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פיתוח אנימציות אינטראקטיביות וחקר השימוש בהן ללמידת ולהוראת שיטות ביוטכנולוגיות מתקדמות

Learning and teaching biotechnological methods using interactive animations

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"עוד תראי את כל הדרך
עוד תלכי בה היא שלך
גם אם לא תהיה תמיד קלה.
תביטי ותראי את כל הדרך
תקבעי את מסלולה,
תעברי את כל הדרך כולה".

שמרית אור/ מתי כספי

עבודה זו מוקדשת להוריי היקרים, פרידה וחנוך פורשט, שהאמינו בי תמיד וחינכו אותי להאמין בעצמי.

תודות

ראשית התודות למנחה שלי, פרופ' ענת ירדן, על ההנחיה המסורה והקפדנית, המקצועית והאישית. ידיעותייך הרבות, חדות המחשבה, תשומת הלב לפרטים והיכולת להשאיר מקום לפרספקטיבה אישית שימשו לי כהשראה ואפשרו לי לצעוד ולהתפתח לאורך הדרך, ללמוד ולממש את עצמי בצורה הטובה ביותר.

תודה לוועדה המלווה שלי, פרופ' ניר אוריון ופרופ' מייקל ווקר, על האמון שנתתם בי, על ההכוונה והדגשים החשובים שעזרו לי לקדם את המחקר, ואת כתיבת התיזה.

תודה לתלמידים ולמורים שהשתתפו בשלבים השונים של פיתוח האנימציות ובמחקר המתפתח, תודה על שיתוף פעולה פורה ומהנה, על תובנות משמעותיות ועל רצון טוב.

תודה לגרפיקאים איתם עבדתי, **לקרן קצב, לשלומית דוידסון, לאסף מסעוד ולזיו אריאלי,** על המקצוענות, הרעיונות היצירתיים והביצועים המושלמים, כמו גם על הרבה שעות עבודה נעימות ומקדמות.

תודה לחבריי בקבוצת הוראת הביולוגיה על האוזן הקשבת, העצות הטובות והשיחות הנעימות והמפרות.

תודה לחברי הסגל במחלקה על התכנים המשמעותיים, על הידע העצום והסגנונות המגוונים והמעניינים אליהם נחשפתי ומהם למדתי.

תודה לאנשי הצוות במחלקה, ליטי ורון על הייעוץ הסטטיסטי המצוין והמעורבות האישית, **למרינה ארמיאץ'** על שירותי המחשוב, על דייקנותך ונועם הליכותייך**, לתרצה קאודרס** על העזרה המקצועית ועל האדיבות, **לאורנה עמר, ברק כהן ונתנאל עותמי** על הנגישות, על סיועם בכל עת, ועל האיכות שבביצוע.

תודה מיוחדת לשגיב, בן זוגי היקר, אהוב ושותף, על האהבה, התמיכה, הפרגון והסיוע לאורך כל הדרך.

ולילדיי האהובים, יואבי ושירה, על מי שאתם, התגשמות חלום, ועל שאתם נותנים לי כוח ומזינים אותי בכל מעשיי.

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Abstract

Animations have a great potential for improving the way people learn. A number of studies related to different scientific disciplines have shown that instruction involving computer animations can facilitate the understanding of processes at the molecular level. The purpose of this study was to explore the use of animations as visualization tools in order to promote high school biology and biotechnology students' comprehension of biotechnological methods in the framework of learning biotechnology. This study aims to represent the complexity of learning about biotechnological methods using animations, in terms of the cognitive factors involved, as well as the pedagogical ones. Using written questionnaires, I found that an animation is significantly advantageous to students' comprehension of the Polymerase Chain Reaction (PCR), compared to still images equivalent to the animation. I also found that prior knowledge is not an essential factor when learning about PCR using animation; thus the dynamic display of a biotechnological process by animation may compensate for a student's insufficient knowledge in imagining the relevant motions. While learning about PCR using still images, low prior knowledge was found as an obstacle to learning. Using the conceptual status framework for analyzing biology majors' discourse while learning about the PCR, I have learned that the use of the animation was advantageous in understanding the mechanistic aspects of the biotechnological method, compared to students who learned this method using still images. This advantage was also reflected while analyzing biotechnology majors' concept maps, before and after learning about the restriction enzymes digestion process using animation.

Findings regarding the challenges involved and the recommended teaching strategies for enacting animations in class were obtained by analyzing teachers' focus group, teachers' interviews and two exemplary case studies. I found that the teacher's contribution to the enactment of animations in class is pronounced in the following three aspects: establishing the "hands on" point of view, helping students deal with the cognitive load that accompany the use of animations and implementing constructivist aspects of knowledge construction while studying using animations. These findings strengthen my preliminary assumption that students and teachers should work together in transforming knowledge while studying from animations.

I believe this study shed some light on the complexity of using animations in class, thus make a difference in considering the common conception, that animations are an ideal tool for learning and teaching. Through this research I was able to show the unique contribution of animations, and their advantage over still images, for the acquisition of certain kinds of information, namely the mechanistic aspects of biotechnological methods. These findings could have educational implications in learning of various scientific disciplines, in which mechanistic understanding and reasoning causality is crucial. In addition, in this study I was able to show the unique contribution of animations to certain kinds of learners, namely students with low prior content knowledge. The constructivist mediation of the teacher while learning from animations enables the students to employ this unique tool of animations most effectively.

תקציר

באנימציות טמון פוטנציאל רב לקידום הדרך בה אנשים לומדים. מחקרים שנערכו בדיסציפלינות מדעיות שונות הראו כי אנימציות ממוחשבות מסייעות בהבנה של תהליכים ברמה מולקולרית. מטרת עבודה זו הייתה לחקור את השימוש באנימציות ככלי חזותי לצורך קידום הבנה של שיטות ביוטכנולוגיות מתקדמות בקרב תלמידי ביולוגיה וביוטכנולוגיה בתיכון (יא"-יב"ב, 5 יח"ל). מחקר זה מתמקד בהצגת המורכבות שבשימוש באנימציות ללמידה ולהוראה, מבחינת ההיבטים הקוגניטיביים והפדגוגיים הכרוכים בכך.

בעזרת שימוש בשאלונים כמותיים מצאתי כי קיים יתרון מובהק לאנימציות בקידום ההבנה של שיטת ה-**PCR** (**Polymerase Chain Reaction**), על פני שימוש באיורים, בקרב תלמידי ביולוגיה בתיכון. מצאתי כי הידע הקודם אינו מרכיב הכרחי בלמידת שיטת ה-**PCR** מאנימציה, בעוד שבלמידה מאיורים מהווה ידע קודם מרכיב קריטי. בעזרת ניתוח שיח של תלמידים, תוך שימוש במסגרת הניתוח של מעמד התפיסה (**Conceptual status**) למדתי כי לשימוש באנימציות ישנו יתרון מובהק בקידום ההבנה של ההיבטים המכניסטיים של שיטת ה-**PCR** בקרב תלמידי ביולוגיה בתיכון, בהשוואה לתלמידים שלמדו מאיורים. תרומה מובהקת זו באה לידי ביטוי גם בניתוח מפות מושגים של תלמידי ביוטכנולוגיה בתיכון, שנבנו לפני ואחרי צפייה באנימציה שהמחישה חיתוך מקטע **DNA** באמצעות אנזימי הגבלה.

ניתוח קבוצת מיקוד שהתקיימה עם מורים לביוטכנולוגיה בתיכון, כמו גם מניתוח ראיונות עם מורים, התגבשו ממצאים בדבר האתגרים הכרוכים בהפעלת אנימציות בכיתה, ובדבר אסטרטגיות הוראה רלוונטיות מומלצות. בנוסף, מניתוח שני חקרי מקרה עם מורות מובילות לביוטכנולוגיה בתיכון מצאתי כי למורה תרומה חשובה בתיווך למידה משמעותית של שיטות ביוטכנולוגיות מאנימציות. תרומה זו באה לידי ביטוי בשלושה מישורים עיקריים: קידום הבנת היבטים מעשיים הכרוכים בשימוש בשיטות הביוטכנולוגיות במעבדה, תמיכה בתלמידים בהתמודדות עם אתגרים דוגמת העומס הקוגניטיבי הכרוך בלמידה מאנימציות, ותמיכה בארגון והבניית הידע הנרכש תוך כדי למידה מאנימציות. ממצאים אלה מחזקים את ההשערה שעמדה בבסיס מחקר זה, לפיה תלמידים ומורים צריכים לפעול במשותף בזמן למידה מאנימציות.

לסיכום, אני מאמינה כי עבודה זו שופכת אור מסוים על המורכבות הכרוכה בלמידה מאנימציות, ולכן מחדשת בהקשר לתפיסה הרווחת לפיה מדובר בכלי אידיאלי ללמידה. ניתן ללמוד מעבודה זו כי לאנימציות תרומה ייחודית בהבנת היבטים מכניסטיים של תהליכים מולקולריים, כמו גם תרומתה ללומדים בעלי ידע מוקדם מועט. אני מאמינה כי לאנימציות עשויה להיות תרומה רבה בלמידה גם של תהליכים ברמת המקרו, בהם יש אינטראקציה בין אובייקטים שונים ונדרשת הבנה של יחסי הגומלין בין האובייקטים השונים. תיווך המורה בזמן למידה מאנימציות יכול להפוך את הלמידה בעזרת כלי זה ללמידה קונסטרוקטיביסטית, ולאפשר ללומד להפיק את המרב מכלי ייחודי זה.

1. 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. This definition is made more specific by spearing it into activities that can be considered "traditional", i.e bread-making, brewing wine and beer, and those involving genetic engineering, that can be considered "modern" or "new technologies" (France & Gilbert, 2005). Over the last two decade, agriculture, industry and medicine are being altered by new technologies, including gene therapy in medicine, pesticide resistant crops and genetically modified foods (Edmonston, 2000).

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 (Conner, 2000; Solomon, 2001; Steele & 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 biology and biotechnology majors (Israeli Ministry of Education, 2003, 2005), as well as for non-science majors (Dori, Tal, & Tsaushu, 2003). Although biotechnology education has gained a significant recognition, less has been published about how to teach this topic effectively for science majors.

One of the most problematic issues to comprehend while learning biotechnology is the methods involved (Falk, Brill, & Yarden, 2008). Molecular biology methods are completely unfamiliar to most students, because they are remote from their everyday experiences and the students usually have no opportunity to experience them hands-on in the school laboratory (Olsher, Berl, & Dreyfus, 1999; Steele & Aubusson, 2004). In addition, the methods are based on the understanding of molecular processes, 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. Thus, as Steele and Aubusson (2004) have already manifested, further research is needed to identify ways to promote the effective teaching of biotechnology in school science. Even though teachers regard this topic as important and interesting to students, yet most of them choose not to teach it, due to its subject matter difficulties (Steele & Aubusson, 2004). 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. Researchers who take a constructivist approach to teaching recommend, in the face of such difficulties, to enhance teaching through active engagement using models and visualization (Marbach-Ad, Rotbain, & Stavy, 2008).

Multimedia instructional environments in general, and animations in particular, have a great potential for improving the way people learn (Kelly & Jones, 2007; Kozma, 2003; Mayer & Moreno, 2002; Reiber, 1991; Stith, 2004; Williamson & Abraham, 1995). One of the most unique advantages of animation is that in some situations, it can provide a virtual alternative to practical work. 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 it appears in simulations, is helpful in reducing error and focusing attention on particular abstract concepts, or isolating variables that are normally combined (Hennessy, Deaney, & Ruthven, 2006).

My major objective in this study was to investigate the unique contribution of animations in facilitating high school biology and biotechnology students' comprehension of molecular processes in the context of learning biotechnological methods. In addition, this study aims to represent the complexity of learning using animations, in terms of the cognitive factors involved, as well as the pedagogical ones.

2. Theoretical framework

My research on the unique contribution of animations in the context of learning and teaching biotechnological methods is based on three theoretical frameworks. The first refers to the cognitive basis of learning using visualization tools (Mayer & Moreno, 2002; Paivio, 1986; Sweller, 1994; Tversky & Morrison, 2002). The second refers to the theoretical framework of conceptual learning (Posner, Strike, Hewson, & Gertzog, 1982), and possible tools for its diagnosis, namely the conceptual status framework (Hewson & Lemberger, 2000; Tsui & Treagust, 2007) and concept mapping (Novak & Gowin, 1984; Trowbridge & Wandersee, 1998). The third refers to the essential role of the teacher while enacting animations in class(Ardac & Akaygun, 2005; Hennessy et al., 2006;

Tabak, 2004), by means of promoting meaningful learning (Ausubel, 1963; Perkins, 1993) while studying from multimedia environments in general (de Jong & van Joolingen, 1998), and animations in particular (P. Soderberg & F. Price, 2003). Those three theoretical frameworks will be discussed in detail below.

2.1 The cognitive basis of learning using visualization tools

The potential of animations for promoting students' understanding of diverse disciplines in science education has been discussed at length in the literature (Ardac & Akaygun, 2005; Hegarty, 2004; Hoffler & Leutner, 2007; Tversky & Morrison, 2002). By animation, we refer to a simulated motion picture depicting the movement of drawn objects. In contrast, video refers to a motion picture depicting the movement of real objects. Similarly, an illustration is a static picture of drawn objects, whereas a photograph is a static picture of real objects (Mayer & Moreno, 2002).

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; also seem to be most relevant when we discuss science education. One of those theories is the Cognitive Theory of Multimedia Learning (Mayer & 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 (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. Predominantly in science education, when we are dealing with phenomena that are mostly 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 view of that the capacity of working memory sets very narrow limitations. Especially in science education, where there is a burden of diverse concepts and processes while learning, most of them totally new for the learners (Yarden, Marbach-Ad, & Gershony, 2004), as well as a requirement to generate large conceptual frameworks (Trowbridge & Wandersee, 1996), it faces a considerable challenge to memory in particular and cognition in general. Hence there is a need in finding tools to assist reducing the inherent cognitive load as well as the organic limited 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 at the same time, 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 a system for delivering information to 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 prefer visual presentations and others that prefer verbal presentations, a multimedia presentation might be equally effective in delivering information to both kinds of learners. We are most familiar with the multiplicity of learning styles students own (Felder, 1993; Tobias, 1990), so tools such as animation, which can be effective to visual learners as well as verbal learners, might be extremely valuable.

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 rests on the belief that they can promote comprehension, and foster insights into abstract phenomena (Scaife & Rogers, 1996), demands which are most common in scientific disciplines. Indeed, this holds especially true for subjects that are naturally spatial, abstract and hard to describe or visualize. Memory has been reported to be greater for pictures than words. Pictures, whether still or dynamic, can facilitate content storage and retrieval under certain conditions (Large, 1996).

Distinguishing between static and dynamic visualizations

While multimedia may be a relatively new technology, 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). A number of primary studies in education in general, and in science education in particular, aimed to compare instructional animations with static pictures, and their impact on learning outcomes. Tversky and Morrison (2002) reviewed over 20 primary studies that compared learning from static displays (e.g., pictures) and animations. Their goal in this meta-analysis study was to integrate the findings of a large number of studies, in order to find overall-effects of instructional animations compared to static pictures on learning outcomes. Furthermore, factors or variables moderating the effect size were aimed to be identified. In general, a meta-analysis study is traditionally conducted in three main steps: (1) location and selection of appropriate studies, (2) coding of study features and calculating effect sizes, and (3) statistically analyzing effect sizes and the influence of study features (Hoffler & Leutner, 2007).

According to the results of Tversky and Morrison (2002), in most of the studies being investigated no advantage of animations over static graphics were found. Where a difference was found in favour of the animations, it was because more information was available in the animations than in the static displays. Another meta-analysis of 26 primary studies, which were published between 1973 and 2003, indicated that in 21 pair wise comparisons, a statistically significant advantage was found in favour of the animations, while the static pictures were significantly superior in only two pair wise comparisons (Hoffler & Leutner, 2007).

Obviously, there are some significant differences in the interpretation of information from dynamic vs. static displays, which are not consistently in favour 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 re-inspect 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, 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), meaning that they use that which can be easily observed. For that reason, some educational practices favour the use of dynamic visuals over static illustrations because they provide the learners with a ‘ready-made’ explicit and dynamic representation of the situation (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 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 find it difficult to extract information from complex animations. Blissett and Atkins (1993) have reported that individuals with less prior knowledge or lower-ability learners tend 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). ‘‘With some animations, learners may face higher levels of cognitive load than would be expected for static alternatives’’ (Lowe, 2003, p. 158).

Even though there is no obvious cognitive advantage to dynamic over static media, most educators and researchers continue to believe that dynamic media have enormous potential for instruction and training (Hegarty, 2004). Therefore, this study is confronting the challenge lies in determining what conditions or what learning terms may enable dynamic visualizations to be effective in learning. Mayer and Moreno (2002, p.88) previously suggested that "Instead of asking, 'Does animation improve learning?' we should ask 'When and how does animation affect learning?'. This study has tried to put a spot light on the unique advantage of animations in relating to specific cognitive as well as pedagogical aspects.

Facilitating students' understanding of molecular processes using animations

Visual representations play a crucial role when complex phenomena are not directly observable. A number of studies related to different disciplines, mostly in chemistry, have shown that instruction involving computer animations can facilitate the understanding of chemical processes at the molecular level (Ardac & Akaygun, 2005; Barnea & Dori, 1995; Sanger, Brecheisen, & Hynek, 2001; Williamson & Abraham, 1995). It is noteworthy that most of the research on using animations for molecular-level domains comes from chemistry whereas only a few studies deal specifically with molecular biology (McClean et al., 2005; Stith, 2004).

According to Sanger and Greenbowe (1997) study in chemistry education, students who had viewed molecular-level computer animations were found less likely to demonstrate the misconception that electrons flow in aqueous solutions without the assistance of ions than students who had not. In another study, students who viewed animations illustrating the molecular processes of diffusion of perfume molecules in air, and osmosis through a selectively permeable membrane, were less likely to exhibit misconceptions regarding equilibrium, and were less likely to have anthropomorphic views of matter (Sanger et al., 2001). An improved molecular understanding of a chemical change was also identified while using dynamic versus static visuals (Ardac & Akaygun, 2005). These results favour the use of dynamic visuals over static visuals when presenting molecular representations.

Similarly, in biology, students who viewed an animation on cell death scored significantly higher on the test than those who had not viewed the animation (Stith, 2004). In another study, 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).

