiplicity of learning styles (Felder 1993; Tobias 1990), and therefore tools such as animation, which can be effective for visual as well as verbal learners, could be extremely valuable.

Supporting Students' Learning with Animation

Using animation alone does not ensure learning. It is 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). Students appear 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). Furthermore, according to Kelly and Jones (2007), students sometimes miss essential features when they watch only animations.

Students in the studies reviewed by de Jong and van Joolingen (1998) engaged in unplanned, inefficient, and inconclusive experimentation while studying from simulations and animations. Productive learning requires staged, structured tasks and systematic experimentation (Linn 2004). It is most important to make implicit reasoning explicit so as to highlight any inconsistencies (Hennessy et al. 2006). According to constructivism (Ausubel 1963), for students to learn the new concepts and processes they encounter in a meaningful way, they must relate the new knowledge and information they come across with concepts and claims they already hold. Students must also reflect on their actions to construct usable knowledge (Hmelo and Day 1999).

In view of the above, the teacher appears to play a crucial role in learning from animations. There is a strong necessity for teacher's support, together with the software support, for the two to interact to produce a robust form of support (Tabak 2004) According to Soderberg and Price (2003), teachers should discuss and challenge students' own ideas, as well as highlight the limitations of the computer models themselves. The results of Ardac and Akaygun's (2005) study imply that the effectiveness of whole-class instruction with animations might improve if teachers would challenge and question the inconsistencies and contradictions between verbal explanations and the corresponding molecular representations. From a constructivist perspective (Ausubel 1963; Perkins 1993), more effort should be made by the teacher to engage students more deeply and thoughtfully in any kind of subject-matter learning. Connections should be made between students' lives and the subject matter being learned, between principles and practice, between the past and the present. Students should be asked to think through concepts and situations, rather than memorize (Ausubel 1963; Perkins 1993).

Studying Teachers' Perspectives While Enacting Animations in Class

The role of the teacher is central in the diffusion of curricular initiatives (Barab and Luehmann 2003; Remillard 1999). More specifically, the successful introduction of computer-aided instruction as a tool for enhancing learning, as well as teaching, depends on the teacher's having a positive attitude (Dori and Barnea 1997). According to Zacharia's (2003) study, science teachers' beliefs affect their attitudes, and these attitudes affect their intentions to incorporate computer-aided instructional tools in class. Consequently, while examining the enactment of animations in class, it is important to study the teachers' perspective, namely the teachers' perceptions, challenges and recommended pedagogical strategies.

The teacher's perspective is also important in gaining knowledge on how to successfully enact animations in class. According to Hazzan's (2003) study with high-school mathematics teachers toward integrating computers into their future classroom teaching, teachers reported that students sometimes progress without understanding the previous stages in the animations, which negatively affects their learning from animations (Hazzan 2003). One important issue to discuss with the teachers might be their views on the timing of using animations in class, i.e., the learning stage at which they should be implemented. The technology is often used to follow up and apply theory, such that students are first familiarized with key concepts, terms, or procedures (Barton and Still 2004). Some teachers prefer that all feasible experiments be carried out manually first. Conversely, others use virtual experiments as they appear in animations to predict and plan the subsequent practical work (Hennessy et al. 2006).

In this study, teachers' perceptions regarding the complex relationships between theories, "hands-on" activities and the use of animations in class are investigated. In addition, we introduce two central approaches used by two biotechnology teachers, aimed to structure and support the learning of biotechnological methods while using animation in class.

Research Goal and Questions

The study introduced in this paper is part of a larger study aimed at exploring how the use of animation improves the learning of biotechnological methods in the context of learning biotechnology (Yarden and Yarden 2010). Our goal is to characterize the different learning terms under which the use of animation is most effective, focusing on the characteristics of teachers' classroom enactments while teaching biotechnological methods using animations. Thus, the variables of teachers' challenges as well as their pedagogical strategies of enacting animations in class are investigated in this paper. Accordingly, this paper was guided by the following research questions:

(a) What are the teacher's perceptions concerning enacting animations in class while learning biotechnological methods?
(b) What might be the teacher's contribution to the enactment of animations in class while learning biotechnological methods?

The Context of the Study

The Curriculum

Biotechnology education has gained significant recognition in a number of international curriculum frameworks worldwide (Conner 2000; Solomon 2001; Steele and Aubusson 2004). The Israeli Ministry of Education has also acknowledged the relevance and importance of teaching biotechnology at the senior high-school level, for both biotechnology and biology majors (Israeli Ministry of Education 2005, 2006).

At the end of the 10th grade, students in Israel choose to major in at least one scientific or non-scientific topic, which is evaluated in a national matriculation examination at the end of 12th grade (16–18 years old). The syllabus for biotechnology major studies, 90 h of teaching (Israeli Ministry of Education 2005), includes compulsory core topics as well as elective ones. One of the obligatory topics is a unit in genetic engineering. Through this unit, students are exposed to basic concepts and processes in molecular biotechnology that involve comprehension of several biotechnological methods.

Visualizing Biotechnological Methods

At the molecular level, biotechnological methods are completely invisible and intangible to students. To demonstrate the mechanism behind those methods, we therefore developed animations which accompany a new textbook which we developed in genetic engineering (Michael and 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).