According to Marbach-Ad, Rotbain and Stavy (2008) study, who aimed to determine whether the use of computer animation can contribute to high school students achievement in molecular genetics, it is advisable to use computer animations in molecular genetics, especially when teaching about dynamic processes. Learning molecular processes concerns initially the need to understand the molecular structures. Understanding the structure of molecules such as DNA is crucial to comprehending its function. According to Pallant and Tinker (2004) study of the use of two molecular dynamics models (Molecular Workbench and Pedagogica), animations helps to organize the large chunks of information, reducing the amount of memorization required. In addition, since molecular processes (e.g., DNA replication) occur on a minute space scale, involving multiple and diverse entities, instruction involving computer animations can facilitate the development of students' visualization skills and their abilities to think about those processes at the molecular level in a stepwise fashion (Williamson & Abraham, 1995). Finally, animations seem to be also helpful in terms of students' motivation, while learning at the molecular level. Many high school students, especially those who do not study advanced chemistry, develop a ‘‘phobia’’ of biology subjects on the molecular level (Marbach-Ad et al., 2008). According to Barnea and Dori study (1996), using computerized animation while learning chemistry, can reduce this fear by turning the learning into a kind of a game.

2.2 Conceptual learning and tools for its diagnosis

Learning is a rational activity that is based on comprehending and accepting ideas because they are seen as intelligible (Posner et al., 1982). It does not, of course, follow that motivational or affective variables are unimportant to the learning process. The claim that learning is a rational activity is meant to focus attention on what learning is, not what learning depends on. It is suggested (Pascual-Leone & Irwin, 1994; Salomon & Perkins, 1989) that there are two ways in which learning occurs. The first involves low cognitive functions and referring to concrete, experiential learning. The other involves high cognitive functions and referring to abstract, conceptual learning (Pascual-Leone & Irwin, 1994; Salomon & Perkins, 1989). Conceptual learning means extracting the generic attributes from some material, situation or behavior, and creating a mental representation (such as a sign, a picture or a linguistic expression) of these attributes. This mental representation is the individual’s own construction, and may also include other knowledge and beliefs that the individual imputes into the representation (Salomon & Perkins, 1989). The requirement to incorporate appropriate, but new, knowledge into one’s understanding is the epitome of conceptual learning (Maclellan, 2005).

Learning successfully in scientific domains requires the construction of conceptual knowledge (Lucangeli, Tressoldi, & Cendron, 1998), which means the acquisition and application of new knowledge resulting in concepts and symbolic representations not previously in the individual’s knowledge network (Maclellan, 2005). It would be exemplified in learning the meaning of a new idea, or making connections between two previously unrelated ideas (Hewson & Lemberger, 2000). There is a general consensus among conceptual learning researchers that the learners’ conceptual ecology or their prior knowledge, including ideas, commitments, and beliefs, provides the context within conceptual learning occurs (Hewson & Lemberger, 2000; Posner et al., 1982). In general terms, new ideas and knowledge are acquired through conceptual understanding (Maclellan, 2005). Striving to construct conceptual understanding is essential for solving problems (Hung & Jonassen, 2006).

As learning usually involves some way of representing information, science teachers make use of different representational techniques in the classroom to communicate ideas to students verbally or visually via texts, images, animations, and so on (Tsui & Treagust, 2007). Representations are simply the way to communicate ideas or concepts, by representing them either *externally* - taking the form of spoken language (verbal), written symbols (textual), pictures, physical objects, or a combination of these forms, or *internally* - when thinking about these ideas (Hiebert & Carpenter, 1992). Conceptions can be regarded as the learner’s internal representations, constructed from external ones (Tsui & Treagust, 2007). Duit and Glynn (1996) considered conceptions as learners’ mental models of an object or event.

From the conceptual learning perspective, representability is essential for making difficult concepts more intelligible (Tsui & Treagust, 2007). In this study, I investigated the unique contribution of animation on students' internal conceptions of molecular processes. For that purpose, I embraced the perspective of conceptual learning (Hewson & Lemberger, 2000; Posner et al., 1982).

Conceptual status framework

A central question of recent philosophy of science is how concepts change under the impact of new ideas or new information (Posner et al., 1982). The key factor in conceptual learning is the status of a conception that is held or considered by a learner, and it is entitled conceptual status. The conceptual status can illuminate deep conceptual learning, whether or not it involves a conceptual change (Hewson & Lemberger, 2000).

The first condition, according to three conditions of conceptual status, is intelligibility, and it is measures the extent to which the learner knows what the new conception means and can represent it. The next one, plausibility, measures the extent to which the learner believes that the new conception is true, and finds it consistent with or is able to reconcile it with other accepted ideas. The third condition, fruitfulness, reflects whether the learner finds the new conception useful in solving problems or suggesting new possibilities and directions (Tsui & Treagust, 2007). Each status element provides an inventory for categorizing a student's conception and judging whether the status of a person's conception is the extent to which the conception meets the conditions of intelligibility, plausibility or fruitfulness (Hewson & Lemberger, 2000).

This perspective fits the kind of learning we believe is occurring in our study, in which students are taught about the concepts and procedures, involved in the learning of biotechnological methods. Previous studies which analyzed students' comprehension of molecular genetics using the conceptual status framework (Hewson & Lemberger, 2000;

Tsui & Treagust, 2007) suggested that status is a viable hallmark for conceptual learning. Using status analysis categories, a cross-case analysis of the gene conceptions of students in Grades 10 and 12 in three Australian senior high schools indicated that multiple representations supported conceptual understanding of genetics but not among all students. Only few students' post instructional conceptions were intelligible–plausible–fruitful (Tsui & Treagust, 2007). In Hewson and Lemberger study (2000) it was also shown that status can enable researchers to identify students' conceptual learning, that would otherwise be less accessible. The purpose of their study was to expand a simple dominance model of genetic inheritance into a family of closely related models through a problem-solving approach. The example of genetic learning demonstrates that the students used status in identifying the limitations of their initial conception of a gene, in expanding it, and in constraining the ways to which it was expanded (Hewson & Lemberger, 2000). In the next chapter I will bring in another central and well known device, concept mapping, which can also enable to identify students' conceptual learning.

The concept mapping technique

The desire to explore students' understanding of a certain subject concept is shared by psychologists (e.g. Ausubel), science educators (e.g. Novak) and philosophers (e.g. Gowin). Novak and Gowin (1984) developed the concept map technique as a way of capturing learners' understanding of key concepts (Novak & Gowin, 1984). Concept mapping is a technique for externalizing concepts and propositions that express the relationships between concepts. It is intended to represent meaningful relationships between concepts, in the form of propositions (Novak & Gowin, 1984). Propositions are two or more concept labels linked by words. The concepts in the concept map are placed in boxes, lines are drawn from one concept to another, and ‘linking words’, which connect between the concepts, are written near these lines (White & Gunstone, 1992).

The concept mapping technique was originally used as a way of determining how changes in students conceptual understanding occur (J. D Novak, 1990). Among its many uses, concept maps allows for evaluation of prior knowledge and diagnosis of alternative conceptions (Trowbridge & Wandersee, 1998). It is a highly sensitive tool for measuring changes in knowledge structure (J.D Novak, 1990). It is also an activity which fosters active engagement among students (Okebukola, 1990). Because concept maps are an explicit representation of the concepts and propositions a person holds, they allow teachers and learners to exchange views on why a particular propositional linkage is good or valid, or to identify missing links between concepts that suggest a need for new learning (Yarden et al., 2004). Trowbridge and Wandersee (1994) have identified critical junctures in the understanding of seed concepts in evolution using the concept map technique, in the context of an introductory college course in evolution. Marbach-Ad (2001) has also used concept maps, in order to find out how high-school students understand the relationships between concepts in genetics. The results of her study imply that concept maps can serve as a good diagnostic tool, since the differences which were identified using this tool were validated using written questionnaires and interviews.

In this study I used the concept mapping technique, as well as the conceptual status framework, in order to trace and diagnose biology and biotechnology students' conceptual understanding of two biotechnological methods, in the framework of learning biotechnology.

2.3 The role of the teacher while enacting animations in class

Using animations alone does not ensure learning. It is occasionally linked with unquestionable, sometimes simplified models of a scientific process, that gives 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).

Students in the studies of “scientific discovery learning”, reviewed by de Jong and van Joolingen (1998), engaged in unplanned, inefficient, and inconclusive experimentation while studying from simulations. In addition, according to Kelly & Jones (2007), students sometimes miss essential features when they watch animations alone. 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), in order that students will learn new concepts and processes they encounter in a meaningful way, they must also relate new knowledge and information they come across with concepts and claims they already hold. 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). Students must also reflect on their actions to construct usable knowledge (Hmelo & Day, 1999).

In view of the above, it seems the teacher plays a crucial role while learning from animations. There is a strong necessity for teacher's coaching together with the software supports to address the same learning need and interact with each other 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 computer models themselves. The results of Ardac and Akaygun (2005) study imply that the effectiveness of whole class instruction of animations might improve if teachers will challenge and question the inconsistencies and contradictions between verbal explanations and the corresponding molecular representations. In view of constructivist perspectives, a growing effort should be made by the teacher in order 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 are asked to think through concepts and situations, rather than memorize (Ausubel, 1963; Perkins, 1993).

The role of the teacher is also central in the diffusion of curricular initiatives(Barab & 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 positive attitudes of the teachers (Dori & 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 into class. Consequently, while examining the enactment of animations in class, it is important to study the teacher's perspective, meaning teachers perceptions, challenges and recommended pedagogical strategies.

Teachers' perspective is also important in order to gain knowledge about how to enact successfully animations in class. During Hazzan's (2003) study, with high school mathematics teachers toward integrating computers into their future classroom teaching, teachers have reported that students' sometimes progress without understanding previous stages in animations, which affect negatively on their learning from animations (Hazzan, 2003). One of the issues important to discuss with the teachers might be, for instance, their views regarding the timing of using animations in class, in terms of the learning stage. The technology is often used to follow up and apply theory so that students are first familiarized with key concepts, terms, or procedures (Barton & Still, 2004). Some teachers prefer all feasible experiments to be carried out manually first. Conversely, others use virtual experiments as appeared in animations for prediction and planning before practical work (Hennessy et al., 2006).

In view of the above, teachers' perceptions as well as challenges regarding these complex relationships between theory, “hands-on” activities and the use of animations in class were investigated in the course of this study. I attempt to introduce two central approaches used by two leading teachers, aimed to structure and support the learning of biotechnological methods while using animations in class.

3. Research goals and questions

The purpose of this study is to explore the use of animations as visualization tools in order to promote high school biology and biotechnology students' comprehension of biotechnological methods in the framework of learning biotechnology. This study aims to identify the cognitive as well as the pedagogical factors involved in using animations while learning and teaching biotechnological methods. Accordingly, I introduce below the research goals and the derived research questions my research is focused on:

Goal 1- To study how the use of animations affects high school biology and biotechnology students' comprehension of biotechnological methods.

In order to address this goal, I developed animations that introduce the main steps of certain biotechnological methods. Those animations include interactive features as well as accompanied computerized tasks that are detailed in the "Context of the study" chapter. In addition, the following research questions were formulated:

1a. Is there a difference in the comprehension of the PCR method between students who learned using animation and those who learned using still images?

1b. What are the relationships between students' prior content knowledge and their comprehension of the PCR method, using animation or still images?

1c. What is the difference in the conceptual status of the PCR method between students who learned using animation and those who learned using still images?

1d. What are students' experiences and attitudes towards computerized learning environments in general and animations in particular, and does students' experiences and attitudes affects students' comprehension of the PCR method?

1e. What is the influence of using animation, following learning about restriction enzymes digestion process traditionally with the teacher, on students' comprehension?

1f. What are students' reflections on the use of animations while learning biotechnological methods?

Goal 2- To characterize the pedagogical characteristics of enacting animations in class while teaching biotechnological methods

2a. What are the teachers' perceptions, and the challenges they face, when enacting animations in biotechnology in class?

2b. What are the teachers' approaches regarding teaching biotechnological methods using animations?

2c. What might be the contribution of the teacher to the enactment of animations in class while learning biotechnological methods?

4. Research context

4.1 The developed animations

In this study I attempted to characterize the cognitive as well as pedagogical factors involved in using animations while learning and teaching biotechnological methods. Eleven Flash animations were developed in the course of this study for the use of high school biology majors and biotechnology majors, all include interactive features and accompanied by computerized tasks.

The first three animations were developed for high-school biology majors, as part of an innovative curriculum of learning biotechnology using adapted primary literature (Falk, Piotkevitch, Brill, Baram-Tsabari, & Yarden, 2003). The first animation introduces the ELISA (Enzyme Linked Immuno Sorbent Assay) technique, the second introduces the PCR (Polymerase Chain Reaction) technique, and the third visualizes the separation of a specific cell type from a mixture of different cell types, using magnets' bound-antibodies. Those animations were incorporated into a website entitled "Gene Tamers" (http://stwww.weizmann.ac.il/g-bio/biotech/), which accompanies and supports the learning of the biotechnology curriculum for biology majors.

The development of each of the animations was taken between several weeks to several months. Through the design of each of the animations I paid special attention to the drawing of the objects, aiming to design them to be accurate scientifically and with the relevant scientific characters. In addition, we also pay a lot of attention in designing the colors and dynamic features, in order to reduce to minimum the cognitive load which is involved while studying from animations (Hegarty, 2004). Those steps through the development of each of the animations had implications on the dissemination of the animations. Accordingly, I kept focusing the teachers as well as the students to the important features discussed above, in order to make the study from the animation most meaningful to them.

The next eight developed animations were designed for biotechnology majors and are aimed to introduce the following biotechnological methods: DNA digestion using restriction enzymes, gene cloning, the construction and the use of genomic libraries, the construction and the use of cDNA libraries, DNA sequencing, PCR, DNA chips and incorporating of genes into plants. Those animations were incorporated into an internet site entitled: "Genetic engineering: from principles and methods to research and applications" (http://stwww.weizmann.ac.il/g-bio/geneengine/animations.html). This site includes also links to other relevant animations, students' and teachers' forums and other pedagogical supports.

According to the literature, it seems that one of the most helpful and effective features of animations is an interactive use (Hegarty, 2004; Rebetez, Sangin, Betrancourt, & Dillenbourg, 2004; Stith, 2004). Stopping, starting, and replaying an animation can allow reinspection, focusing on specific parts and actions. Animations that allow close-ups, zooming, alternative perspectives, and control of speed are even more likely to be facilitative to learners (Tversky & Morrison, 2002). In view of that, 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 the various procedures are carried out in the lab, meaning whenever a new stage was encountered, such as heating; a new step was demonstrated in the animations. In addition, the steps were selected according to transitions between macro to micro perspectives and vise versa.

4.2 The accompanied written texts

Each of the developed animations includes written texts, which appear in close proximity to the animation. According to the Spatial Contiguity Principle (Mayer & Moreno, 2002), students learn more deeply when on-screen text is presented next to the portion of the animation that it describes, rather than when on-screen text is presented far from the corresponding action in the animation. The theoretical rationale is that learners are better able to build mental connections between corresponding words and pictures when they are near each other on the screen. In contrast, when they are not near each other, learners must waste limited cognitive capacity in searching for the portion of the animation that corresponds to the presented text. In view of that, in the first animations we developed - the PCR animation for biology majors, the accompanied written texts appears at the bottom of each screen in the animation. The written texts describe what is being shown in the animations, as can be seen in Figure 1:

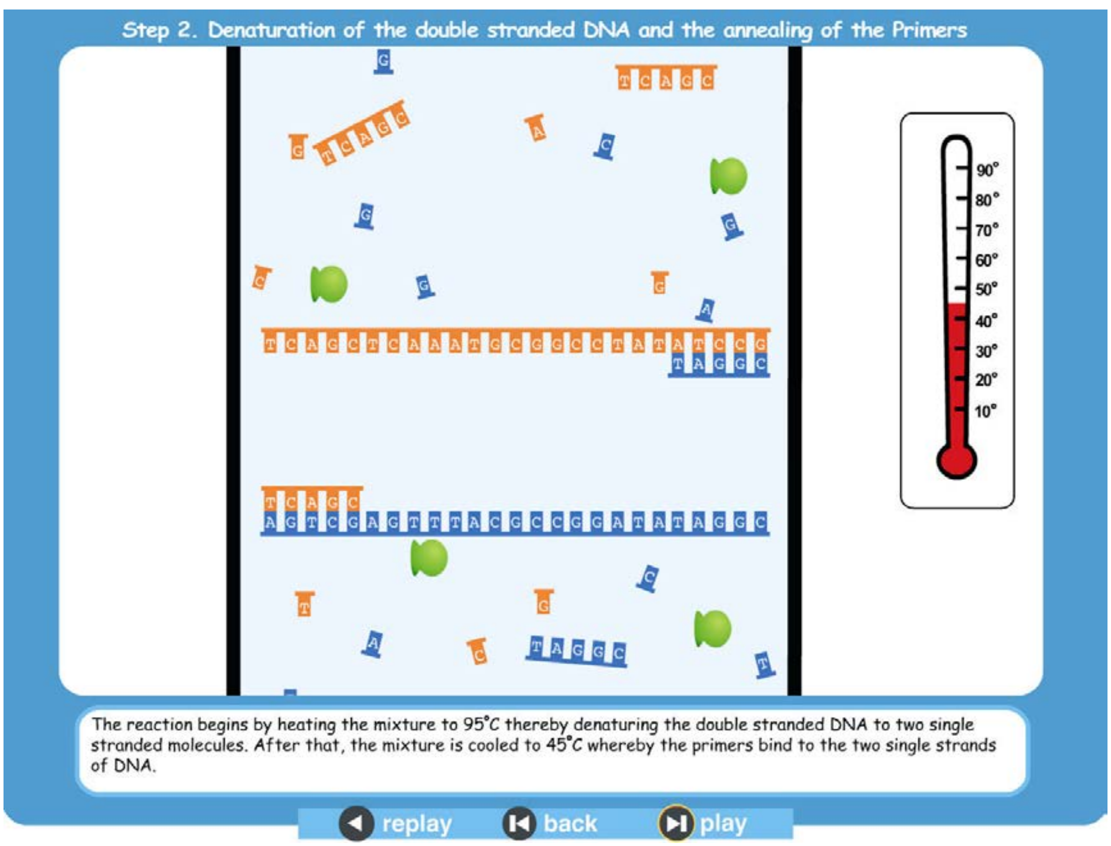

Figure 1: A sample frame from the PCR animation for biology students (http://stwww.weizmann.ac.il/g-bio/biotech/animations/PCR/anim_pcr.swf).

Since we wanted the students to notice more straightforwardly the changes in the accompanied text along the animations, in the subsequent animations we developed, we incorporated the accompanied written texts in text boxes which disappeared and reappeared during the animation, in order to make it more noticeable (Figure 2). Still, we kept the principal issue that the text will appear in close proximity to the animation.

***Figure 2*:** A Sample frame from the DNA chips animation for biotechnology students (http://stwww.weizmann.ac.il/g-bio/geneengine/anim1.html).

4.3 The accompanying computerized tasks

Components of active learning, such as integrated computerized tasks, seem to be significant in promoting comprehension while viewing animations (Acuna & Sanchez, 2004; Kramer, Prechtl, & Bayrhuber, 2004; Lowe, 2004). Thus, in all of the developed animations, we included interactive computerized tasks. Those tasks are aimed to identify students' attention to key issues in the biotechnological methods being demonstrated, as well as to understanding the symbols which appear in the animations. Some of the task accompany the animation, and are aimed to being executed after the students have watched the animation, as shown in Figure 3.

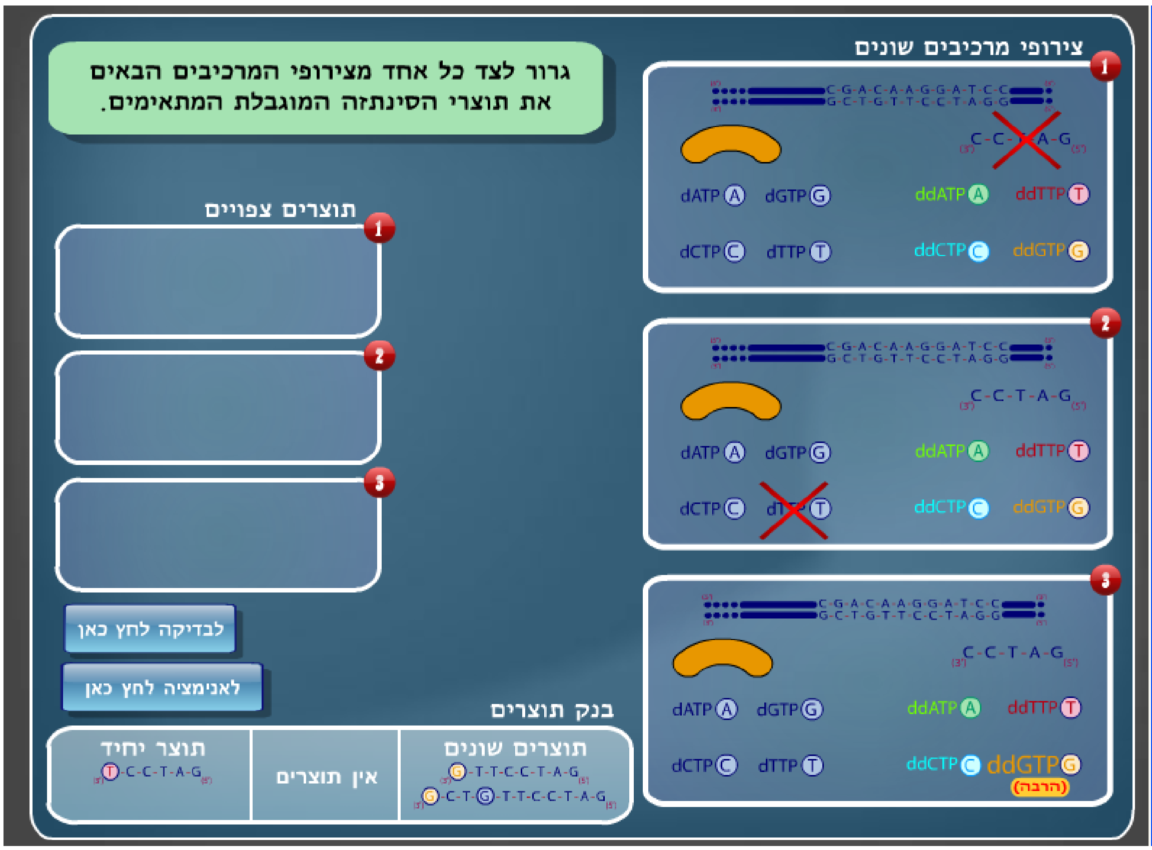

Figure 3: The DNA chips' accompanied task for biotechnology students (http://stwww.weizmann.ac.il/g-bio/geneengine/anim7.html).

In other animations we developed, the tasks were integrated in the middle of the animations (the restriction enzymes' animation, the cloning animation), or at the beginning of the animation, as an introduction to the animation itself (the construction of the genomic and the cDNA libraries animations, and the PCR animation for biotechnology majors, see Figure 4).

Figure 4: The biotechnology majors' PCR animation's accompanied task (http://stwww.weizmann.ac.il/g-bio/geneengine/anim3.html).

4.4 The studied animations

Two animations were selected for this research, the PCR animation which was studied through its use by biology majors, and the restriction enzymes' animation, which was studied through its use by biotechnology majors. I will now introduce the characteristics of each of the animations being studied:

The PCR animation

The PCR animation (see http://stwww.weizmann.ac.il/g-bio/biotech) introduces sequentially the procedure of amplifying a desired DNA fragment in a test tube using PCR. The animation starts with the insertion of the relevant materials into a test tube including: the DNA sample, some buffer, the nucleotides, the DNA polymerase enzyme and the primers. The subsequent stages of the animation involve demonstration of the temperature changes—first heating, which induces separation of the DNA strands, then cooling, which enables annealing of the primers to the DNA, and finally, raising the temperature, to allow the process of DNA synthesis. The whole procedure then starts all over again and is repeated a few dozen times.

The PCR cards

In order to study the effectiveness of the PCR animation in promoting students' comprehension of the biotechnological method, we compared the use of the animation to the use of an alternative visualization tool. Thus, we developed a series of cards with still images taken directly from the PCR animation (see Appendix 1). The series contains five cards, each card showing a picture taken from a "frozen" frame of the PCR animation, and introducing a central stage of the PCR method. The pictures on the cards are accompanied by the same written text that appears on the relevant frame in the animation.

The restriction enzymes animation

The restriction enzymes animation (http://stwww.weizmann.ac.il/g-bio/geneengine/anim1.html) introduces sequentially the procedure of digesting a DNA molecule using two different restriction enzymes: EcoRI and AluI. The animation begins with a visualization of two DNA strands, built of nucleotides which are linked to each other by phospodiester bonds. Then the procedure of digesting the DNA molecule using the EcoRI restriction enzyme is described in the animation in details; from adding the enzyme's solution to the DNA sample, through demonstrating how the enzyme is associated with the DNA strands and then the digestion itself and the formation of sticky ends. After the students are exposed to the way the EcoRI restriction enzyme cuts the DNA strands, then the process of cutting the DNA using the AluI restriction enzyme is carried out in an interactive manner. The students are requested to click on "buttoms" in the correct order of the events, and only then they can view the process sequentially. In this manner this part of the animation combines an interactive feature with an active learning component of solving a task (according to the Cognitive Theory of Multimedia Learning (Mayer & Moreno, 2002).

5. Research Methodology

5.1 Research approach

This research can be characterized as a basic research, since it explores the theoretical question of how the use of animations promotes students' comprehension of biotechnological methods. Nevertheless, this research can also be classified as an applied research, since it includes the development of animations, and studying their effectiveness while using them in different learning terms, on high school biology and biotechnology students' comprehension of the biotechnological methods.

As a mixed research, this research combines the use of quantitative as well as qualitative research tools. The quantitative research tools, namely written questionnaires, are used in order to check possible causality and/or correlation between variables such as students' prior content knowledge and students' understanding of biotechnological methods. The qualitative research tools (i.e discourse analysis, observations and interviews, focus groups etc) are used in order to gain deeper understanding regarding the process of learning the biotechnological methods through using animations.

5.2 Research variables

Independent variables:

- The use of alternative visualization tools: different animations (i.e PCR and the restriction enzymes' animations), and cards with still images taken directly from the PCR animation . (nominal variable).
- The use of animations in two different learning stages: at the beginning of learning the biotechnological method (PCR) or after learning it traditionally with the teacher (Restriction enzyme animation). (nominal variable).
- The impact of the interactive format of the animations: continuous version/ step by step version. (nominal variable).

Dependent variables:

- Students' comprehension of the biotechnological methods (i.e PCR, DNA digestion process using restriction enzymes). (quantitative variable).

- Students' conceptual status of the PCR method (nominal variable).
- Students' reflections on different components of the animations (i.e the interactive features, the accompanied computerized tasks), and on the use of the animation as a visualization tool in general (nominal variable).

Moderator variables:

- Students' prior content knowledge in topics that are relevant for learning the biotechnological methods using animations (quantitative variable).
- Students' experiences in using computer programs in general and animations in particular (quantitative variable).
- Students' attitudes towards learning using computerized learning environments in general, and animations in particular (nominal variable).
- Teachers' challenges when they enact the animations in class, and their recommendations (nominal variable).
- Teachers' contribution to the enactment of the animations in class (nominal variable).

5.3 Research samples

The target population of this study is high-school biology and biotechnology majors, from 11th to 12th grades. Biotechnology teachers also serve as part of the research population.

Students

Research samples included biology as well as biotechnology students from schools which are attended by a culturally non-deprived population. The classes were chosen according to their teachers' initiative and motivation to take part in this study (nonrandom sampling, based on volunteers). The students' sample in this study can be considered as a representative sample, since the students came from diverse high school, from urban schools as well as from high schools in rural communities. In addition, all the participating classes can be characterized as heterogeneous classes, counting excellent students together with students with lower achievements.

Students' population that participated in this study was composed of two samples, A and B.

Sample A: 173 12th grade high-school biology majors from nine biology majors' classes participated in a phase of the study in which we studied the use of the PCR (polymerase chain reaction) animation. Five classes out of the total nine classes were sampled from the same school, and the other four classes were from four different high schools. One hundred and seven students were females and 66 were males.

Sample B: 38 11th grade high-school biotechnology majors from two biotechnology major classes participated in a phase of the study in which we studied the use of the restriction enzymes' animation. The students were sampled from two high schools. Twenty four students were females and 14 were males

Teachers

Teachers' focus group

Thirty high school biotechnology teachers who participated in a professional development workshop, aimed to investigate how the teachers plan for and support learning with animations, while learning biotechnological methods in class (nonrandom sampling, based on convenience). The participating teachers in this sample can serve as a representative sample of biotechnology teachers, since they can be characterized with diverse teaching experiences, as well as diverse formal education in science and science education. They also teach in diverse kind of high schools; urban, public as well as private schools. The participating teachers were in diverse stages of familiarity with the animations which were introduced and discussed (see the chapter "the context of the study"); from biotechnology teachers who were totally unfamiliar with the animations to teachers who were already exposed briefly to the animations, and biotechnology teachers who already used the animations in their classes and could share with others their experiences and insights.

Case studies

Two exemplary leading teachers, Ravit and Dora (pseudo names), were sampled from teachers' focus group, in order to explore more closely their teaching approaches and pedagogical strategies being employed while enacting animations during teaching biotechnological methods. Since I was concerned with studying the contribution of the teachers to the enactment of the animations in class, I was looking for teachers who use animations in their classes and believe in the power of this tool. Therefore I chose Ravit and Dora, in addition to their initiative and motivation to take part in this part of the study. Moreover, those two teachers were prominent during the teachers' focus group and each of them has expressed an alternative approach regarding the enactment of animations in class. For that reason, I found it interesting to study their use of animations in class in their own teaching environment.

Both Ravit and have extensive teaching experience. Ravit teaches biotechnology in high school for more than ten years, she has a B.Sc in biology, M.Sc in immunology and she earned her PhD while studying tissue cultures. Dora teaches biotechnology in high school for nine 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 those two teachers in the two case studies can not be considered as a representative sample, but rather as an extreme sample of two exemplary teachers.

5.4 Research design

This study begun with an extensive literature review, in order to learn about the cognitive theoretical basis, and the potential of animations in promoting biology and biotechnology students' comprehension of biotechnological methods. In addition, an extensive internet sites review was carried out in order to screen for various animations which already exist on the web, in order to learn about the latest trends in the field. Subsequently, I started developing the animations, as well as cards containing still images taking directly from the animations. I also developed students' written questionnaires, and started to observe biology majors' classrooms, in order to focus on the issues which seems important to study while learning biotechnological methods using the animations. I documented students' work with the animations in nine biology majors' classrooms through audio-taping and analyzed students' discourse analysis and students' focus groups. In addition, I used knowledge, experiences and attitudes and feedback written questionnaires. A quasi-experimental method, with an experimental group and a comparison group, was used in order to probe whether animations can act as facilitators to learning. The experimental group was the group in which the PCR animation was used in order to visualize the PCR method, while the comparison group was the group in which the equivalent still images were used, in order to visualize the PCR method.

In the next stages of this study my observations focused on two biotechnology majors' classrooms, which learned about the process of DNA digestion using the restriction enzymes animation. Students' work with the animation was documented this time using the concept maps technique. During this stage I also conducted biology as well as biotechnology teachers' professional development workshops in order to share with the teachers the developed animations and the rationale behind them, as well as to recruit teachers for additional classrooms observations. During one of the professional development workshops I conducted, a teachers' focus group with biotechnology teachers, which dealt with teachers' challenges while teaching biotechnological methods using the animations, as well as with the teachers' recommended teaching strategies. All the discussions were audio–taped, fully transcribed and qualitatively analyzed.

Through the advanced stages of this study, I have completed developing eleven animations of eleven selected biotechnological methods, all including interactive features and computerized tasks. In addition, an internet site in genetic engineering, for biotechnology students as well biotechnology teachers, was designed. On this phase of the study the focus was on the qualitative analysis of teachers' enactments of animations in class. Two leading teachers biotechnology were documented during their enactment of the animations in class. Subsequently, the teachers were interviewed concerning their potential contribution to the enactment of animations in class. In the next table, Table 1, research goals, together with the relevant research questions, samples, treatments and research tools are being summarized.

Table 1- Research design

Research goal	Research questions	Research sample	Procedure	Research tools
Goal 1- To study how the use of animations affects high school biology and biotechnology students' comprehension of biotechnological methods.	1a. Is there a difference in the comprehension of PCR method between students who learned using animation and those who learned using still images? 1b. What are the relationships between students' prior content knowledge and their comprehension of the PCR method, using animation or still images? 1c. What is the difference in conceptual status of the PCR method between students who learned using animation and those who learned using still images? 1d.What are students' experiences and attitudes towards computerized learning environments in general and animations in particular, and does it affect students' comprehension of the PCR method?	173 12th grade high-school biology majors.	A quasi-experimental method. The experimental group was the group in which the PCR animation was used in order to visualize the PCR method, while the comparison group was the group in which equivalent still images were used, in order to visualize the PCR method. All the students learned about the PCR method for the first time through using one of the visualization tools, and their teachers did not discuss this method in advance.	-The PCR animation prior content knowledge questionnaire (see Appendix 2). -The PCR animation post activity knowledge questionnaire (see Appendix 3). - The experiences and attitudes questionnaire (see Appendix 4). - The feedback questionnaire (see Appendix 5). - Students' discourse analysis (8).

Research goal	Research questions	Research sample	Procedure	Research tools
	1e. What is the influence of using animation, following learning about restriction enzymes digestion process traditionally with the teacher, on students' comprehension?	Thirty eight 11th grade high-school biotechnology majors.	Two biotechnology majors' classes watched the restriction enzymes' animation after learning it traditionally with their teacher. The students were asked to build concept maps before and after they watched the animation that demonstrates this method.	- Concept maps (76).
	1f. What are students' reflections on the use of animations while learning biotechnological methods?	Seven focus groups with approximately 20 students each. Two focus groups were conducted in two biology majors' classes; the other 5 focus groups were conducted in 5 biotechnology majors' classes.	The students watched the PCR animation / the restriction enzymes animation and then participated in the focus groups.	- Students' focus groups (7).
Goal 2- To characterize the pedagogical characteristics of enacting animations in class while teaching biotechnological methods	2a. What are the teachers' perceptions and the challenges they face, when enacting animations in biotechnology in class?	30 high school biotechnology teachers who participated in a professional development workshop		- Teachers' focus group.
	2b. What are the teachers' approaches regarding teaching biotechnological methods using animations?	Two exemplary biotechnology teachers		-Teachers' interviews (2).

Research goal	Research questions	Research sample	Procedure	Research tools
	2c. What might be the contribution of the teacher to the enactment of animations in class while learning biotechnological methods?	Two exemplary biotechnology teachers and their own biotechnology major classes (n=2).	During the lessons being documented, in Ravit's class the animations were viewed simultaneously by all of the students, through the guidance of Ravit. In Dora's class however, in one lesson the students worked in pairs, while in the other lesson the animations were viewed simultaneously by all of the students, through the guidance of Dora. In both cases, the lessons were based on the animations being used, and both teachers employed specific strategies developed before-hand for using the animations.	- Classrooms' observations (3). -Teachers' interviews (2).

5.5 Research validity and reliability

Validity

The internal validity of this research is gained due to the following factors:

1. Triangulation: in order to study the dependent variable of "students' comprehension of the biotechnological methods", I used three independent research tools - knowledge written questionnaires, discourse analysis and concept maps. The triangulation of corresponding findings from the three different sources strengths the causal explanation between the animations' unique contribution as visualization tool, and students' comprehension of the biotechnological methods.
2. Another cross-checking was made in the meta-cognitive aspect, which relates to the variable of "students' reflections to different components of the animations, and on the use of the animation as a visualization tool in general". Data which was ascended from students' feedback questionnaires were cross-checked with data that rose from students' focus groups. In the case of teachers' focus group, the data was cross checked with data that was raised from teachers' interviews, in order to strength its validity.
3. The significant results of the statistical tests strength the causal explanation,

The external validity of this research is gained due to the use of diverse populations: biology as well as biotechnology high school majors, which can strengthen the population validity. For example, in order to strength the validity of the findings which were raised from analyzing students' focus groups, seven focus groups were conducted in biology as well as biotechnology majors' classes, and the findings from those different samples were crosschecked. In addition, the study of the two different animations in the course of this study (the PCR animation and the restriction enzymes' animation) which relate to the similar research questions also raises the content variation validity. It is important to emphasize at this point that this study was done in the natural setting of a classroom within a context of intensive biology or biotechnology majors' lessons, not an isolated experience, thus adding additional validity to the findings.

Reliability

The reliability of this research is a consequence of research tools' analysis reliability. The reliability of the quantitative research tools analysis, such as the attitudes questionnaire and the feedback questionnaire analysis, was gained using experts judgment classification and the α chronbach test for reliability. Regarding the reliability of the qualitative research tools analysis (i.e students' discourse analysis, students' concept maps), those were gained with another researcher, resulting in a high level of agreement between the researchers (95% and 96%, respectively).

5.6 Research tools

Quantitative research tools -written questionnaires

Three types of written questionnaires were used in the course of this study. The knowledge questionnaires were used before and after the activity with the PCR animation (Pre and Post-questionnaires). The experience and attitudes questionnaire was used before the activity with the PCR animation, while the feedback questionnaire was used following the activity. All the questionnaires were developed together with experts of the subject matter, as well as experts from science education, in order to gain content validity. I will now introduce the purpose of each of the questionnaires, as well as their structure in details.