According to the literature, it appears that one of the most helpful and effective features of animations is their interactive use (Hegarty 2004; Rebetez et al. 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 and Morrison 2002). In view of this, each of the developed animations exists in two alternative versions: 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 procedures are carried out in the lab, i.e., 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 written text, which appears in close proximity to the animation and describes what is being shown (according to the spatial contiguity principle—(Mayer and 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 and Moreno 2002). 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.

Research Design and Methodology

Sample

Teachers' Focus Group

The teachers' sample in this research includes 30 high-school biotechnology teachers who participated in a professional development workshop aimed at investigating how the teachers plan for and support learning with animations while learning biotechnological methods in class. The participating teachers in this sample can be considered a representative sample of biotechnology teachers, since they can be characterized by diverse teaching experiences, as well as having diverse formal education backgrounds in science and science education. They also teach in diverse high schools: urban, public and private.

The participating teachers were in various stages of familiarity with the animations which were being introduced and discussed—from biotechnology teachers who were totally unfamiliar with the animations to teachers who had already been briefly exposed to them, and those who had already used the animations in their classes and could share their experiences and insights with others.

Case Studies: The Teachers

Two teachers, Ravit and Dora (pseudonyms), were sampled from the teachers' focus group, to more closely explore their teaching approaches and pedagogical strategies while enacting animations during the teaching of biotechnological methods. Since we were concerned with studying the teachers' contribution to the enactment of the animations in class, we were looking for teachers who use animations in their classes and believe in the power of this tool. Since in addition to their initiative and motivation, they satisfied these criteria, Ravit and Dora were chosen for this part of the study. Moreover, these two teachers stood out during the teachers' focus group and each of them expressed an alternative approach regarding the enactment of animation in class. We therefore thought that it would be interesting to perform a detailed study of their use of animation in the classroom, in their own teaching environment.

Both Ravit and Dora have extensive teaching experience. Ravit has taught biotechnology in high school for more than 10 years; she has a B.Sc. in biology, and a M.Sc. and Ph.D. in immunology. Dora has been teaching biotechnology in high school for 9 years; she has a B.Sc. in biology and before becoming a teacher, she worked for several years in laboratory research in a hospital. Therefore, these two teachers in the two case studies could not be considered a representative sample, but rather an extreme sample of two exemplary teachers.

The Students and the Curriculum

The case studies were conducted in two 12th grade biotechnology majors' classes, in two secular, mixed, urban high schools. There were about 25 students in each class and their cognitive levels were estimated by their teachers as average-high.

In Israel, at the end of the 10th grade, students choose to major in at least one scientific or non-scientific topic, which is evaluated in a national matriculation examination. The syllabus for the biotechnology-major studies in Israel requires 450 h of teaching (Israeli Ministry of Education 2005) and includes, in addition to an obligatory topic in genetic engineering, two elective topics (i.e., immunodiagnostics, bioinformatics), hands-on learning in the laboratory and an inquiry project (entitled Biotech), all assessed in a national matriculation examination at the end of 12th grade. In order to provide the necessary basic scientific background to the learning of biotechnology, the biotechnology majors are required to choose one additional scientific topic, physics, chemistry or biology, for their matriculation examination.

Research Tools

Teachers' Focus Group

To expose biotechnology teachers to the developed animations, as well as to discuss their views and insights about teaching biotechnological methods using the animations, we conducted a focus group during the course of a teachers' professional development workshop.

The focus group (60 min long) was managed by two science education researchers, and was based on some moderator questions. Those questions were: "How many times do you use animation in class while teaching biotechnological methods?", "Which strategies do you employ while enacting animation in class?" and "What are the benefits from enacting animation in class?". At the same time, during the course of the focus group, the participating teachers raised their own concerns and interests about the use of animation for the teaching of biotechnology.

Teachers' Interviews

Semi-structured 60- to 90-min long interviews were carried out with the two exemplary teachers (Ravit and Dora). In those interviews, we discussed their beliefs, aims and instructional strategies, and their students' outcomes during the enactment.

Documenting Teachers' Enactment of the Animations in Their Classrooms

To document classroom events occurring while learning biotechnological methods using the animations, we audiotaped selected lessons in classrooms of the two exemplary biotechnology teachers (Ravit and Dora). Throughout the observations in the two classes, we focused in particular on the specific teaching strategies employed by the teachers, which seem to promote students' understanding of the biotechnological methods being taught.

Data Analysis

Teachers' Focus Group

The teachers' focus group was audio-taped and fully transcribed. Since the nature of the discussions was open, we used the narrative-based theory (Shkedi 2003). The transcripts were coded into categories under shared topics, and consequently subcategories were united into key categories through the creation of mapped and focused categorizations, and finally a narrative description was written (Shkedi 2003).

Class Observations

The enactments of the animations in the two exemplary teachers' classes of biotechnology majors' were audio-taped and fully transcribed. The transcripts were qualitatively analyzed according to the narrative-based theory (Shkedi 2003). Following mapping and focused categorization from class-observation transcripts, the two teachers were interviewed. Accordingly, the transcripts from the class observations were treated as a primary data source, while the transcripts from the teachers' interviews were treated as a secondary source, aimed at supporting directions that had already been identified through analyzing class observations.

Teachers' Interviews

Teachers' interviews were audio-taped and fully transcribed. Through the interviews, the two exemplary teachers were asked to explain representative episodes from the focused categorization of the class-observation transcripts.