1. The prior content knowledge PCR questionnaire

To monitor students' prior content knowledge, which might affect their understanding of the PCR method, we first examined students' prior content knowledge in topics that are relevant to understanding the PCR method. Those topics include DNA replication, nucleotides' functions in the cell, and the function of the DNA polymerase enzyme. In the questionnaire (see Appendix 2), the students were asked to respond to five True/False (T/F) statements and to answer one open question, all designed to examine their prior content knowledge in topics which are relevant to understanding the PCR technique (e.g., DNA replication). The T/F statements were aimed at probing students' understanding of the process of DNA replication and the role of nucleotides in this process. The students were asked to explain their responses to the T/F statements. In the open-ended question, students were asked to write 4 or 5 sentences about how the process of DNA replication occurs in a living cell.

2. The post-intervention PCR questionnaire

This questionnaire (see Appendix 3) was aimed at examining students' understanding of the PCR method following the activity with the animation or still images. It was composed of three parts:

1. The first part included five T/F sentences, aimed at probing students' understanding of

the PCR method in the following issues: the function of the DNA polymerase enzyme, the primers and the nucleotides in the PCR procedure, the specific temperatures used during the different stages of the PCR method, and the outcomes of the PCR method in terms of the amount of DNA.

2. In the second part of the questionnaire, the students were asked to compare the DNA replication process that occurs during the PCR procedure to the equivalent process that occurs in a living cell, in terms of the location, the temperatures of the process, the participating enzyme, and the use of nucleotides, primers and the products of the process.

3. The third part of the questionnaire was composed of three open-ended questions, aimed at probing students' understanding of the PCR method by activating high-order cognitive skills, namely analysis and synthesis (Bloom, 1956). The students were asked to explain why it is necessary to know the sequence of a gene in order to amplify it by the PCR method, and were asked to give two explanations for the association between the primers and the DNA strands. In the third question, the students were asked to calculate the number of DNA molecules after five cycles of the PCR procedure, as well as the number of DNA strands.

3. The experience and attitudes questionnaire

In the first part of the questionnaire (see Appendix 4) the students were asked whether they have a computer at home, and is it connected to the Internet. In addition, they were asked to mark their experience with common computer programs in general (i.e Word, Excel, Power Point), and with animations in particular. For this purpose, a four stages scale, ranging from "very experienced" to "no experience at all", was used. In the second part of the questionnaire a Likert-type scale (6 = strongly agree and 1 = strongly disagree) was used in order to probe students' attitudes towards learning in computerized environments, and questions of their preferences towards cooperative learning, learning from the teacher, or learning independently.

4. The feedback questionnaire

In this questionnaire (see Appendix 5) a Likert-type scale (4 = strongly agree and 1 = strongly disagree) was used in order to probe students' reflections following learning the PCR method using the PCR animation. This questionnaire consisted of 15-20 items (depending whether the students worked with or without the computerized tasks). The items dealt with students' preferences in terms of the interactivity of the animation, the usefulness of the accompanied texts and the integrated computerized tasks, and the best way to use the animation; through cooperative versus independent learning.

Qualitative research tools

5. Students' focus groups

Focus group is a research method which is based on accumulating data from group interviews. Focus group interviewing is particularly suited for obtaining several perspectives about the same topic. The benefits of focus group research include gaining insights into people's shared understandings and the ways in which individuals are influenced by others in a group situation (Morgan, 1988). In order to learn about students' views concerning the process of learning biotechnological methods using animations, I conducted 7 focus groups with 20 students approximately per group. In each focus group biology students who used one of the developed animations, or the equivalent cards with still images, participated. The focus groups were heterogeneous in terms of students' level of achievements, experiences ant attitudes towards the use of animations in class. The focus groups were running based on 8 moderator questions, to which the students were asked to respond. The following questions were discussed:

1. What are the main difficulties you engage in learning biotechnological methods?

2. Which difficulties were solved through the use of the animation? How exactly the animation helped in confronting those difficulties?

3. Which components of the animation were most helpful and contributed mostly to your understanding of the biotechnological method?

4. What are your preferences regarding the use of the continuous version versus the "step by step" version of the animation. What are the advantages and disadvantages of each version?

5. What do you think about the integrated tasks in the animation?

6. In which learning stage do you think it is best to use the animation (at the beginning of learning the biotechnological method, after learning it traditionally with the teacher, and towards the end of the learning)?

7. What do you think will be the best way to use the animation in class (through the guidance of the teacher, independently)?

8. What are your preferences regarding the use of animations versus still images while learning biotechnological methods? Which one of them is most effective?

6. Teachers' focus group

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

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

7. *Teachers' interviews*

Semi-structured interviews, 60-min to 90-min long were carried out with the two exemplary teachers (Ravit and Dora, see "case studies" description above). Through the interviews we discuss with the two teachers their beliefs, aims, instructional strategies, and students' outcomes during the enactment.

8. Documenting teachers' enactment of the animations in their classrooms

In order to document classrooms' events which occur while learning biotechnological methods using the animations, we audio taped selected lessons in classrooms of the two exemplary biotechnology teachers (Ravit and Dora, see "case studies" description above).

Through those observations in classes we focused especially on the specific teaching strategies employed by the teachers, which seems to promote students' understanding of the biotechnological methods being taught.

9. Students' discourse analysis

Since we believe that learning using visualization tools in general and animations in particular is a complex process that can not be monitored only by using quantitative research tools, we chose to use the discourse analysis technique. While the students studied the PCR method from the PCR animation or from the equivalent still images, they worked in pairs and were requested to speak aloud during the process. Their discussions were audio-taped and transcripts of the conversations were prepared.

Four transcripts from the animation group and four from the still images group were randomly chosen and qualitatively analyzed based on the conceptual status framework (Hewson & Lemberger, 2000; Tsui & Treagust, 2007). Status analysis categories have status elements under each status, as they are detailed in Table 1. We used those status elements and their general definitions as "top-down" key factors, in order to identify the conceptual statuses held by the students regarding their conceptions of the PCR method.

Table 2: **Categories for analyzing conceptual status, adapted from Hewson and Lemberger (2000)**

Status of Conceptions	Status Elements
INTELLIGIBILITY	Representational modes: INTELLIGIBILITY ANALOGY (analogy or metaphor to represent conception) IMAGE (use of pictures or diagrams to represent conception) EXEMPLAR (real-world exemplar of conception) LANGUAGE (linguistic or symbolic representation of conception)
PLAUSIBILITY	Consistency factors: OTHER KNOWLEDGE ('reasoned' consistency with other high-status knowledge) LAB EXPERIENCE (consistency with laboratory data or observations) PAST EXPERIENCE (particular events consistent with conception) EPISTEMOLOGY (consistency with epistemological commitments) METAPHYSICS (refer to ontological status of objects or beliefs) PLAUSIBILITY ANALOGY (another conception is invoked) Other factors: REAL MECHANISM (causal mechanism invoked)
FRUITFULNESS	POWER (conception has wide applicability) PROMISE (looking forward to what new conception might do) COMPETE (explicitly compare two competing conceptions) EXTRINSIC (associate new conception with experts)

10. Students' concept maps

In the current study we used concept maps in order to validate and expand other findings we already got concerning animations' effect on students' understanding of biotechnological methods. Concept maps have a long and noble intellectual history, intended originally as graphic organizers to be constructed by the specialist - not by the learner -and they consisted of boxed concepts connected by unlabeled lines, so the exact nature of the relationship between them remained unspecified for the learner (Trowbridge & Wandersee, 1998).

There is a great variety of graphic organizers, including flowchart, roundhouse diagram, and vee diagram used in teaching today as a diagnostic tool (Yarden et al., 2004). In my study we decided to use the concept map technique, but not in the classic way characterized by Novak and Gowin (1984). Thus, students were not initially trained to draw maps due to the time limitations imposed. Instead, I explained the basic principles of concept maps and showed examples of concept maps in various topics (Novak & Gowin, 1984). I stressed before the students the importance of drawing as many lines as possible between the eight given concepts with which the participants were presented, and of writing a proposition for each line.

In practice, Thirty eight 11th grade biotechnology majors (sample B), who learned the process of DNA digestion using restriction enzymes, were asked to build concept maps before and after they watched an animation that demonstrates this method. Each student got a written list of the following 8 concepts: DNA, restriction enzyme, restriction site, nucleotides, sticky ends, DNA strands, phosphodiester bonds and palindromic sequence. The 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 on the line a sentence which reflects a proposition between those two concepts. After the students watched the restriction enzymes animation they were asked to build another concept map from the same 8 given concepts.

5.7 Data analysis

Quantitative analysis

We used descriptive statistics (i.e. calculations of frequencies), as well as static tests (i.e t-test, paired samples t-test, $\chi 2$ test) in order to analyze significant differences and patterns in the data being analyzed. The t-test gives an indication of the separateness of two sets of measurements, and is thus used to check whether two sets of measures are statistically different and usually that an experimental effect has been demonstrated. There are two main types of t-test: Independent-measures t-test, when samples are not matched, and Matched-pair t-test, when samples appear in pairs (e.g. before-and-after, being performed on the same samples or subjects). The $\chi 2$ goodness of fit test performed is used to test the null hypothesis that a random sample arises from a specified distribution against the alternative hypothesis that the sample does not arise from the specified distribution.

The findings were analyzed using the SPSS software. Regarding students' attitudes and feedback questionnaires, each of those questionnaires was divided into main dimensions, using experts' judgment classification and the α chronbach test for reliability.

Qualitative analysis

Student's focus groups and teachers' interviews

All the discussions during the students' focus groups, as well as through teachers' interviews were audio taped and fully transcribed. Since those discussions and interviews were based on moderator questions, the responses were organized into categories according to the questions being asked. Each category or aspect was accompanied by relevant quotes, which express the relevant reality as was described by the interviewees.

Teachers' focus group

Teachers' focus group was also audio taped and fully transcribed. In that case, since the nature of the discussions was much more open, and was not structured absolutely according to moderator questions, we used the Narrative based theory (Shkedi, 2003). The transcript was coded to categories under shared topics , consequently sub categories were united into key categories, through the creation of mapped and focused categorizations, and finally a narrative description was written (Shkedi, 2003).

Class observations (case studies)

The enactments of the animations in class, in the two exemplary biotechnology majors' classes, were recorded and fully transcribed. Those transcripts were qualitatively analzed according to the narrative constructivist procedure recommended for multiple-case analysis (Shkedi, 2005). Following mapped and focused categorizations, the two exemplary teachers were interviewed and were asked to explain representative episodes illustrating the main categories resulting from the focused categorization of the class observations transcripts. Accordingly, the transcripts from the class observations are treated as a primary source for data, while the transcripts from the teachers' interviews were treated as a secondary source, aimed to support directions that were already identified through analyzing classes' observations.

Students' discourse

Four transcripts of conversations of couples who learned the PCR method using animation, and four transcripts of conversations of couples who learned the same topic using cards with still images, were randomly chosen and qualitatively analyzed based on the conceptual status framework (Hewson & Lemberger, 2000; Tsui & Treagust, 2007). Each transcript was divided into episodes based on the scientific content. Then we used the descriptions of status elements (see Table 1) as an inventory to identify the specific status elements held by the students through the content episodes. For example, in order to identify the inclusion or exclusion of the status element *image*, which serves as a record for the conceptual status of *intelligibility*, we were looking through analyzing students' discourse whether the students have used pictures from the animation or from the still images, to represent their conceptions. Students' metacognitive comments about their conceptions were analyzed in that way as well. To illustrate the explicit inclusion or exclusion of a status element during an episode, it was indicated with a "+" or a "-" sign, respectively. Then the inclusion or exclusion of the status elements was used to identify the conceptual status itself, which represents students' conceptions of the PCR method. For reliability verification, those transcripts were also analyzed by another researcher, with an agreement of 95% between the two researchers.

Students' concept maps

Thirty eight paired concept maps were collected and analyzed both qualitatively and quantitatively. I counted all the propositions in the pre-watching concept maps (which were built before the activity with the animations) as well as in the propositions in the post-watching concept maps (which were built following the activity with the animations), and calculated the average number of propositions and the average percent of correct propositions in each of the maps, in terms of the scientific accuracy. We also classified each proposition in the pre as well as in the post-watching concept maps as structural versus functional propositions. Propositions which dealt with the structure of molecules such as DNA, sticky ends, restriction sites, such as: "restriction site is composed of nucleotides" were classified as structural, while propositions while dealt with function 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", were classified as functional proposition (as detailed in the relevant results). In order to validate the categorization of the propositions, a sample of the students' maps analyzed by another researcher, with an agreement of 96% between the two researchers.

6. Results

1a. Is there a difference in the comprehension of PCR between students who learned using animation and those who learned using still images?

A quasi-experimental method, with an experimental group and a comparison group, was used in this study. The experimental group was the group in which the PCR animation was used in order to visualize the PCR method, while the comparison group was the group in which the equivalent still images were used, in order to visualize the PCR method (see description of the cards in the "Context of the study" chapter).

The experimental group was originally divided into two sub-groups: both watched the PCR animation, but in one of the groups the animation was accompanied by three computerized tasks. Since no significant differences were found between the two sub-groups, using an ANOVA test, they were re-united into one group for the data analysis.

The results, obtained using a t-test, indicated no significant differences between the two groups in terms of prior content knowledge (Figure 2, left). Next, we examined whether the use of different visualization tools affects students' comprehension of the PCR method. By comparing students' mean scores in the post-intervention questionnaire (t-test), we found a significant advantage for the animation group over the still images group ($t = 4.64$, $p < 0.0001$, Figure 2, right). Since no differences were found between students' prior knowledge, we concluded that use of the PCR animation as a visualization tool provides an advantage to learners of the PCR method.

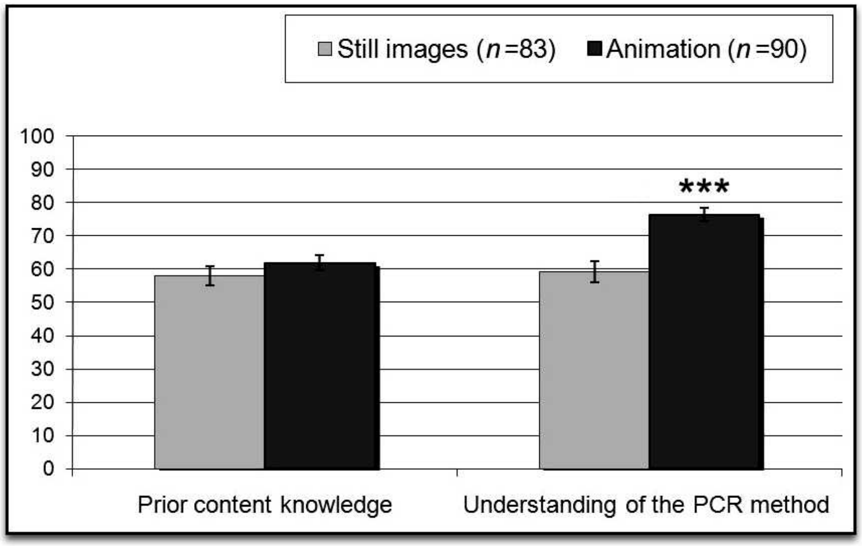

Figure 2: **Comparison between students' mean scores in prior content knowledge and understanding of the PCR method following learning using different visualization tools.** The significant differences are marked by *** (p<0.001).

1b. What are the relationships between students' prior content knowledge and their comprehension of the PCR method, using animation or still images?

Students' prior knowledge was used in this study as a moderator variable that enabled elucidating its effect on students' comprehension of the PCR method. We had already learned that there were no significant differences between the treatments in terms of students' prior content knowledge. In order to delve more deeply into the kinds of relationships that may exist between students' prior content knowledge and their comprehension of PCR, students' scores in the post-intervention questionnaire were correlated with their prior content knowledge, in each of the two groups. In addition, a regression was calculated in students' scores in the prior content knowledge questionnaire.

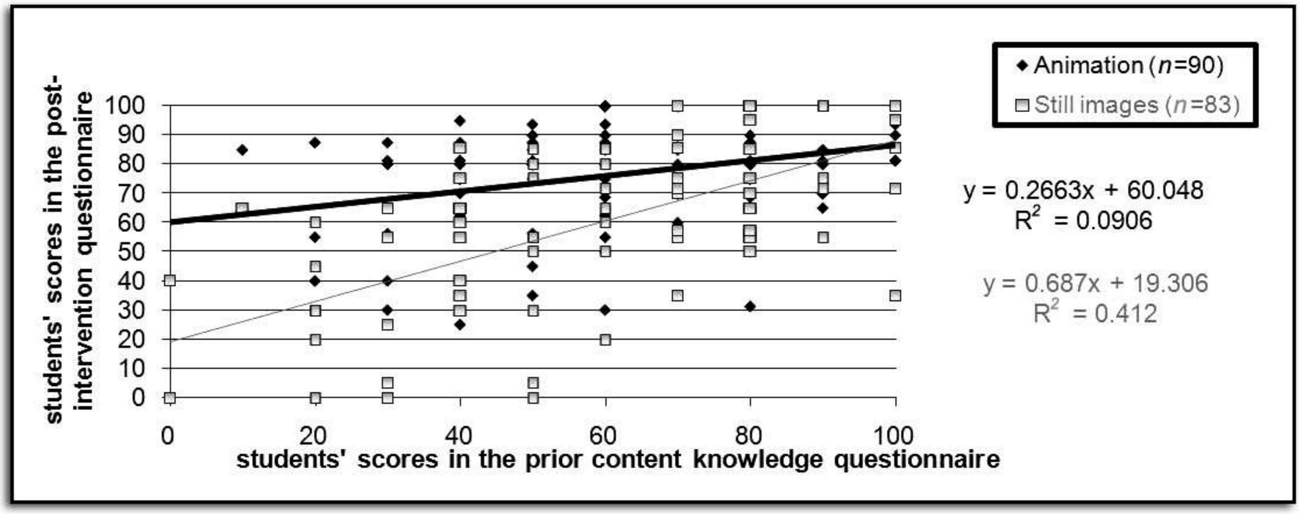

Figure 3: **A regression of students' scores in the prior content knowledge questionnaire, with their scores in the post-intervention questionnaire, in each of the two alternative groups.**

As can be seen in Figure 3, a relatively high correlation was found between students' prior knowledge and their understanding of the PCR method in the still images group (R2 = 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, in 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 = 0.0906). As can be clearly seen in Figure 3, students with a particular score in the prior content knowledge questionnaire, for instance 40 points, achieved low scores in their post- intervention questionnaires if they learned PCR using still images, and higher scores in their post- intervention questionnaires if they learned PCR using the animation. In other words, students' 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. Even low prior knowledge did not harm students' ability to learn the PCR method and understand it correctly, if they learned it using animation.

1c. What is the difference in conceptual status of the PCR method between students who learned using animation and those who learned using still images?

To gain a deeper understanding of the differences in comprehension of the PCR method between students who learned using animation and those who learned using cards with still images, we employed qualitative research tools to supplement the above-described quantitative ones. We chose to use discourse analysis technique, which is based on analysis of students' conceptual status (Hewson & Lemberger, 2000; Tsui & Treagust, 2007). Eight transcripts of students' conversations were randomly chosen, four from the animation group and four from the still images group, and subjected to analysis of students' conceptual status.

The differences in conceptual status between students who learned PCR using animation and those who learned using still images were mostly found in three kinds of content episodes: the function of the DNA polymerase enzyme, the function of the primers, and the specific temperatures at which different stages in the PCR method occur. The differences in students' conceptual status, which were found in each of the three content episodes, are presented below.

The function of DNA polymerase

In the content episodes which dealt with the function of DNA polymerase, we found that students who learned the PCR method using animation reflected mostly the following status elements in their conversations: *metaphysics,* which indicates that they referred to the ontological status of DNA polymerase, and *real mechanism*, which indicates that the students understood the causal mechanism in which DNA polymerase is involved. Below are two examples of such episodes, which include the expression of those status elements:

1: The reaction begins by the separation of the two DNA strands... [Reading from the text which accompanies the animation]

2: So [DNA] polymerase is causing the small ones [the nucleotides] (+image), right? (+real mechanism)

1: Yes, and this is why they put a lot of them [nucleotides], so instead of only two strands there will be a lot of them. (+real mechanism)

The students in the above example seem to understand the causal mechanism between DNA polymerase and the nucleotides, namely the creation of new DNA strands using the nucleotides through the synthesis function of the DNA polymerase.

Below we present another example from another conversation, which illustrates students' understanding of the function of DNA polymerase:

1: Does it [the DNA polymerase] separate them [the DNA strands]? [As written in a True/ False statement in the post- intervention questionnaire]

2: No, it does not (+real mechanism). It does the replication (+metaphysics). Here [watching the animation], now they [the DNA strands] are separating, you see, it [the DNA polymerase] doesn't do the separation; it makes a new DNA (+metaphysics).

1: Does it do it at 95oC? [as written in a True/ False statement in the post- intervention questionnaire]

2: No, it does it at 65oC. (+real mechanism)

Once again, in this example, the students clearly understood the causal mechanism in which DNA polymerase is involved (+real mechanism) or in this case, not involved, as it does not cause the separation of the DNA strands. The students could address DNA polymerase to its exact ontological function, which is the process of DNA replication (+metaphysics), and could address the exact temperatures in which this reaction occurs (+real mechanism). Since the expression of the status elements of metaphysics and real mechanism can serve as a mark of the conceptual status of plausibility (Hewson & Lemberger, 2000), we can assume that students who learned the PCR method using animation understood the function of DNA polymerase in the correct way, and found it consistent with other ideas that they had already accepted, such as DNA replication.

In contrast, in equivalent transcripts from conversations among pairs who learned the PCR method using still images, we discovered that the above-mentioned status elements (real mechanism and metaphysics) were excluded from their conversations. For example:

1: I did not understand what the DNA polymerase is doing. (-metaphysics)

2: It is written [in the text].

1: I did not understand what DNA polymerase is doing (-metaphysics), I mean, do they [the primers] stick by themselves?

2: Here, [reading the text] "The DNA polymerase is synthesizing a new DNA strand."

1: What does it mean? They [the primers] are already attached, so what does it [the DNA polymerase] do? (-metaphysics)

2: Maybe it [the DNA polymerase] is connecting between them [the primers], I don't know… (-real mechanism)

As can be seen in this example, students who learned about PCR using still images did not understand what the DNA polymerase's ontological function was, and raised questions regarding this issue over and over again (-metaphysics). In addition, they raised questions and made incorrect statements regarding the mechanism in which DNA polymerase is involved (-real mechanism), for example, by suggesting a kind of causal mechanism between DNA polymerase function and the annealing of the primers. Thus, the exclusion of the metaphysics and real mechanism status elements in the conversations from the still images group can indicate that these students lacked the conceptual status of plausibility regarding DNA polymerase. Namely, the students who learned about PCR using still images did not understand the function of DNA polymerase in the correct way, and could not reconcile it correctly with other accepted ideas they had, such as DNA replication.

The function of the primers

Differences in students' conceptual status between those who learned using animation and those who learned using still images were also found in episodes that dealt with the function of the primers in the PCR method. Upon analyzing students' conversations, we realized that this issue was not easy to understand for students in either group. We gained this insight from the number of questions students raised, as well as from misunderstandings they expressed in their statements. Nevertheless, students who learned the PCR method using the animation expressed diverse status elements from two different conceptual statuses. They expressed the status element of image, which indicates that they used the pictures that appeared in the animation in order to represent the primers, and the status element of language, which indicates that they used linguistic representations of the primers as well. Those two status elements mark the conceptual status of intelligibility, which means that the students know what the concept of primers means, and that they can represent it. The students also expressed the afore-mentioned status elements, metaphysics and real mechanism, marking the higher conceptual status of plausibility. Here is a representative example of the expression of such status elements in students' conversations while using the animation:

1: What are primers? [Reading a True/False statement from the post- intervention questionnaire] "Fragments of DNA which serves as enzymes in the reaction of..."

2: They are not enzymes. (+metaphysics)

1: Right. They are not enzymes. They are like attaching to the big fragment of DNA, right? (+real mechanism)

2: Yes. The primers are those we saw in the beginning [of the animation], which are attached in 45oC, those big small ones (+image), I think they are involved in the initial stages of the process (+language).

As can be seen in this conversation, the students use the symbols from the animation to represent primers visually (+image), and verbally (+language). We also find in this conversation that the students understand the ontological status and the function of the primers, by reiterating that they are not enzymes (+metaphysics). In addition, the students understand the causal mechanism in which the primers are involved (+real mechanism), namely the annealing to the DNA strands. The expression of these latter two status elements indicates that students who used the PCR animation go beyond the conceptual status of intelligibility in their understanding of the concept of primers. The students clearly express the next conceptual status of plausibility, which means that they not only know what the conception of primers means and can represent it (intelligibility), but also believe this conception to be true and find it consistent with other accepted ideas (plausibility), such as annealing to the DNA strands.

However, in conversations of pairs who learned about the PCR method using still images, we noticed that the students lacked the high conceptual status of plausibility. For example:

1: "The primers are short DNA fragments which serve as enzymes" [reading a True/False question from the post- intervention questionnaire]. It is true. (-metaphysics)

2. Yes.

1: They serve as enzymes, right?

2: I think they are. (-metaphysics)

We note that this time, as opposed to the case of students who learned using the animation, the students from the still images group did not understand the true ontological status of the primers (-metaphysics) and believed, incorrectly, that the primers are enzymes.

The specific temperatures at which different stages in the PCR method occur

The third topic, in which differences in students' conceptual status were found between students who learned PCR using animation and those who learned using still images, dealt with the specific temperatures at which different stages in the PCR method occur. As in the two topics introduced above, pairs who learned the PCR method using animation reflected a variety of status elements in their conversations, most of them indicating the high conceptual status of plausibility. For example:

[The students are solving a question in the post- intervention questionnaire. While solving the question they watch the animation.]

1: You see, they [the DNA strands] are heated and are separating...

2: O.K, but in the question they are asking why these [the primers] are attached and not these [the DNA strands]?

1: Because they are smaller (+real mechanism). The primers are starting (+language), and then the DNA polymerase is helping to complete them [the DNA strands] (+real mechanism).

Another example:

1: They are so nice, those polymerases. While the temperature goes down to 45^{o}C, they attach, then to 65^{o}C. The purpose of the 95^{o}C is to separate [between the DNA strands]. (+real mechanism)

2: They have been separated, then those primers are placed on those [DNA strands], now the enzyme, I think it is those green ones (+image) that will continue to build them (+real mechanism).

1: Right, right.

2: Then they will finish building them. Why 65^{o}C? Once again, I did not understand.

1: Look, at 95^{o}C they separate, 45^{o}C, attach, 65^{o}C, the enzyme continues, in order for the two strands of DNA to attach, a temperature of 45^{o}C is needed. (+other knowledge)

2: They [the DNA strands] are not attached; it is the primers that are attached. (+real mechanism)

As can be clearly seen in these two examples, the students who learned about PCR using animation expressed status elements in their conversations such as image and language, which indicate owning the conceptual status of intelligibility. Moreover, status elements such as other knowledge and real mechanism are also expressed in the conversation, showing that these students also gained the conceptual status of plausibility. The students showed that they already know that annealing to the DNA strands occurs at 45^{o}C, and stated that in the PCR, the primers anneal to the complementary DNA strands and, much less frequently, the strands anneal to themselves, because of the primers' size (+real mechanism). Thus, the students who learned PCR using animation clearly demonstrate that they understand mechanistic aspects of PCR, and that they find them consistent with other accepted ideas, such as DNA replication.

In contrast, in conversations of pairs who used still images while learning the PCR method, the status elements of the conceptual status of plausibility were usually excluded. For example:

1: "Separation of the strands and annealing of the primers" [reading the title of the second card]. "The reaction begins by heating the mixture…[reading the accompanying text].

2: DNA polymerase is this green color, the enzyme. (+image)

1: Yes, polymerase. After they heat they…

2: No, no, it is not. This and this [the DNA strands] are separating, and they are [the nucleotides] attaching.

1: Yes, T A C G. (+image)

2: Then what did we get? (-real mechanism)

1: Wait, these are the primers, wait, after 45oC, "we heat the mixture to 65oC" [continue reading].

2: "We end up with a new DNA" [reading from the text], but…, read again.

1: "We heat the mixture to 65oC. At this temperature, the DNA polymerase creates… At the end of this cycle, we end up with two copies of the original double-stranded DNA molecule" [reading from the text].

2: Well, no, I did not understand it (-real mechanism). Move, move to the next card…

As can be seen in this example, the students who used the cards with the still images expressed confusion and misunderstanding in their conversation. These students used different symbols which appeared in the animation in order to represent concepts such as DNA polymerase and the nucleotides (+image). This probably indicates that they own the conceptual status of intelligibility, meaning that they know what those concepts mean, and are able to represent them. On the other hand, when it comes to higher conceptual demands, such as understanding the causal mechanism in which those concepts are involved (real mechanism), the students who learned about PCR using still images do not understand what happens when the DNA strands separate (-real mechanism). In fact the whole conversation is based on reading the text that accompanied the still images over and over, in an almost desperate attempt to understand what happens, which ends in despair and moving to the next card.

Here is another example from another conversation, in which the students are trying to understand the same issue:

1: I did not understand, what is the basis of the attachment between the primers and the DNA strands? It can only be hydrogen bonds, I mean, after it [DNA polymerase] is starting to transcribe (-real mechanism) it is hydrogen bonds, could it be that there is something on the primers, I do not know, is there any enzyme on the primers or something else? (-real mechanism)

2: It is not written [in the accompanying text], it seems to me it cannot be attached to it [the primer to the DNA strand], it is not complementary, it is the same. (-metaphysics)

1: It is written [in the text] that at 95°C they [the DNA strands] separate, and then it is written that at 45°C they [the primers] are attached, and the question [in the post- intervention questionnaire] is why is it the primers and not the DNA strands?

2: Because this is not the temperature which is aimed to attach them, we probably need another temperature. (-real mechanism)

1: Maybe 45°C is not the optimal temperature for the polymerase.

2: So maybe 45°C is not the optimal temperature for attaching the strands by DNA polymerase. (-real mechanism)

1: We are asked [in a question in the post- intervention questionnaire] to write two explanations, so we can write what we want, so write that between the two DNA strands there are different bonds than between the strands and the primers. (-real mechanism)

In this example, we can see once again how the students depend on the text, this time through their attempts to understand why after the separation of the DNA strands, the primers anneal to the complementary strands and not the strands to themselves. Diverse misunderstandings are revealed in this conversation, such as the students thinking that the DNA polymerase is involved in transcription (-real mechanism), that the primers are not complementary to the DNA strands (-metaphysics) and that a specific temperature is the cause of this association (-real mechanism). The exclusion of such status elements from the two examples discussed above indicates that students who learned the PCR method using still images may have learned the main concepts of PCR, and can represent them (intelligibility), as indicated mostly in the first example, they do not seem to have understood the interactions between the concepts, and could not find them consistent with other accepted ideas, for example DNA replication.

We can therefore conclude that since the most often excluded status elements in the conversations of the still images group were metaphysics and real mechanism, it appears that these students were having difficulty understanding the ontological function of the different molecules involved in the PCR method, and the causal mechanism in which they are involved. We also learned that conversations from the still images group were generally based on reading the text which accompanied the still images over and over again, treating it as a crucial source which will enable them to reach understanding. In contrast, use of the animation gave the students an advantage in understanding those aspects of the PCR method.

Students' conceptual status - a quantitative analysis

Following the qualitative analysis of the students' discourse using the conceptual status framework, we subjected the data to quantitative analysis. First, we gathered all the status elements which were identified in each of the groups' discourses analysed above. We identified 65 status elements in the analysed discourses from the animation group, and 32 status elements in the equivalent discourses from the still images group. The length of the discourses in both groups was approximately equivalent (about 50 sentences on average in each discourse). We then grouped the status elements identified in each of the treatments under the relevant conceptual status: intelligibility, plausibility or fruitfulness (see Table 1). A $\chi 2$ test was used to trace possible differences between the animation and still images groups, in each of the three conceptual statuses.

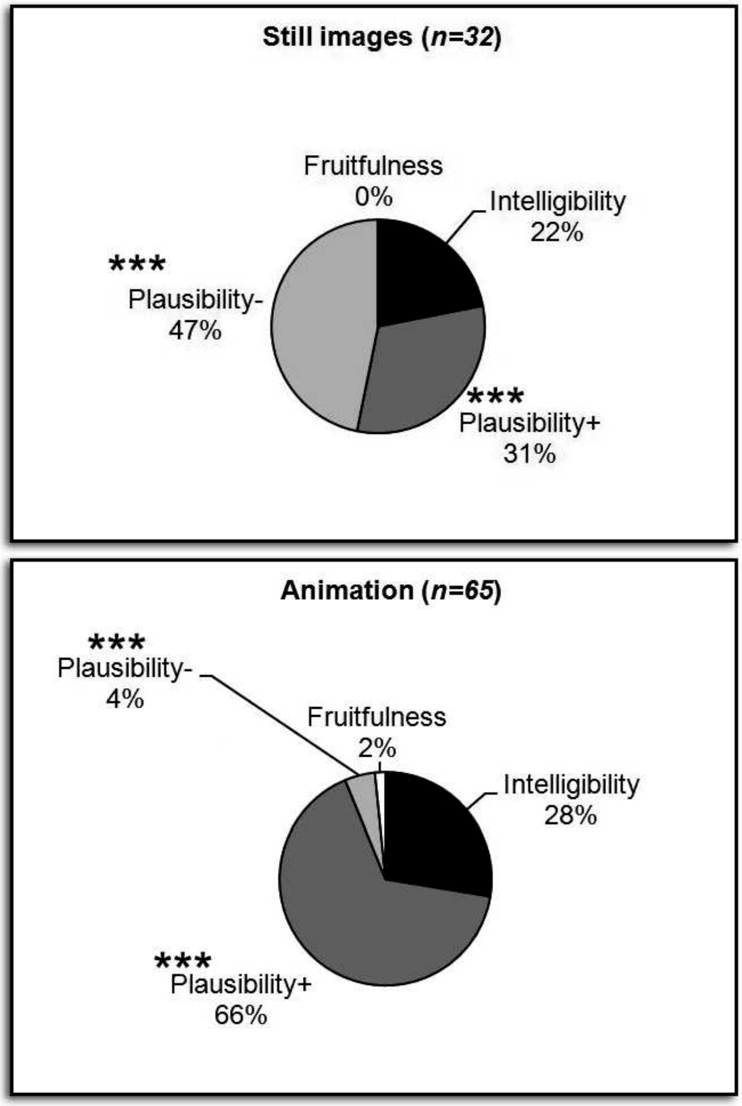

Figure 4: **Comparison between students' conceptual status, following learning using different visualization tools**. The n represents the number of status elements that was identified in each of the two groups' discourses. + represents the inclusions of status elements, while – represents the inclusion of the status elements. The data was analyzed using $\chi 2$ test. The significant differences are marked by *** ($p<0.0001$).

As can be seen in Figure 4, a significant advantage for the animation group compared to the still images group was identified in the conceptual status category of plausibility ($\chi 2$ = 26.19, $p < 0.0001$). The differences were reflected in terms of the significant differences in both inclusions of status elements from the plausibility conceptual status, in favour of the animation group, and exclusions of the same status elements of the plausibility conceptual status in conversations from the still images group. The specific status elements were real mechanism and metaphysics, the same status elements whose recurrent appearance in conversations from the animation group, and absence in conversations from the still images groups, had been reported and demonstrated in the qualitative analysis of the students' discourses.

From the quantitative analysis of students' conceptual status we also learned that students from both groups had reached the kind of understanding reflected by the conceptual status of intelligibility, meaning 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 owning the plausibility conceptual status, appeared to be available only to the students who watched the animation. As it was 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 appears 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. Considering the fact that the students in our study are learning about PCR for the first time, using the alternative visualization tools, this finding is very reasonable. However, the fact that we did find a few inclusions of status elements from the fruitfulness conceptual status in conversations of students who learned using the animation is appealing and encouraging. We therefore believe that in the subsequent stages of learning PCR more deeply, those inclusions could become apparent.

1d. What are students' experiences and attitudes towards computerized learning environments in general and animations in particular, and does it affects students' comprehension of the PCR method?

Since one of the main goals of this study was to examine the effect of animations on students' comprehension of biotechnological methods, we took into consideration an intervening variable that can affect the effectiveness of the animations, that is students' experiences and attitudes towards computerized learning environments in general and animations in particular. In order to control this variable, the students who participated in the activity with the PCR animation (N =173) were asked to fill an attitudes questionnaire (see Appendix 4). This questionnaire was introduced to the students at the beginning of the activity, following filling the prior content knowledge questionnaire.

Analysis of the experience section in the questionnaires revealed that 99% of the students in the sample (N=169) have computers with an access to the Internet at home. Most of the students (96%) reported they are familiar with working with computers in general, and with the Internet in particular (97%), as well as with common computer programs, i.e. Word (98%), Excel (73%) and Power Point (72%). On the other hand, about 50% of the students reported they have no or relatively minor experience with animations. Still, when the students were asked to state their preference for informative presentations, versus computerized tasks or animations, 26% of them reported they prefer computerized tasks, and 35% reported they prefer animations as the most effective learning tools.