Results

Teacher's Perceptions of the Enactment of Animations in Class While Learning Biotechnological Methods (Teachers' Focus Group)

Challenges Alongside Benefits

When the teachers participating in this study used animation in class in the course of teaching biotechnological methods, they seemed to be aware of its challenges as well as its benefits. Notwithstanding, all of the teachers expressed generally positive attitudes towards the use of animation in class, and all of them employed animation, albeit in various different ways, while teaching biotechnological methods.

One of the things the teachers seemed to be most aware of was the cognitive load that might evolve while using visual representations such as animations (Sweller 1994). On several occasions during the focus group, a few teachers requested clearer representation of objects, such as molecules and chemical bonds, in the animations. Nevertheless, it was noted that while these teachers were somewhat dissatisfied with the way objects were represented in the animations, at the same time they were aware of the constraints and limitations of representations in animations, reflected in their concern that the animations not be burdened with too many details:

> Miki: Maybe you [the developers] can add the hydrogen bonds into this scene of the animation [where the restriction enzyme is shown cutting the phosphodiester bond]?
> Eli: The hydrogen bonds are not connected to the story of cutting the phosphodiester bond. They are not involved. It might only make it more complicated to watch this scene in the animation. There are details you have to ignore while making a scene in an animation, otherwise the burden will be too great.

Another aspect in teachers' views of the visual representations in the animations was their concern that while watching animations, students might develop misconceptions due to the way molecules and chemical bonds are represented. For instance, some of the teachers expressed their concern that students might grasp the concept of phosphodiester bonds according to their representation in the restriction enzyme's animation:

> In the animation, you see the DNA strand, and the phosphodiester bond is mentioned as the bond between the nucleotides, but only the nitrogen bases are shown. So what the student sees is that base A (adenine) is connected to base T (thymine), and from that point on he might remember that a phosphodiester bond is a bond between the nitrogen bases (Efrat).

Other teachers referred to misconceptions that might evolve concerning the size and shape of the molecules that are symbolized in the animation, as well as the movement of objects, such as enzymes, as represented dynamically in the animation:

> There are problems, for instance, with the size of the enzyme compared to the DNA molecule, and the way in which the enzymes move and associate with the DNA. It [the representation] is not accurate from a biochemical perspective (Ran).

Despite the complexity reflected by the teachers in their statements regarding static and dynamic aspects of the visual representations in animations, at the same time they reported that animations constitute a beneficial tool for learning biotechnological methods. The teachers described the animations as very effective tools compared to other teaching strategies or other visualization tools, such as transparencies, mostly because of the dynamic and continuous nature of the visualization:

> Last year I made transparencies. I drew sticky ends, another transparency in which they were associated, and another transparency with ligase. Visually, this is completely different in animated format. It moves. It is much more beautiful. The animation actually demonstrates a process that starts and ends following a specific order (Dora).
>
> I show them the animation while explaining the process to them. It shows them the entire process continuously. It saves a lot of time in explanations and in understanding (Ravit).

The teachers also use animations while teaching biotechnological methods because they believe that this serves as a good solution for specific difficulties encountered by students learning biotechnological methods. In the next example, the teacher refers to the animation's unique ability to zoom in on specific regions in the molecules and the chemical bonds that are being represented in the animation:

> It is really hard for the students to understand the concept of the phosphodiester bond. I keep telling them that the phosphodiester bond is not *between* the DNA strands, it is *inside* the strand. In the animation, one "zooms into" the DNA strand and the phenomenon is demonstrated for them (Efrat).

In the following example, another teacher refers to the progressive nature of the animation, which allows demonstrating processes such as biotechnological methods over time:

> When I talk about using restriction enzymes the students don't always understand that this process takes *time*. In the animation they can see the whole process, from beginning to end, with a clock on the animation that is running the whole time (Dora).

The teachers also described the animations as a convenient way of improving students' internal mental models. To construct those mental models effectively, most of the teachers recommended using animations in combination with other visualization tools:

> Using animation can serve as an appropriate way to test the models students already have in their minds after looking at the illustrations in the textbook (Heidy).

The Optimal Learning Stage and Format for the Use of Animations

The challenges and benefits expressed by the teachers in relation to using animations while teaching biotechnological methods appeared to influence their views on how to optimally integrate the use of animation into their teaching practice. Most of the teachers recommended integrating the animation in advanced stages of learning: when the students have more prior content knowledge, they can better cope with the details in the animation. The complexity of the animation also affects teachers' decisions on when to integrate the animations into their teaching sequence:

> Complex animations, like the PCR animation which demonstrates a whole process, should be used towards the end of learning the method. Showing it in the beginning with so many details, when the students still don't know the purpose of all of the process, or what factors are involved, makes it hard to understand the animation such that they miss it (Ran).

Aside from its complexity, the format of the animation was another factor raised by the teachers in relation to the suitable learning phase for its use. The teachers referred to the two alternative versions of each animation that were available to them: a continuous version, which shows the whole procedure continuously and a sequential version, which shows the procedure gradually, or "step by step". Regarding the use of those two alternative versions, the teachers expressed diverse preferences. While some teachers stated that when learning a biotechnological method first the students should be exposed to the process in general, and only then get into the details of it, others thought just the opposite: that only after understanding the process gradually can the students see the whole picture:

> When I'm explaining a method to them, I first show them the whole picture, using the continuous version, and only then get into the details. Otherwise it is very hard for them to construct what is going on from all of the little details (Ravit).
>
> I think that when they first learn the details, they can then watch the continuous version and understand how everything is integrated (Dora).

Teacher-Centered Instruction Versus Student-Centered Instruction

Through the teachers' focus group, two central approaches to the teachers' position while enacting animations in the classroom were noted: while some teachers indicated that they control and lead the activity with the animations, others said they tend to work in a mode in which the students are more independent. One of the key factors in the teacher's decision of which approach to establish was the time consumed for learning:

> Eli: When I teach biotechnological methods using animations I put it [the animations] inside my presentations. I have a link to the animation. First I explain, moving forwards and backwards, and it goes very fast.
> Moderator: And you don't let them work alone?
> Eli: Hardly at all since there is no time.

In addition to saving essential time in the intense schedule of the 11th and 12th grades, some teachers believe that the teacher-centered strategy is more effective in terms of students' understanding. They believe that the teacher as leader makes the learning from the animation more meaningful:

> I show them exactly the whole process while I am explaining. It's a must, I think. I also ask all the class the questions that appear in the animation. Instead of everyone answering individually, we all answer together as a group (Rachel).

In contrast, other teachers in the group revealed that when they use animations in their classes, the students work with the animation alone. In this manner, the students are more active as they navigate through the animation and the teacher thus serves as a coordinator between the students and the animation:

> Dora: We let the students work alone with the animation and all of the time we keep asking questions like: 'What do you have now in the test tube?' 'What stage are you on?' and they worked! Right, it took three lessons.
> Moderator: And they worked alone?
> Dora: Yes, and in my opinion they knew it well, better than… It was for three lessons, with an accompanying worksheet that we prepared for them, and they knew ELISA [enzyme-linked immunosorbent assay, a biotechnological method]. A little while later we went over the ELISA really fast in class and a discourse developed, and they [the students] had an opportunity to check their own understanding.

The teachers also mentioned that the students really like working in an independent way and that they wait for such occasions:

> Yes, they [the students] love it; they keep asking me when we will watch another animation in this way (Dora).

Even though those teachers supported the way in which students work with the animations independently, they remained aware of the time limitations. Consequently, they recommended using this strategy at least a few times, and believed that the impact of such experiences would be broad and would have an effect on students' future experiences with animations:

> Moderator: So this way you suggested [students learning independently with animations] is the only way you use animations in class?
> Dora: No, you cannot do this throughout the entire year, not with each of the animations we use. We can watch animations in that way only occasionally, but once you've done it [used the independent students' strategy], your students are in a different place.

Teachers' Contribution to the Enactment of Animations in Class While Learning Biotechnological Methods (Two Case Studies)

Here we aimed to study the teachers' potential contribution to the enactment of animations in class, and our findings were obtained by analyzing the two exemplary case studies. In those case studies, we observed how two biotechnology teachers enact several animations in their classes while teaching a number of biotechnological methods. The analysis revealed that the two biotechnology teachers' contribution to the enactment of animations is pronounced 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 while studying using animations.

Establishing the "Hands-On" Point of View

One of the things that was very obvious in analyzing both class observations was that both Ravit and Dora talked a lot with their students about how the biotechnological methods, which were introduced in the animations, are really carried out in practice in the lab. For instance, they discussed the rationale as well as the practical procedure behind various steps in the biotechnological methods which were demonstrated in the animations. In her interview, Ravit explained that the students should understand, in each step of the animation they are watching, the reason for doing it, and how it is really done in the lab:

> In the animation that demonstrates the creation of a DNA library, the blotting stage is being demonstrated, but you did not give the rationale, why it has to be done like that, using a filter. We want to give

the students a feel for the lab and then show them dynamically how things are done, but still we must *explain* to them, for example, why we are not adding the detector to the gel, or why it is important to add the detector to the filter.

Another way of giving the students the "hands-on" point of view was by discussion with the students and making them aware of the existence of some steps that were skipped in the animation, but are nevertheless important when performing the relevant biotechnological method in the lab. In the next example from classroom observation, Dora and her students are discussing the rationale of a step that is not present in the cloning animation they are watching:

Dora: Tell me, what should we do to the bacteria in order to get an effective transformation?
Student 1: We should heat them.
Student 2: We should heat them more and more.
Dora: And in that way we'll create more and more temporal holes in the cell wall as well as in the membrane, and that enables us to carry out the transformation with plasmids.

Afterward in her interview, Dora explained that without the accompanying discussion of the important steps in the biotechnological method, being demonstrated in the animation, and their rationale, the students might learn the biotechnological methods incompletely:

Those steps are missing in the animation but this is not terrible because we discuss them together. If the animations included all of the steps, the students might not think about why there is a need to perform each step and why it is important.

Guided Watching: Help Dealing with the Cognitive Load

Both Ravit and Dora tend to guide their students while watching the animations. Ravit, as a "teacher-centered" example, did this by leading her students' navigation through the animations. Dora, who tends to employ a more "student-centered" approach, supported her students on several occasions during the learning activity with the animation, whenever they reflected misunderstandings they had while watching the animation. Accordingly, both teachers focused their students' attention on important details in the animation. They both kept asking the students different questions about objects in the animation they were watching. In the next example, Ravit is making sure that her students understand the function of each site in the plasmid, which is being introduced in the cloning animation:

Ravit: Now look, we have two test tubes. In test tube A you can see there is a plasmid…
Student: It has an antibiotic resistance site.
Ravit: What site is it?
Student: The one that is named tetracycline.
Ravit: Right. What are the other sites?
Student: There is a restriction site.
Ravit: Right. What else?
Student: An origin of replication site.