Regarding students' attitudes towards learning using computerized learning environments in general and animations in particular, this part of the questionnaire was analyzed by dividing it into two main dimensions, using 3 experts' judgment classification and the α chronbach test for reliability. The first dimension was students' attitudes towards learning using computerized learning environments. This dimension embraces 6 items from the questionnaire, all dealing with aspects of learning using computerized learning environments. The second dimension gained from the questionnaire reflects students' positions towards learning independently or in couples.

Table 3: Students' attitudes as were reflected in the attitudes' questionnaires:

The dimension	**The relevant items:**	**Students' mean score** (N=169) in a Likert scale of 1-4 (1- totally disagree, 4- very much agree):
Students' attitudes towards learning using computerized learning environments.	I like learning using computer environments.	2.86
	I prefer learning alone while using computerized learning environments than while using textbooks.	2.49
	I prefer learning new processes using computer visualizations rather than visualizations in textbooks.	3.1
	I prefer learning new processes using computer visualizations together with visualizations in textbooks.	3.26
	Animations help me understand things.	3.16
	I prefer learning new processes with the teacher, together with computer visualizations.	3.14
Students' attitudes towards learning independently or in couples.	I prefer working alone while learning using computerized learning environments.	2.01
	I like working in couples while learning.	2.96
	It is boring to learn alone.	2.3

As can be seen in Table 3, in the 6 items which were included in the first dimension of students' attitudes towards learning using computerized learning environments, the students expressed a clear positive approach towards using the computer, including the use of animations, while learning without the guidance of the teacher, or while learning new processes that demand demonstration. Those 6 items were found to be consistent with each other in the α chronbach test for reliability ($\alpha=0.78$). Since their average score is 3.00 ($N=173$), it reflects a very positive approach of the students towards learning using computerized learning environments.

From analyzing the three items included in the second dimension, which dealt with students' position towards learning independently or in couples, it can be understood that the students prefer learning in couples than alone. Those three items were also found consistent with each other in the α chronbach test for reliability ($\alpha=0.7$), and since the average score of them is 2.42 ($N=173$), it reflects students' preference of working in couples while learning in computerized learning environments.

After characterizing students' experiences and attitudes towards computerized learning environments in general, and animations in particular, we wished to learn whether this variable can affect students' comprehension of the PCR method. Thus, a Pearson correlation test was conducted. No correlations were found between students' experiences and attitudes, and their understanding of the PCR method (as reflected in the post questionnaire). Accordingly, it strength that the significant differences which were identified in favor of students who learned PCR using animation in terms of their understanding of the PCR method, were due to the use of the animation as a visualization tool, and were not affected by the students' experiences and attitudes towards computerized learning environments in general and animations in particular.

1e. What is the influence of using animation, following learning about restriction enzymes digestion process traditionally with the teacher, on students' comprehension?

We used concept maps as a tool for identifying students' understanding of the process of DNA digestion using restriction enzymes. Thirty eight 11th grade biotechnology majors from two high schools (fifteen students from one high school and twenty three students from another high school) were asked to build concept maps before and after watching an animation that demonstrates the process of DNA digestion using restriction enzymes. Since the two sub-groups were found different in the tested parameters (see Table 4) using a Wilcoxson signed rank statistical test, they were not united and the findings concerning each sub-group are being introduced independently. The Wilcoxson signed rank statistical test was used also to test whether the differences identified between the pre-watching and the post-watching maps in each sub-group are significant (a t-test is not suitable because of the small size of the samples). I counted only prepositions in students' concept maps and neglected to count and score the number of concepts, since the concepts were given to students.

Table 4: **Analysis of students' propositions in their pre-watching and post-watching concept maps**

The factors that were tested	**Sample B1 (n=15)**			**Sample B2 (n=23)**		
	Pre-watching concept maps	**Post-watching concept maps**	**Significance of the difference between the paired maps**	**Pre concept maps**	**Post concept maps**	**Significance of the difference between the paired maps**
Average number of propositions	10.66	16.4	**(s<o.ooo1)**	5.21	7.43	**(s<o.ooo1)**
Average percent of correct propositions	84.66	90.2	**(s<o.ooo1)**	81.91	92.91	**(s<o.ooo1)**
Average percent of structural propositions	61.26	56.06	**(s<o.ooo1)**	75.21	65.47	**(s<o.ooo1)**
Average percent of functional propositions	38.74	43.94	**(s<o.ooo1)**	24.79	34.53	**(s<o.ooo1)**

As can be seen in Table 4, in both samples the number of propositions was significantly larger in students' post-watching concept maps, than in their pre-watching maps. Even though in sample B1 the average number of propositions, in the pre-watching as well as in the post-watching maps, was larger than the equivalent numbers in sample B2. Still in both cases the use of concept maps revealed a significant increase in the number of propositions students had drawn in the post-watching maps. A closer look at the nature of the propositions in both 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 percent of the correct propositions in students' post-watching concept maps in both groups. In view of that, it seems that watching the animation which demonstrates the process of digesting DNA using restriction enzymes had made this biotechnological method clearer and more coherent to the students, as reflected in the accuracy of the propositions made in students' post-watching concept maps in both samples.

When we classified the propositions that students has drawn in their pre-watching as well as in their post-watching maps in terms of structural versus functional type of propositions, we revealed, as can be seen in Table 4, that there is a significant decline in the number of propositions with structural nature between the pre- watching and the post-watching concept maps in both groups. Accordingly there was a significant increase in the number of propositions that were classified as making functional propositions: within the pre-watching concept map, propositions such as: "restriction site is composed of nucleotides" or "palindrome sequence is inside the DNA strands" or "DNA strands are composed of nucleotides" were mostly common. In the post-watching concept maps on the other hand, 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".

In the next two examples of paired pre-watching and post-watching concept maps (Figure 5 and figure 6) the quantitative findings described above are being demonstrated in practice. In the first example the general number of propositions, both in the pre-watching as well as in the post–watching concept maps, is smaller than in the second example, in which the general number of propositions is larger. Still, both maps reflect the differences introduced in Table 4.

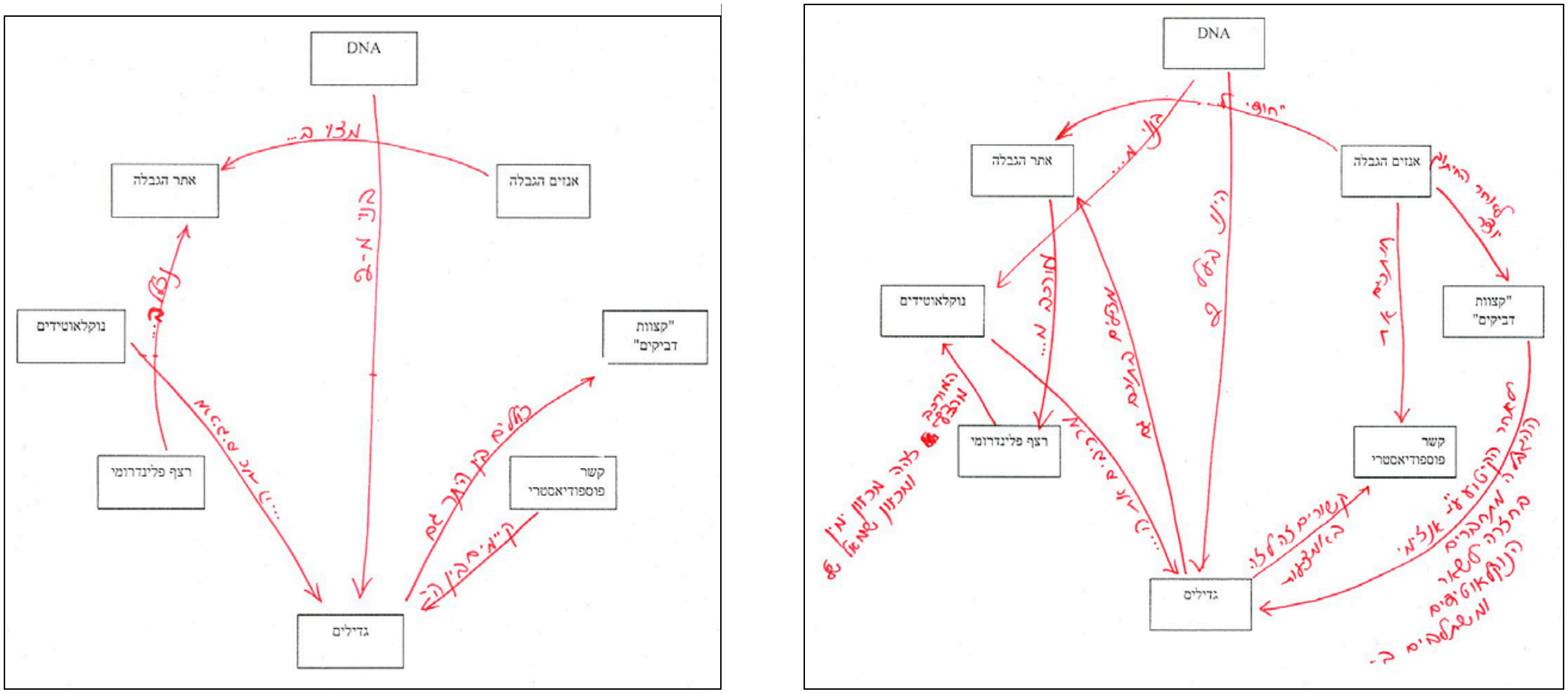

Figure5: An example of student's paired pre-watching (left) and post-watching (right) concept maps (sample B2)

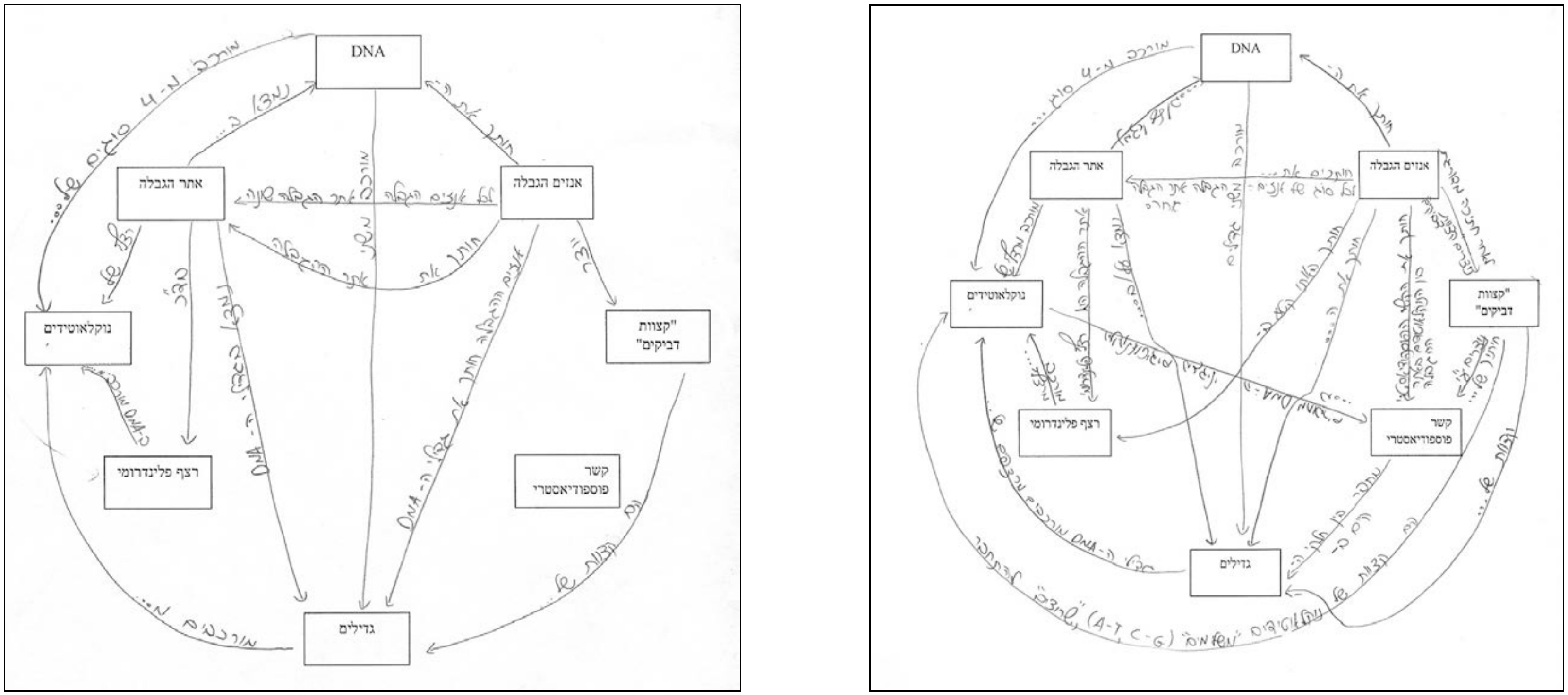

Figure 6: Another example of student's paired pre-watching (left) and post-watching (right) concept maps (sample B1)

As can be seen in Figure 5, there is an increase in the number of propositions between the pre-watching and the post-watching concept map. There are also more accurate propositions in the post-watching map than in the paired pre-watching concept map, as well as more propositions that can be classified as *functional* in the post-watching concept map as in 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, and there is a tendency to *functional* propositions rather than *structural* in the post-watching concept map than in the paired pre-watching concept map. While in the pre-watching concept map those concepts appeared in the propositions: "DNA strands include sticky ends" and "Phosphodiester bond is between the DNA strands" (*structural* nature of propositions), in the paired post-watching concept map they appeared in new propositions such as: "The restriction enzyme cuts the phosphodiester bond", or "after the digestion (of DNA) the restriction enzyme creates sticky ends".

In Figure 6 it is also observable that there is an increase in the number of propositions between the pre-watching and the post-watching concept map, for instance in the case of the concept "restriction enzyme". Looking deeper into the nature of the propositions it can be noticed once again, as in Figure 5, that the concepts "sticky ends" and "phosphodiester bond" are more connected to other concepts in the post-watching concept map, with propositions that their nature can be classified mostly as *functiona*l, for instance: "After a graduated digestion (of DNA) the sticky ends are being created", or "The sticky ends are being created after the cutting of the phosphodiester bond". 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").

To sum up both the quantitative findings, together with the concrete examples, it can be noted that the use of the restriction enzyme animation has influenced the students in terms of enlarging the number of propositions between concepts in general, and the correct ones in particular. Additionally, it seems the use of animation while learning the process of DNA digestion using restriction enzymes has enlightened the functional relationships between molecules that participate in this biotechnological method, as it reflected in students' post-watching concept maps. This contribution, in terms of promoting the understanding of mechanistic aspects of a biotechnological method, was also reflected in the case of learning the PCR method using animation (Yarden & Yarden, 2009), and will be further discussed in the discussion.

1f. What are students' reflections on the use of animations while learning biotechnological methods?

The data for this research question was collected and analyzed using two research tools: a quantitative tool, students' feedback questionnaire (see Appendix 5), and a qualitative tool, students' focus groups.

Students' reflections on the use of animations while learning the PCR method, as were exposed from analyzing the feedback questionnaires.

The students' feedback questionnaire was introduced to the experimental animation group (N=90). The twenty items in this questionnaire were dived into three main dimensions using 3 experts' judgment classification and the α Chronbach test for reliability. The first dimension embraces 7 items (α= 0.72), which according to the experts' judgment, as well as the α Chronbach test for reliability, all represent students' reflections to different components of the PCR animation. The second dimension was gained by merging 3 items from students' feedback questionnaire (α= 0.74), which dealt with students' reflections on the use of the continuous version of the PCR animation, versus the "step by step" version. The last dimension I gathered through analyzing students' feedback questionnaires concerned students' reflections regarding the use of the animation while working independently or in couples. This third dimension was gained by merging 2 items (α= 0.66). We will now introduce gradually the results to each of the three dimensions described above.

Table 5: **Students' reflections on different components of the PCR animation (the first dimension).**

The items:	**Students' mean score (**N=90) in a Likert scale of 1-4 (1- totally disagree, 4- very much agree):
The PCR animation helped me understand clearly the PCR method.	3.3
The accompanied text helped me better understand the PCR method.	3.7
In the "step by step" version, it is good that the text appears first, and subsequently the movie.	3
I would prefer that in the "step by step" version the text and the movie would appear together.	1.98
The appearance of the symbols with in the text helped me better understand the PCR method.	3.55
The PCR animation helped me understand general things such as DNA replication.	2.94
The PCR animation confused me.	1.2

Our desire, as the developers of the animation, was to learn about students' reflections on different components of the PCR animation and its effect on their learning, because the same components exist also in other animations we developed. As can be seen in Table 5, students' reflections to different components of the PCR animation, namely the accompanied text, the interactive features and the designed symbols were very positive, concerning its effectiveness on learning the PCR method and the process of DNA replication. The average score of the seven items included in this dimension is 3.04 (N=90), thus representing a positive reflection towards the PCR animation being used.

The next dimension gained through analyzing students' feedback questionnaire was students' reflections on the use of the continuous version of the PCR animation, versus the "step by step" version. Once again this feedback was important not only because of the specific case of the PCR animation, but also since additional animations were developed using the same format, and we wanted to know whether the use of the interactive version (the "step by step" version) has any advantage over the continuous one. The results of this dimension are introduced in Table 6.

Table 6**: Students' reflections on the use of the continuous version of the PCR animation, versus the "step by step" version (the second dimension).**

The items:	**Students' mean score (**N=90) in a Likert scale of 1-4 (1- totally disagree, 4- very much agree):
I preferred watching initially the "step by step" version.	3.32
I preferred watching initially the continuous version.	1.9

The continuous version can serve as a summary, after learning using the "step by step" version.	3.38

As can be seen in Table 6, the results indicate clearly that the students preferred using the interactive version, the "step by step" version, at the initial stages of learning the PCR animation, finding the continuous version inappropriate for this purpose. Students' position was reflected also in a relatively high average score (3.38) to the third item in Table 6, in which watching the continuous version can serve as a summary, after understanding the PCR using the "step by step" version. In addition, since the average score of the three items in this dimension of students' reflections on the use of the continuous version of the PCR animation, versus the "step by step" version is 2.93 (N=90), it also represents students' preference for the interactive version in learning the PCR method.

The third dimension we gathered through analyzing students' feedback questionnaires concerned students' reflections regarding the use of animations while working independently or in couples, an aspect of the activation of the animations in class. The results to this dimension are introduced in Table 7.