In the interview, Ravit explains that by guiding students through watching animations she is making the animation much 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 explains that she is directing the students while they watch the animations because of the nature of the *subject matter* (the biotechnological methods), which is abstract and complex. According to Ravit, especially in animations on this topic, careful watching is needed in order to identify, for instance, fundamental differences between the structures of similar molecules:

I'll tell you, in the case of the structure of carbons, at first glance everything looks the same. The student might notice the difference, but he might not understand the meaning of the difference, and this is exactly the crux of matter! This small difference between molecules can make a huge difference in understanding. That is why when students are looking at two structures of substances in the animation the teacher should focus them on the tricky spot.

The importance of identifying exactly what is shown in the animation seems to direct Dora as well. In the next example, she is reacting to some student comments, made while they are watching the animation, and accordingly asks some leading questions and supports them so they can see the differences between different kinds of bacteria in the cloning animation:

Student 1: There is one bacteria without a plasmid.
Student 2: There is one that has not perceived a plasmid and one that has.
Dora: There is only one bacteria with an uncloned plasmid? One of the plasmids is cloned. Which is it?
Student: This one.
Dora: Right. So what is this? And this? [pointing to the screen]

Student: This plasmid has resistance to the antibiotic tetracycline.
Dora: Is it cloned?
Student: No.

Later in her interview, Dora summarizes the type of support she believes she gave her students in this episode:

> 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. From a constructivist perspective (Ausubel 1963; Perkins 1993), more effort should be made by the teacher to engage students more deeply and thoughtfully in any kind of subject-matter learning. Connections should be made between students' lives and the subject matter being learned, between principles and practice, between the past and the present. Students should be asked to think through concepts and situations, rather than memorize (Ausubel 1963; Perkins 1993).

Both Ravit and Dora treated the animation activity as an important cornerstone in the broad construction of students' understanding of the biotechnological methods. One of the things that Ravit did in this respect was to clearly establish the animation activity on students' prior knowledge in biotechnology, in order to make this activity more relevant and meaningful:

Ravit: Let's see in the animation how to create a recombinant plasmid. Can someone please tell us how this is done before we watch the animation? How we link a gene, a fragment of DNA into a plasmid?
Liron: You cut them both using the same restriction enzymes.
Ravit: And then what happens?
Liron: You get sticky ends. And then you add the ligase enzyme.
Ravit: OK. Now let's see the animation and check whether what Liron [the student] has just told us is true.

Another thing both Ravit and Dora did to make the animation activity more meaningful was to connect it explicitly to other activities in the students' learning sequence, such as lab experiences:

Dora: Nofar [a student] is asking an interesting question regarding the animation: "How can we tell which is the insert at the end of the cloning?" Since we cloned two plasmids, we really cannot tell which is the insert and which is the recombinant plasmid.
Student: But when we deal with a DNA and a plasmid…
Dora: Right. In your next projects in the lab you will take a fragment of DNA from a virus and clone it into a plasmid. In that case the insert is the fragment from the virus and the plasmid has received it.

Later in her interview, Ravit stresses why she believes it is so important to link the animation activity to the other learning activities the students have been exposed to:

> 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." That is why all the time, while working with the animation, I keep going back to what I have already taught on other occasions. The student is curious: if he does not understand something from the animation he can go back to other learning experiences he has had.

The next aspect of using animations in a constructivist way was reflected differently in the two case studies. This aspect was identified as supporting students' understanding of biotechnological methods while watching the animations. Since the teachers have different teaching styles, they tended to perform differently with regard to this aspect. Ravit, with her "teacher-centered" approach, supports her students by explaining and expanding on the meaning of concepts she believes are crucial for their understanding of the biotechnological method being taught using the animation. In the next example, Ravit is opening a discussion with her students while they watch the cloning animation, by raising the transformation concept which she believes is significant for their understanding:

Ravit: You saw the recombinant plasmids. Now what are we doing with the plasmids after the recombination?
Student: We introduce them into bacteria.
Ravit: We are making transfor…
Student: ..mation.
Ravit: The process is called transformation. This is the insertion of a recombinant plasmid into the bacteria.

Later in her interview, Ravit explains why conceptualization of the process the students have 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.

While Ravit bases her supporting efforts while enacting the animations on her own pedagogical and content knowledge, Dora bases her supporting efforts on students' difficulties and misunderstandings which they are exposed to during the enactment of the animations. In response to the student's question, Dora discusses the process of plasmid replication, *beyond* what is shown in the animation, in order to make the processes *in* the animation more understandable for the 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 another example, a discussion concerning the concept of sticky ends, which is being demonstrated in the animation, is brought up once again by a student's question. Dora takes this opportunity to expand the students' understanding regarding the object of sticky ends which is being demonstrated in the animation, in order to clarify it for them:

> Student: Why is it called sticky ends?
> Dora: To what does it stick?
> Student 1: They stick to each other.
> Student 2: They stick to the plasmids.
> Student 3: They stick to the cloned region, which we want to insert.
> Dora: How does it stick? There is no "glue" so how does it stick?

Later in her interview, Dora reveals 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 enabled her to support the students while they were watching the animation, whenever they encountered concepts or objects which were not so comprehensible:

> When I was exposed to students' specific difficulties through their viewing of the animation I had the opportunity to spotlight objects and concepts in the animation which are not understandable enough to the students.

Discussion

Through this research we tried to identify teachers' challenges, pedagogical strategies and potential contributions to the enactment of animations in class while studying biotechnological methods. In the course of the analysis of two exemplary case studies, we recognized two alternative teaching approaches to supporting students' knowledge construction while studying biotechnological methods from animations.

Teachers' Perceptions of the Enactment of Animations in Class

Our aim was to shed light on biotechnology teachers' perceptions of the practice of animations in their classroom. Teachers' perceptions and reflections on the enactment of animations in class were elicited during a professional development workshop for biotechnology teachers, in which the teachers were exposed to newly developed animations in genetic engineering.

In analyzing teachers' statements during the workshop, we noticed that the teachers reflected the complex reality of enacting animations in class while teaching biotechnological methods. This complex reality is influenced by administrative aspects such as time limits, by cognitive aspects such as handling the cognitive load, and by pedagogical considerations such as the optimal learning stage for the use of animations, the optimal format of the animation, and the optimal teaching strategy for the use of animations in class.

Data suggested that the biotechnology teachers in this study attribute more advantages than disadvantages to the use of animations in class while teaching biotechnological methods. Due to the concrete, dynamic and continuous nature of animations and to the way in which they can demonstrate work that is carried out in the lab, the teachers recommended using animations while teaching biotechnological methods.

In Zacharia's (2003) study, which dealt with enacting computerized learning tools in class while teaching physics, the teachers also acknowledged the utility of computerized demonstrations: they reduce ambiguity by demonstrating or modeling correct options, and they help the learner identify the cause-and-effect relationship that might be obscured by time or bulk of material. According to the teachers' responses in Zacharia's (2003) study, as well as in this study, the use of computer demonstrations as animations or simulations offers options when alternative approaches are not available (owing to cost, danger or context). The reported disadvantages were mostly focused on the fact that these tools do not reflect reality (providing ideal conditions or circumstances). According to Hazzan (2003), the teachers' major didactic and cognitive concern, while using animations in class, was that learners may progress without understanding the previous stages (Hazzan 2003). In our study, the teachers reported that the representations in the animations might effect the evolution of misconceptions concerning the nature of chemical bonds and the accurate structures of molecules. It seems that although animations can provide learners with explicit dynamic information, the inclusion of a temporal change introduces additional information-processing demands (Lewalter 2003). According to de Jong et al. (1999), instruction through computer simulations and animations should make use of further prompting to support students' regulative processes. Thus, the role of the teacher while enacting the animations in class appears to be extremely important.

Teachers' Contributions to the Enactment of Animations in Class

Most of the computerized tools enable students to proceed in a trial-and-error fashion and finish the practice without understanding the topic at hand. Due to the cognitive load involved (Hegarty 2004), students sometimes miss essential features when they only watch animations (Kelly and Jones 2007). In this study, we explored the teacher's possible contribution to the enactment of animations in class, by analyzing two exemplary case studies. The analysis revealed a marked contribution by the two biotechnology teachers to the enactment of animations in the following three aspects: establishing a "hands-on" point of view while studying biotechnological methods from animations, helping students comprehend with the cognitive load that accompanies the use of animations, and implementing constructivist aspects of knowledge construction while studying using animations. In those two teachers, we also recognized two alternative constructivist approaches in terms of supporting students' knowledge construction while studying from animations. The two approaches, which had to do with the teachers' position while enacting animations in class, were in fact initially recognized during the teachers' focus group: while some teachers indicated that they control and lead the animation activity, others said they tend to work such that the students are more independent.

Those two teaching approaches were re-exposed during the case studies. One of the teachers, Ravit, supports her students' knowledge construction while studying from the animations by explaining and expanding the meaning of concepts she believes are crucial for their understanding of the biotechnological method being taught using the animation. According to Soderberg and Price (2003), the teacher's role while studying from computer representations is to structure tasks and questions in ways that prompt students to think about underlying concepts and relationships being introduced in the simulations and animations. This involves being available when learners are most receptive to guidance, helping them reformulate their thinking, for instance, by rationalizing explanations with everyday knowledge (Parker 2004).

In the case of the second exemplary biotechnology teacher in our study, Dora, the supporting efforts were based on students' difficulties and misunderstandings, which she picked up on during the enactment of the animations. This approach was also supported by Hennessy et al. (2006), who claimed that teachers should be encouraged to employ mini-plenaries to quickly identify and address misconceptions, and to use students' errors as teaching points while studying from animations or simulations. According to Tabak (2004), whole-class discussions enable a teacher to explicate the demands of constructing scientific knowledge and to synthesize ideas across groups, in order to reach a consensus and approach normative views. In light of the fact that Dora had planned the animation activity by providing an accompanying worksheet which was designed to focus the students on certain issues in the animation while watching, it can be said that such an instructional design sequence integrates both socio-pedagogical and material supports (Krajcik et al. 2000).