Table 7: **Students' reflections regarding the use of animations while working independently or in couples (the third dimension).**

The items:	**Students' mean score (**N=90) in a Likert scale of 1-4 (1- totally disagree, 4- very much agree):
It helped me work in couples while watching the animation.	3.08
If I had worked alone, watching the animation had been more effective.	1.8

As can be seen in Table 7, the merging of two relevant items in the feedback questionnaire yielded the clear result that the students believe that watching the animation while working in couples is more effective than watching it independently. This result is interesting also since it goes together with a similar result we got while analyzing the attitudes' questionnaire described earlier. In analyzing that questionnaire we also established that one of the dimensions was a dimension which dealt with students' attitudes towards learning independently or in couples. In this case also the result was that students prefer learning in couples than alone.

Students' reflections on the use of animations while learning the PCR method, as were exposed in analyzing students' focus groups.

In order to discuss with the students their views about learning biotechnological methods using animations, we conducted 7 focus groups with approximately 20 students each. Two focus groups were conducted in two classes of high school biology majors, who learned the PCR method using cards with still images. Those students' watched later the PCR animation (the two alternative versions- the continuous version and the step by step version), and then participated in the focus groups. The other 5 focus groups were conducted in 5 classes of high school biotechnology majors, who learned the process of the restriction enzymes digestion of DNA, while watching the restriction enzymes animation. In all seven focus groups the same moderator questions were used, only in the two focus groups among the biology majors, one further question was discussed, regarding the use of the still images, versus the use of the PCR animation. We will now introduce the main findings concerning each of the questions used in the focus group discussions, followed by representative quotes.

1. What are the main difficulties you engage in learning biotechnological methods?

From analyzing students' statements, two major difficulties were revealed. The first was the difficulty in imaging abstract things that can not be seen, "theoretical" as many students called it. The students stated that the demand in this topic to understand "how things are arranged or built", makes learning of biotechnological methods even more difficult:

"This subject is very theoretical. We keep talking on something and try to imagine how it looks, but it is very hard since you don't know how it looks" (Nir)

"We learn about a graduated digestion, we understand the principle, but still, how does it exactly occur? How does the molecule look like afterwards?" (Dan)

Another obstacle students mentioned often in their statements was the burden of understanding concepts while learning biotechnological methods, most of them with "complicated and confusing" names to remember:

"There are a lot of concepts while learning biotechnological methods, most of them with long and similar names" (Shay)

"The big difficulty in this topic is to connect between all the concepts" (Alon).

2. Which difficulties were solved through the use of the animation? How exactly the animation helped in confronting those difficulties?

In answering this question, the majority of the students stated that the animation helped them confronting the two difficulties they mentioned earlier, mostly the difficulty in understanding how things "look and are built":

"The animation helps to see it. It demonsates, it enables to understand how it happens, the DNA digestion and the configuration of the sticky ends" (Dor)

"The animation enables to understand the graduated digestion. I would not understand it otherwise. It enables to understand how the enzyme works" (Noa)

The animation also helped students in their second difficulty, the burden of "complicated" concepts:

"It really helped understand the concepts: palindromic sequence, sticky ends, restriction site, the more complexed concepts" (Nir)

3. Which components of the animation were most helpful and contributed mostly to your understanding of the biotechnological method?

Through answering this question we wished to learn about students' feedbacks to various components of the animations, which are common in all the animations we developed, and its effect on students' understanding. From analyzing students' statements we learned the students acknowledged mostly the written text:

"The text is important since it gives you an important background, so you can understand what is being demonstrated in the animation" (Yulia)

The students' views regarding the importance of the written text as accompanied information was reflected also in their suggestions for adding a narrator feature to the animation:

"Narrator is good cause in that way you can hear *while* you watch the animation" (Shay)

Still, most of the students were convinced that a written text is more effective than a narrator:

"I'll tell you why a text is better than a narrator: if I read and suddenly I am not focused, I can read the text again. But if the narrator will tell something and I'll will not be focused, it is gone". (Sarit)

Another effective component the students mentioned frequently were the "experimental features" in the animation movie, such as the buffer solution, the tubes etc:

"I suddenly noticed that we are using buffer in this method. Through the animation we were exposed to the experimental sides of the method, which were not introduced while we learned it in class". (Naama)

4. What are your preferences regarding the use the continuous version versus the "step by step" version of the animation. What are the advantages and disadvantages of each version?

As revealed earlier while analyzing students' reflections on the feedback questionnaire, it seems that the majority of the students preferred watching the "step by step" version, especially during the early stages of learning. The continuous version was suggested to serve as a summary visualization tool, towards the end of learning the biotechnological method (the digestion of DNA by restriction enzymes, or PCR):

"I think it is better to watch first the 'step by step' version, to understand what is going on in the animation, and then to watch the continuous version, that summarizes it all together" (Noga)

"When I watch the continuous version I keep going back to the beginning, cause I am slow. It runs really fast and I prefer watching the animation gradually" (Ronit)

5. What do you think about the integrated tasks in the animations?

With this question we wished to focus the students on the effectiveness of a specific component of the animations - the integrated tasks. From analyzing students' reflections in the focus group we learned that the students saw the integrated tasks as an important component of the animations, since by encountering the tasks and solving them they felt they practice the knowledge they just gained through watching the animation:

"The tasks are important, cause through solving them we were able to see what we learned from watching the animation. The animation itself is most important but the tasks help us see what we have understood, or not" (Vered)

Students' positive attitudes towards the integrated tasks were also exposed clearly in their "recommendations" to increase the number of integrated tasks, as well as their complication:

"I wish there will be more tasks, that I will be more active while watching the animation" (Nir).

"I hope you can add more tasks to the animations and that they will be more challenging" (Dan).

6. In which learning stage, do you think, it is best to use the animations?

Analyzing students' reflections in the focus groups revealed that most of them thought it will be difficult to base the initial learning of biotechnological methods only on animations. When some students do recommend using animation at the initial stages of learning, it was only in the case of the "step by step" version:

"Learning this subject for the first time while watching the animation might be too difficult. In that case, it can only be while watching the graduated version, which is much clearer for the beginning" (Mor)

7. What do you think is the best way to use the animations in class?

By asking this question we wanted to complete the picture regarding how the students see the activation of the animations in class. From analyzing students responses it seems that the majority of the students embrace the role of the teacher regarding this visualization tool, and believe it will be most effective to watch the animation through the guidance of the teacher:

"I think it is better to watch the animation with the teacher, instead of alone. The teacher can help you understand what is being demonstrated" (Shay).

"It is possible that the teacher will give the background, and then every student will watch the animation alone and focus on the things he does not understand" (Shiri)

8. What are your preferences regarding the use of animation versus still images while learning biotechnological methods? Which of them is most effective?

This question was asked in the two focus groups with biology majors, in which the students learned the PCR method first by using cards with still images and later watch the PCR animation. From analyzing students' reflections it can be seen clearly that the majority of the students' prefer the animation as a visualization and learning tool, much more than the still images:

"Watching the still images was quite boring. After all, it is like viewing the text book" (Alon)

"It was much easier to understand from the animations. Regarding the actions of the restriction enzyme, it is much clearer what it exactly does from the animation than from the still images" (Sharon).

In summary, it was shown here that students express a need to use visualization tools while learning biotechnological methods, due to the difficulty in imaging abstract things, as well as the demand to understand "how things are arranged or built". For that manner the students found the animations they used, as opposed to the still images, helpful regarding those obstacles.

The students expressed their clear tendency to the "step by step" version of the animation, because of its interactive nature. The students also stated that the "step by step" version is more appropriate to be used during the early stages of learning biotechnological methods. On the contrary, the continuous version was suggested to serve as a summary visualization tool, towards the end of learning. The students acknowledged mostly the accompanied text as well as the "experimental features" in the animation. They found these components most helpful in assessing the understanding of the animations, as well as the biotechnological method which is demonstrated in the animation. Regarding the integrated tasks in the animations, the students found them as an important component of the animations, since by encountering them they felt they practice the knowledge they just gained through watching the animation. The students also expressed clearly their recommendations that the number of integrated tasks, as well as their complication, should be increased. Finally, regarding the learning terms, the students embraced the role of the teacher in activating the animations in class. In addition, the students also expressed their clear preference of watching the animation while working in couples.

The wish to obtain students' feedbacks, regarding different aspects of using the animations, help answer the main goal of this study, which is to identify the unique contribution of animations and the terms of using them, under which the use of animations is most effective in promoting students' understanding of biotechnological methods. The results to this research question will be discussed in the discussion session in light of Mayer's and Moreno's (2002) seven essential principles, in which they identified the conditions under which animations mostly promote learners' understanding.

2a. What are teachers' perceptions, and challenges they face, when enacting animations in biotechnology in class?

Through the findings of this research question we wish to shed light on biotechnology teachers' perceptions concerning their practice of animations in class. The findings were characterized using a qualitative analysis (Shkedi, 2003) of high school biotechnology teachers' discourse, which were raised during a professional development workshop. During this workshop the teachers were exposed to the new developed animations in genetic engineering. In addition, a focus group during the workshop (n=30), aimed to investigate how the teachers plan for and support learning with animations was used as an additional source of information. I will now introduce the main findings regarding the teachers' perceptions, concerning the different aspects that were raised by the teachers regarding enacting animations in class while teaching biotechnological methods.

Challenges side by side with profits

When teachers use animations in class in the course of teaching biotechnological methods they seemed to be aware to the challenges together with the benefits involved in using this tool. Still, it can be pronounced that all the teachers have expressed general positive attitudes towards the use of animation in class, and that all of them are employing the use of animations, though in various ways, while teaching biotechnological methods.

One of the things the teachers seemed to be most aware to was the visual as well as the cognitive load that might evolve while using visual representations like animations (Sweller, 1994). During the focus group some teachers raised, in several occasions, some requests regarding the visual representations of objects such as molecules and chemical bonds in the animations. During these occasions, it could be noticed that while the teachers were sometimes dissatisfied with the way objects were represented in the animations, on the same time they were aware to the constraints and the limitations of the representations in animations, and they reflect their concerns that the animations should not be burdened with too many details:

Miki: Maybe you [the developers] can add the hydrogen bonds into this scene in the animation [where it is shown that the restriction enzyme cuts 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 problematic to watch this scene in the animation. There are details you have to ignore while making a scene in an animation, otherwise it will be too burdened.

Another aspect of teachers' views regarding the visual representations in the animations was the teachers' concerns that while watching animations students might develop misconceptions due to the way molecules and chemical bonds are represented in the animations. For instance, some of the teachers expressed their concerns about how students might grasp the concept of phosphodiester bond, due to the way it is represented in the restriction enzyme's animation (see the context of the study, p…) they watch:

"You see in the animation the strand of the DNA, 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 now on he might remember that a phosphodiester bond is a bond between the nitrogen bases" (Efrat).

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

"There are problems, for instance, with the size of the enzyme compared to the DNA molecule., And the way the enzymes are moving and associating with the DNA, it is not true from the biochemical perspective" (Ran).

In spite of the complexity the teachers have reflected in their statements, regarding static as well as dynamic aspects of visual representations in animations, they reported that at the same time animations is a favored tool for learning biotechnological methods. The animations are described by the teachers as very effective tools versus other teaching strategies or other visualization tools, like transparencies, mostly because of their dynamic and continuing nature of visualization:

"Last year I made transparencies. I drew sticky ends, another transparency where they are associated, and another transparency with ligase. Visually it is completely different when you look on it in an animation. It moves, it is much more beautiful. The animation actually demonstrates a process that starts and ends with a specific order" (Dora).

"I am showing them the animations while I am explaining to them about the process. It shows them all the process continuously. It saves a lot of time of explaining and of understanding" (Ravit)

The teachers also use animations while teaching biotechnological methods since they believe it serves as a good answer for specific difficulties students had in learning biotechnological methods in particular. In the next example the teacher refer to the unique ability of the animation to zoom in into 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 all the time that the phosphodiester bond is not *between* the DNA strands, it is *inside* the strand. In the animation there is the "zoom in" into the DNA strand and it is being demonstrated to them" (Efrat).

In the next example another teacher is refereeing to the progressive nature of the animation, which allows demonstrating processes such as biotechnological methods that takes 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, its beginning and its end, and there is (in the animation) also a watch that is working all the time" (Dora).

The teachers also described the animations as a convenient way for practicing students' internal mental models. In order to construct those mental models effectively, most of the teachers have recommended using animations in addition to other visualization tools:

"Using animation can serve as an appropriate way to test the models students already have in their minds, after they watch the illustrations in the textbook. Brining an additional illustration seems to me a little bit tiring. But when it is shown in an animation, and they have to see who this enzyme is and where it is coming from, it adds to their understanding. It also brings up a lot of questions from the students" (Heidy).

To sum up, it can be seen that the teachers refereed to the use of the animations in class in a fully conscious point of view, considering the advantages together with the disadvantages or challenges involoved in using this tool. The teachers are aware to the problems that might develop due to the cognitive load that characterized most of the animations, especially the complexed ones, such as the animations of biotechnological methods that demonstrate whole processes. They also take into consideration that the representations in the animations might effect the evolvement of misconceptions concerning the nature of chemical bonds and the accurate structures and dynamic orientation of molecules. Still, considering carefully all the limitations, the teachers have recommended powerfully to use animations while teaching biotechnological method, due to their dynamic and continuous nature. The teachers have also recommended using animations in addition to the other alternative representations, such as illustrations in textbooks, since it adds more dimensions of visualization, such as the time dimension, and also can serve as a suitable opportunity to put into practice students' mental models. Considering the particular difficulties in learning and teaching biotechnological methods, namely its abstract nature and its practical aspects of conducting the methods in the lab, the teachers have found the animation as an appropriate and effective answer to those specific problems. According to the teachers, it is due to the concrete and dynamic nature of animations and to the way they can demonstrate the work that is carried out in the lab.

The optimal learning stage and the optimal format of using animations

The challenges and the profits teachers have expressed in relation to using animations while teaching biotechnological methods seem to influence their views about how to integrate the use of animations in an optimal way into their teaching practice. Most of the teachers have recommended integrating the animation in the advanced stages of learning; given that the students have more prior content knowledge thus they can cope with the details in the animation in a better way. The complexity of the animation has also effects on teachers' decisions when to integrate the animations in their teaching sequence:

"Complexed 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 what is the purpose of all the process, or what factors are involved, it makes it hard to understand the animation and in that way you miss it" (Ran).

Besides its complexity, the format of the animation was an additional factor which was raised by the teachers in relation to the suitable learning phase of using animations. The teachers referred to 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 their 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 think oppositely that only after understanding the process gradually the students can see the whole picture:

"When I'm explaining them about a method I first show them the whole picture, using the continuous version, and only then get into details. Other wise it is very hard for them to construct from all the slight details what is going on" (Ravit)

"I think that only when they first learn the details then later they can watch the continuous version and understand how everything is integrated" (Dora).

It can be concluded that in light of the detailed nature of the animations, the teachers consider the appropriate learning stage to integrate the animations in an optimal way. One of the major issues while choosing the appropriate learning stage is to select the proper *format* of the animation. While some teachers tend to believe that first the students should be exposed to the details of the biotechnological method, using a step by step version, others employ first the continuous version, believing that the students should learn first the method generally, and only later go into each stage of it.

Enacting animations in class- Teacher centered versus student centered

One of the things that were noticeable from the beginninrg through the teachers' focus group was two central approaches on the subject of teachers' position while enacting animations in class. While some teachers indicated they control the activity with the animations and lead it, others said they tend to work in a mode in which the students are more independent. One of the key factors in teachers' decision 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. I am explaining at the beginning, going forward and backwards, and it goes very fast.

Moderator: And you don’t let them work alone?

Eli: Almost not since there is no time.

Besides saving essential time of the intense schedule of 11^{th} and 12^{th} grades, some teachers also believe that the teacher centered strategy is more effective in terms of students' understanding. They believe that the leading of the teacher makes the learning from the animation more meaningful:

"I am showing them exactly the whole process while I am explaining. It’s a must, I think. I am also asking them the questions that appear in the animation. Instead that everyone will answer 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 through their navigation with 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 the time we keep asking questions like: 'what you have now in the test tube?' 'On what stage are you?' and they worked! Right, it took three lessons.

Moderator: and they worked alone?

Dora: Yes, and to my opinion they knew it good, better than… It was for three lessons, with an accompanied worksheet we prepered for them, and they knew ELISA [a biotechnological method]. In a while we went over the ELISA really fast in class and a discourse developed, and they had their 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 once again animation in this way" (Dora)

Even tough those teachers supported the way in which students work with the animations independently, still they were also aware to the time limitations. Consequently they recommended using this strategy at least a few times, and believed that the impact of such experiences will be broad and will have its effects on future experiences the students will have with animations:

Moderator: So this way you suggested [when students learning independently with animations] is the only way you use animations in class?

Dora: No, you can not do it during the entire year, not in each of the animations we use. We can watch animations in that way only in a few occasions, but, once you did it [use the independent students' strategy], your students are in different place.

From analyzing teachers' statements trough their professional development workshop, it can be concluded that some central insights regarding enacting animations in class were exposed. The teachers have reflected a complexed reality of enacting animations in class while teaching biotechnological methods. This complexed 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 and the optimal format of using the animation, together with finding the optimal teaching strategy to use animations in class.

2b. What are the teachers' approaches regarding teaching biotechnological methods using animations?

In order to check more closely the central approaches which were revealed during teachers' focus group, the "teacher centered" versus the "student centered" approach, two exemplary leading teachers were chosen from the sample of the biotechnology teachers that attended in professional development workshop, for two exemplary case studies. The findings described here are aimed to shed more light on teachers' perceptions which were already identified. It includes the two teachers' believes, as well as practical teaching strategies they use while enacting animations in class though teaching biotechnological methods. The two teachers, Ravit and Dora (Pseudo names. See some personal details in the Methodology section), were interviewed and the transcripts of those interviews were analyzed qualitatively (Shkedi, 2003). The interviews were managed around the same moderator questions, and are represented in Table 8, where the similaries in the two teachers' styles are exposed together with the differences in the two teachers' approaches.