Both Ravit and Dora implemented elements of constructivist teaching (Perkins 1993) while they used animations in class, namely, they clearly established the animation activity on students' prior knowledge, and connected it explicitly to other activities in the students' learning sequence, such as lab experiences. Constructivist teachers tend to explore how their students see any problem or issue they encounter in any learning situation, and why their path towards understanding seems promising to them (Glasersfeld 1998). The findings of this study, concerning teachers' contribution to the enactment of animations in class while studying biotechnological methods, strengthen the expectations and recommendations raised by other relevant studies (Ardac and Akaygun 2005; Hennessy et al. 2006; Kelly and Jones 2007). Accordingly, the role of the teacher while enacting animations in class is critical in rendering the animations more meaningful. We suggest that students and teachers work together in transforming knowledge while studying from animations, as in other lessons and activities in school (Scardamalia and Bereiter 1991).

In this study, we also spotlighted teachers' fundamental involvement in, and contribution to the enactment of animations in class while studying biotechnoloigcal methods. These results might have implications for the enactment of animations in classes teaching a variety of disciplines, such as helping students comprehend under the cognitive load involved while studying from animations in general. It is important to emphasize that this study was performed in a natural classroom setting in the context of intensive biology/biotechnology majors' lessons, and does not represent an isolated experience, thus adding additional validity to the findings.

The major limitation to be taken into account is that the results regarding the teachers' contribution to the enactment of animations in class were obtained using a *qualitative* research approach, with two case studies. Nevertheless, these findings can be considered to have external validity because the two exemplary teachers, and their two classes of biotechnology majors who participated in this study, can be considered an extremist sample. In other words, since it was demonstrated that the teacher's contribution to studying from animations is essential for motivating students in classes of experienced and constructivist teachers, it might be assumed that in the case of less motivated classes, the teacher's contribution is significantly higher. We suggest that in the future, the use of animations for the students be mediated by their biology/biotechnology teachers, and teachers' input should be studied in practice using an experimental design and a quantitative approach.

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References

Ardac D, Akaygun S (2005) Using static and dynamic visuals to represent chemical change at molecular level. Int J Sci Educ 27(11):1269–1298

Ausubel DP (1963) The psychology of meaningful verbal learning. Grune & Stratton, New York

Baddely A (1998) Human memory. Allyn and Bacon, Boston

Bahar M, Johnstone A, Sutcliffe RG (1999) Investigation of students' cognitive structure in elementary genetics through word association tests. J Biol Educ 33:134–141

Barab SA, Luehmann AL (2003) Building sustainable science curriculum: acknowledging and accomodating local adaptation. Sci Educ 87:454–467

Barak M, Dori YJ (2005) Enhancing undergraduate students' chemistry understanding through project-based learning in an IT environment. Sci Educ 89(1):117–139

Barton R, Still C (2004) Planning, teaching and assessment using computer-aided practical work. In: Barton R (ed) Teaching secondary science with ICT. Open University Press, Cambridge, pp 52–68

Conner L (2000) The significance of an approach to the teaching of societal issues related to biotechnology. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans

De Jong T, van Joolingen WR (1998) Scientific discovery learning with computer simulations of conceptual domains. Rev Educ Res 68(2):179–201

De Jong T, Martin E, Zamarro J, Esqembre F, Swaak J, Van Joolingen W (1999) The integration of computer simulation and learning support: an example from the physics domain of collisions. J Res Sci Teach 36(5):597–615

Dori YJ, Barnea N (1997) In-service chemistry teachers' training: the impact of introducing computer technology on teachers' attitudes and classroom implementation. Int J Sci Educ 19(5): 577–592

Falk H, Brill G, Yarden A (2008) Teaching a biotechnology curriculum based on adapted primary literature. Int J Sci Educ 30(14):1841–1866

Felder R (1993) Reaching the second tier: learning and teaching styles in college science education. J Coll Sci Teach 23(5):286–290

Glasersfeld E (1998) Cognition, construction of knowledge, and teaching. In: Matthews MR (ed) Constructivism in science education. Kluwer, Netherlands, pp 11–30

Hazzan O (2003) Prospective high school mathematics teachers' attitudes toward integrating computers in their future teaching. J Res Technol Educ 35:213–226

Hegarty M (2004) Dynamic visualizations and learning: getting to the difficult questions. Learn Instr 14:343–351

Hennessy S, Deaney R, Ruthven K (2006) Situated expertise in integrating use of multimedia simulation into secondary science teaching. Int J Sci Educ 28(7):701–732

Hmelo C, Day R (1999) Contextualized questioning to scafold learning from simulations. Comput Educ 32:151–164

Hoffler TN, Leutner D (2007) Instructional animation versus static pictures: a meta-analysis. Learn Instr 17(6):722–738

Israeli Ministry of Education (2005) Syllabus of biotechnological studies (in Hebrew). State of Israel Ministry of Education Curriculum Center, Jerusalem (www.biotech.ort.org.il)

Israeli Ministry of Education (2006) Syllabus of biological studies (in Hebrew). State of Israel Ministry of Education Curriculum Center, Jerusalem. (www.bioteach.snunit.k12.il/upload/.bb)

Kelly RM, Jones LL (2007) Exploring how different features of animations of sodium chloride dissolution affect students' explanations. J Sci Educ Technol 16:413–429

Krajcik J, Blumenfeld P, Marx R, Soloway E (2000) Instructional, curricular, and technological supports for inquiry in science classrooms. In: Minstrell J, Van Zee E (eds) Inquiring into inquiry learning and teaching in science. American Association for the Advancement of Science, Washington, pp 283–315

Lewalter D (2003) Cognitive strategies for learning from static and dynamic visuals. Learn Instr 13:177–189

Lewis J, Wood-Robinson C (2000) Genes, chromosomes, cell division and inheritance—do students see any relationship? Int J Sci Educ 22(2):177–195

Linn MC (2004) Using ICT to teach and learn science. In: Holliman R, Scanlon E (eds) Mediating science learning through information and communications technology. Routledge Falmer, London, pp 9–26

Marbach-Ad G (2001) Attempting to break the code in student comprehension of genetic concepts. J Biol Educ 35(4):183–189

Mayer R (1996) Learners as information processors: legacies and limitations of educational psychology's second metaphor. Educ Psychol 31:151–161

Mayer R, Moreno R (2002) Animations as an aid to multimedia learning. Educ Psychol Rev 14(1):87–99

McClean P, Johnson C, Rogers R, Daniels L, Reber J, Slator BM, Terpstra J, White A (2005) Molecular and cellular biology animations: development and impact on student learning. Cell Biol Educ 4:169–179

Michael D, Yarden A (2007) Genetic engineering: from principles and methods to research and applications (a student text, and an internet site http://stwww.weizmann.ac.il/g-bio/geneengine/animations.html). The Amos de-Shalit Israeli Center for Science Teaching (in Hebrew)

Newton LR, Rogers L (2001) Teaching science with ICT. Continuum, London

Okebukola PAO (1990) Attaining meaningful learning of concepts in genetics and ecology: an examination of the potency of the concept-mapping technique. J Res Sci Teach 27(5):493–504

Olsher G, Berl DB, Dreyfus A (1999) Biotechnologies as a context for enhancing junior high-school students' ability to ask meaningful questions about abstract biological processes. Int J Sci Educ 21(2):137–153

Paivio A (1986) Mental representations: a dual coding approach. Oxford University Press, New York

Parker J (2004) The synthesis of subject and pedagogy for effective learning and teaching in primary science education. Brit Educ Res J 30(6):819–839

Perkins D (1993) Teaching for understanding. Am Educ: Prof J Am Fed Teach 17(3):28–35

Rebetez C, Sangin M, Betrancourt M, Dillenbourg P (2004) Importance of permanence and cognitive skills when learning from animations. Paper presented at the European Association for Research on Learning and Instruction (EARLI) SIG2 meeting, Valencia

Remillard JT (1999) Curriculum materials in mathematics education reform: a framework for examining teachers' curriculum development. Curriculum Inq 29:315–342

Sanger MJ, Greenbowe TJ (1997) Common student misconceptions in electrochemistry: galvanic, electrolytic, and concentration cells. J Res Sci Teach 34(3):377–398

Sanger MJ, Brecheisen DM, Hynek BM (2001) Can computer animations affect college biology students' conceptions about diffusion & osmosis? Am Biol Teach 63(2):104–109

Scaife M, Rogers Y (1996) External cognition: how do graphical representations work? Int J Hum Comput Stud 45:185–213

Scardamalia M, Bereiter C (1991) Higher levels of agency for children in knowledge building: a challenge for the design of newknowledge media. J Learn Sci 1:37–68

Shkedi A (2003) Words of meaning: qualitative research—theory and practice (in Hebrew). Ramot, Tel Aviv

Soderberg P, Price F (2003) An examination of problem-based teaching and learning in population genetics and evolution using EVOLVE, a computer simulation. Int J Sci Educ 25(1):35–55

Solomon J (2001) Teaching for scientific literacy: what could it mean. Sch Sci Rev 82(300):93–96

Steele F, Aubusson P (2004) The challenge in teaching biotechnology. Res Sci Educ 34:365–387

Stith BJ (2004) Use of animation in teaching cell biology. Cell Biol Educ 3:181–188

Sweller J (1994) Cognitive load theory, learning difficulty, and instructional design. Learn Instr 4:295–312

Tabak I (2004) Synergy: a complement to emerging patterns of distributed scaffolding. J Learn Sci 13(3):305–335

Tobias S (1990) They're not dumb, they're different: stalking the second tier. Research Corporation, Tucson

Trowbridge JE, Wandersee JH (1996) How do graphics presented during college biology lessons affect students' learning? J Coll Sci Teach 26(1):54–57

Tversky B, Morrison JB (2002) Animation: can it faciliate? Int J Hum Comput Stud 57:247–262

Wellington J (2004) Multimedia in science teaching. In: Barton R (ed) Teaching secondary science with ICT. Open University Press, Cambridge

Wittrock MC (1974) Learning as a generative activity. Educ Psychol 11:87–95

Yarden H, Yarden A (2010) Learning using dynamic and static visualizations: students' comprehension, prior knowledge and conceptual status of a biotechnological method. Res Sci Educ 40(3):375–402

Yarden H, Marbach-Ad G, Gershony JM (2004) Using the concept map technique in teaching introductory cell biology to college freshmen. Bioscene J Coll Biol Educ 30(1):3–13

Zacharia Z (2003) Beliefs, attitudes, and intentions of science teachers regarding the educational use of computer simulations and inquiry-based experiments in physics. J Res Sci Teach 40(8):792–823