Table 8: **Similaries and differences in the two teachers' teaching approaches in general, and strategies of using animations in particular**

The aspect	**Ravit's approach**	**Dora's approach**
The teaching	Constructivist. From theory to	"With" the students and not "in

The aspect	Ravit's approach	Dora's approach
approach	practice. "Each lesson of mine is based on the last lesson, layer on layer. I always prefer giving the students the basic concepts, only later I go to practice. It means the student should know first what is a plasmid, a restriction enzyme, and only then he can employ this knowledge into the learning activities".	front" of them. "I have no frontal lessons, when I lecture and the students are passive. It is more like conversations, questions and answers, or the students perform activities and I move between them and help"
The rationale in using animations while teaching biotechnological methods	o Demonstration o like virtual labs o As a tool for promoting active learning. "First of all it serves for demonstration. What the student has seen on the board suddenly becomes concrete… It moves from the paper to the hands. It is like the student is doing an experiment in the lab" "This animation [the gene library animation] is builds up in an active way. The student "takes" the fragments, transform them, it is actually active learning"	o Assimilating the knowledge in practice o A good preparation for the work in the lab. o As a stimulator for eliciting questions and discussions. "The purpose [in watching the animation] was that the students will go over them and assimilate what they already have learned, before they will make cloning in practice in the lab…It also serves as a trigger for students questions, a stimulate for discussions"
Practical aspects of using the animations in class	The animation serves for summary, after the knowledge was taught by Ravit. "After they already got the key concepts from me and we have learned what the concepts are and why they are important, the students move to the active part of watching the animation. It could serve as a good summary before the test"	The students watch the animation independently and the activity is accompanied by a worksheet. Dora serves as a coordinator and helps the students handle the animations they watch. The animation can

The aspect	Ravit's approach	Dora's approach
		be used for diverse purposes in diverse learning stages; in the beginning as a trigger for learning, or in the final stages as a summary activity. "I help the students while they watch animations but the worksheet focuses them on certain places I want them to focus while watching. Other wise it is like watching a movie, what you understood you understood and that is it". "I can use animations as an exposure, and afterwards we start learning a topic. Sometimes it is towards the end as a summary"
The role of the teacher during the activity with the animation.	The teacher is a dominant guide, a comptroller of learning that helps students focus on the important details in the animations. "The students guided me trough the exploration with the animation, I asked questions, they answered me, they were active trough the whole activity even though I navigated through the animation. I controlled the activity but I gave the students the feeling they control me; they tell me how to navigate the animation".	The teacher is responsible to give the students the basis of knowledge and to help them cope with the animation independently. "The student is the one who has to learn using the animation. The teacher is there in order to give the student the required basis, to help the student utilize his knowledge through the activity with the animation".

It can be noticed that both Ravit and Dora represent two alternative approaches of enacting animations in class (Table 8). Even though the two teachers are relatively similar in their tendency to a constructivist style of teaching, still there is a clear difference in the position they take as teachers through the actual enactment of animations in class. While Ravit, the "teacher centered", pays attention to control the activity with the animations and navigate it, Dora, the "student centered" prefers to let the students work independently, navigate the animations according to their own interests and speed, though she accompanies it with a relevant worksheet. The findings regarding the possible benefits students might have while learning biotechnological methods through employing each of the teaching approaches described above are detailed in the next research question.

2c. What might be the contribution of the teacher to the enactment of animations in class while learning biotechnological methods?

In this research question we aimed to study the potential contribution of the teacher to the enactment of animations in class. The drives to this research question lies on other studies which reported that using animations or simulations alone does not ensure learning (Hennessy et al., 2006; Kelly & Jones, 2007). It seems this learning activity is occasionally linked with unquestionable, often simplified models of the scientific process. In addition, students sometimes seemed to miss essential features when they watch animations alone (Ardac & Akaygun, 2005; Kelly & Jones, 2007). Therefore, we decided to study what might be the contribution of the teacher 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 leading 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 accompany 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. They do that, for instance, by discussing with the students the rationale as well as the practical procedure behind various steps in the biotechnological methods which were demonstrated in the animations. In the next example from classroom observation, while the students watched the animation that demonstrates cloning a plasmid in bacteria (see http://stwww.weizmann.ac.il/g-bio/geneengine/anim2.html), Ravit discussed with her students the practical reason for using two different kinds of antibiotics:

Ravit: How can I tell I cloned the plasmid with the desired gene? I need a marker that will be expressed.

Student: the gene we chose to clone has an antibiotics resistance that can be expressed.

Later in her interview, Ravit explains why it is important to discuss with the students the rationale behind different stages of a biotechnological method being demonstrated in the animation, this time in the case of creating a gene library. She believes the students should understand, concerning each step they see in the animation, what is the reason for doing that, and how it is really done in the lab: "In the animation that demonstrates the creation of a DNA library the stage of blotting 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 the feel of the lab and show then dynamically how things are being 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 discussing with the students and bringing up to their awareness the existence of some steps that were skipped from the animation, still important while performing the relevant biotechnological method in the lab. In the next example from classroom observation, Dora is discussing with her students the rationale of a step that is not present in the cloning animation they watch:

Dora: Tell me, what we should do to the bacteria in order to get an effective transformation?

Student1: We should heat them

Student2: 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 the transformation with plasmids.

Afterward in her interview, Dora is saying things which we already heard from Ravit. Accordingly, without the discussion on the important steps in the biotechnological method and their rationale, the students might learn incompletely the biotechnological methods as they are being demonstrated in the animations: "Those steps are missing in the animation but it is not terrible at all because we discuss them together. Even if the animations had included all steps, still the students might not think why there is a need to do each step and why it is important".

It can be concluded that according to class observations as well as teachers' statements in the interviews, the teacher's contribution in terms of "bringing" the hands on point of view while learning biotechnological methods from animations is essential. Besides gaining a practical understanding of particular stages of the relevant biotechnological methods, "bringing" the hands on point of view by the teacher enables the students understand the rationale of the biotechnological methods in general.

Guided watching: Helping dealing the cognitive and the visual loads

Both Ravit and Dora tend to guide their students while watching the animations. Ravit, as a "teacher centered", did that along her students' navigation through the animations, while she is leading them. Dora, who tends to employ a more "student centered" approach, supported her students on several occasions through the learning activity with the animation, whenever they reflect to her some 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 watch. 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 antibiotics 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 more?

Student: an origin 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 seat, read a book, and let them watch the animation alone till it ends. I believe that in that way they will lose some important points they might miss because they have not noticed them through all the details and changes in the animation"

Besides the nature of animations, with its dynamic changes and the 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) that is abstract and complex. According to Ravit, especially in animations in this topic, carefulness is needed during watching 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, in a first look everything looks the same. The student might notice the difference, but he might not understand the meaning of the difference, and this is exactly where the patent is! This small difference between molecules can make a huge difference in understanding. That is why when students are looking on 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 reacting to some students' comments, during their watch of the animation, and accordingly asking some leading questions and supporting them so they could see the differences between different kinds of bacteria in the cloning animation:

Student1: there is one bacteria without a plasmid

Student2: there is one that has not perceived a plasmid and one who did

Dora: there is only one bacteria with an unclonned plasmid? One of the plasmids is cloned. Who is it?

Student: this

Dora: right. So what is this? And this? [pointing on the screen]

Student: this plasmid has a resistance to the antibiotics tetracycline.

Dora: is it cloned?

Student: no

Later in her interview, Dora is summarizing the kind 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 on 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 his unique elements."

In summary, this time teachers' contribution was in terms of guiding the students while navigating the animations and assisting them to focus on the objects they watch and on the important details. According to both teachers this assistance is necessary in order to make the animations clearer for the students, and moreover, due to the complicated nature of objects such as structures of molecules, which make it even harder for students to grasp.

Implementing constructivist aspects of knowledge construction

Both Ravit and Dora implemented elements of constructivist teaching while they used animations in class. They both treated the activity with the animation as an important corner stone in the broad construction of students' knowledge and understanding of the biotechnological methods. For that purpose, one of the things that were done by Ravit was to establish clearly the activity with the animation on students' prior knowledge, 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 it is done before we'll 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 the story Liron [the student] has just told us is true.

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

Dora: Nofar [a student] is asking an interesting question regarding the animation: 'How can we tell who the insert in the end of the cloning is?' Since we cloned here two plasmids, we really can not 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 in a plasmid. In that case the insert is the fragment from the virus and the plasmid has received it.

In another example, Ravit also acts to connect the activity with the gene library animation to a tour the students will have in the future, as well as to their lab experiences:

Ravit: you see in the animation that we need to "open" the cells, and I want to ask you- how do we open cells? In our next tour you will perform a procedure that will include opening cells. Now, from what you already know from the lab, how do we open cells?

Later in her the interview, Ravit is stressing why she believes it is so important to link the activity with the animation to the other learning activities the students are exposed to: "it is most important to link the activity with the animation to the tour, to experiences we 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 I work with the animation, I keep going back to what I have already taught in other occasions. The student is curious, if he does not understand something from the animation he can go back to other learning experiences he had."

While the constructivist aspects being introduced so far were common to both Ravit and Dora, the next aspects 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 have different performances regarding this aspect. Ravit, with her "teacher centered" approach, supports her students' by explaining and expanding the meaning of concepts she believed are crucial for their understanding 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, raising the transformation concept 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 transfo…

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 the conceptualization of the process the students had just watched in the animation is so important: "the students are watching a process in the animation but they must know the name of it, 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 is basing her supporting efforts on students' difficulties and misunderstandings she is exposed to during the enactment of the animations. As can be seen in the next example, watching the cloning animation serves as a good opportunity for students to raise questions regarding the replication of plasmids. In response to students' question, Dora discusses with her students the process of plasmids' 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 it is important that the plasmid will 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 due to a student's question. Through this opportunity Dora tries to expand students' understanding regarding the object of sticky ends which is being demonstrated in the animation, in order to make it clearer for the students:

Student: why is it called sticky ends?

Dora: to what does it stick?

Student1: they stick to each other

Studet2: they stick to the plasmids

student3: 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 to the places were the students had needed assistant in order to gain meaningful understanding. Her presence on that point enables her support the students through they watch the animation, whenever they encounter concepts or objects which were not so comprehensible: " When I was exposed to students' specific difficulties through their watch of the animation I had the opportunity to put a spot light on objects and concepts in the animation which are nor understandable enough to the students".

As can be seen, teachers' contribution in the aspect of implementing elements of constructivist learning is composed from elements that are common to both teachers, together with elements that are unique to the teachers, each according to her teaching approach. Both teachers made efforts to connect the activity with the animations to students past learning experiences, and they both used the activity with the animations as a good learning opportunity to enhance students' understanding of the biotechnological methods being demonstrated in the animations. Ravit, with her "teacher centered" approach, did that by focusing the students around key concepts in the animation, she believes are crucial for understanding the relevant biotechnological method. Dora, on the other way, used students' questions and misunderstanding through the activity with the animation as a trigger for supporting students' problems in understanding. It seems that adding the "hands on" point of view by the teacher to the activity of watching biotechnological methods in animations, and helping students handling the visual and cognitive challenges of watching animations, might makes this learning activity more meaningful.

7. Discussion

7. 1. Overview of the main findings

Learning from animations is not a simple task, even though it might seem like. 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). Accordingly, this study aims to represent the complexity of viewings animations, in terms of the cognitive factors involved, as well as the pedagogical ones.

I have learned that animations do have a unique contribution in promoting biology as well as biotechnology majors' conceptual understanding of biotechnological methods. Using the conceptual status framework for analyzing biology students' discourse while learning the PCR method, we have learned that the use of the animation gave the students an advantage in understanding the mechanistic aspects of this method, namely the ontological function of different molecules and the causal mechanism that invokes them, compared to students who learned this method using still images. This advantage was also reflected while analyzing biotechnology students' concept maps, before and after viewing the restriction enzyme's animation.

The role of students' prior knowledge, while learning using dynamic or static visualization tools, was another aspect investigated in the course of this study. My study shows that prior knowledge is not an essential factor when learning using animation. The explicit, "expert-like", dynamic representation of the situation, as it appears in animations, might explain why during their use, there is less dependence on prior knowledge, as opposed to when static illustrations are used (Williamson & Abraham, 1995).

I have also identified in this study the contribution of two exemplary biotechnology teachers to the enactment of animations in class while studying biotechnological methods, which is pronounced in the following three aspects: establishing the "hands on" point of view, helping students deal with the cognitive load that accompany the use of animations and implementing constructivist aspects of knowledge construction while studying using animations. During the analysis of the two exemplary case studies I have recognized two alternative approaches of teachers in terms of supporting students' knowledge construction while studying biotechnological methods from animations.

7. 2. Learning aspects of enacting animations in class

Learning from animations versus still images

Previous studies have already shown that dynamic displays can be particularly effective when learning content that requires the students to visualize *motion* (Reiber, 1990). Studies that tested the effectiveness of animations versus still images on students' understanding of contents that require visualization of motion *at the molecular level* have also shown significantly higher understanding for students who used dynamic visuals (Ardac & Akaygun, 2005; Williamson & Abraham, 1995). Animations give an accurate and rich picture of the dynamic nature of molecules and molecular interactions, which is often very difficult to understand (NSF, 2001). I believe that in this matter, my study supports the use of animations over still images, when the type of knowledge to be acquired can be classified as dynamic, particularly in demonstrations of molecular phenomena.

The study of Marbach-Ad, Rotbain and Stavy (2008) specifically shows that computer animations are effective especially while studying dynamic processes. According to their findings, there were no significant differences between the illustration and the computer animation treatments in terms of students' understanding of the DNA and the RNA *structures*. In contrast, there were significant differences between the illustration and the computer animation groups regarding the molecular *processes* of DNA replication, transcription and translation. Answers coming from the computer animation group were more accurate and profound than those from the illustration group (Marbach-Ad et al., 2008). In my study I used animations in order to demonstrate biotechnological processes, and indeed I have identified a significant advantage to understanding of the biotechnological method being taught in the case of students who learned from animation, as opposed to those who learned from equivalent illustrations (Yarden & Yarden, 2009).

The advantages of using animations while learning biotechnological methods were reflected in my study also in the meta-cognitive level, within analyzing students' discourse during focus groups, as well as students' feedback questionnaires. According to Pedretti, Mayer-Smith and Woodrow (1998), students’ perceptions and attitudes about technologies should be recognized and accommodated when educators integrate computers and multimedia technologies into students’ educational experience. In my study, the students that participated in the focus groups have expressed their strong need to use visualization tools while learning biotechnological methods, due to the difficulty in imaging abstract things, as well as the demand to understand "how things are arranged" or "how processes occur". For that manner the students found the animations they used very helpful regarding those obstacles, as opposed to the still images, to which they related as "quite boring, like viewing the text book". The students have also acknowledged mostly the accompanied text in the animation. They found this component most helpful in assessing the understanding of the animation, as well as the biotechnological method (PCR) which is demonstrated in the animation.

Some of the students have suggested adding a narrator feature to the animation, since in that way "you can hear while you watch the animation". Those suggestions does not go along with the Redundancy principle, which is one of seven empirical principles that express how should animation be used within multimedia presentations (Mayer & Moreno, 2002). According to Redundancy principle, in the case of animation, narration, and on-screen text, receiving less resulted in better transfer performance than receiving more. Nevertheless, most of the students who attended the focus groups were convinced that a written text is more effective than a narrator, since when "they read and suddenly become not focused; they can read the text again, but with the narrator the information has gone" (p. 81, in the Results section).

From analyzing students' feedback questionnaires, as well as students' focus groups, I revealed that the students have expressed their clear tendency to the "step by step" version of the animation, because of its interactive nature. Clearly, interactivity, a factor known to facilitate learning (Hegarty, 2004), can help overcome the difficulties of perception and comprehension in molecular processes. Stopping, starting, and replaying an animation can allow re-inspection, focusing on specific parts of molecular structures, and molecular interactions. Animations that allow close-ups, zooming, and control of speed, as those I developed and studied in this study, are even more likely to facilitate perception and comprehension (Tversky & Morrison, 2002).

The students in my study have also acknowledged the integrated tasks in the animations, and found them as an important component of the animations, since by encountering them they felt they practice the knowledge they just gained through watching the animation. This brings to light the importance of engaging students in an active way while watching animations. The most straightforward suggestion for using visualization effectively is to make visualization interactive and increase active student involvement in the learning process (Acuna & Sanchez, 2004; Lowe, 2004). These recommendations are in accord with the educational practice reforms advocated by the major professional science education communities (AAAS, 1993; NRC, 1996).

The distinctive contribution of animations to students' development of mental models

Following identifying the advantage animations have on still images, while visualizing motion, the question that came up was what are exactly the distinctive advantages of animation when visualizing motion. According to Reiber (1990), the degree of visual elaboration required to convey a complete image might play an important role in explaining the differential learning effects observed for dynamic versus static visuals. One major advantage of dynamic visuals is that they enable a display of the collective motion of particles, which can be effective in conveying a complete mental image of changes in matter (Ardac & Akaygun, 2005). According to Pallant and Tinker (2004), learning experiences based on molecular dynamics tools should help students develop more scientifically accurate mental models of molecular-scale phenomena, which should in turn help them to reason more effectively at different levels, similarly to experts. In the case of this study, which dealt with the demonstration of events of a biotechnological method (the PCR method), it seems that the use of the animation was more effective in enabling the formation of a coherent mental image, than in the case of using equivalent still illustrations. This contribution might be most significant since the students have learned the PCR method for the first time from the alternative visualization tools, therefore it was most important that the visualization tool would enable them to display successfully the collective motion of components involved in the new process being learned.

Williamson and Abraham (1995), who explored the effect of a computer animation on the particulate mental model of college chemistry students, concluded that animations might help increase conceptual understanding by prompting the formation of dynamic mental models of the phenomena at hand. They also found that students who viewed only static visuals formed static mental models that failed to provide adequate understanding of the phenomena. It was our goal in this study to facilitate biology and biotechnology students' understanding of the interactions between various molecules in the course of the PCR method, by relating them to the corresponding symbolic representations, which were identical in the animation and on cards with the still images (Yarden & Yarden, 2009). Our results imply that for such tasks, the animation serves as a better alternative than the static visuals.

Enhancing mechanistic aspects of conceptual understanding while learning from animations

The detailed picture of the distinct advantage of animation, in terms of students' integration of knowledge while learning PCR, was obtained in this study by analyzing students' discourse, in the framework of a conceptual status analysis. According to Kozma & Russell (1997), verbal explanations play a fundamental role in the development of an integrated knowledge base, acting like a ‘semantic glue’ that holds different representations together. In his study, Kozma (2000) claimed that students should work in rich social contexts that prompt them to interact with each other and with multiple systems, to create meaning for chemical phenomena.

Comparing the relative frequency of diverse status elements in the students discourse of both groups, I identified recurrent inclusions of the status elements *metaphysics* and *real mechanism* in conversations of students who learned about PCR using the animation. However, in conversations of students from the still images group, these status elements were absent, and the students reflected misunderstandings in those aspects. The two specific status elements of *metaphysics* and *real mechanism* represent the learners' ability to understand the ontological function of different molecules, and the causal mechanism that invokes them, respectively. According to Guenther (1998), the ability to understand the cause-effect relationships that exist within a system is one of the most important roots of conceptual learning. Being able to reason causality is an essential cognitive skill that is central when learning scientific topics, since the core properties of all sciences are causally related in nature (Carey, 2002). Reasoning causality enables us to predict, infer, and explain the events or phenomena that we encounter or observe (Hung & Jonassen, 2006).

The differences in the conceptual status, in favour of students who learned PCR using animation, were mostly found in three mechanistic aspects of the PCR method, namely the function of DNA polymerase, the function of the primers and the specific temperatures at which different stages in the PCR method occur. In a different part of this study, I used concept maps as a tool for identifying biotechnology students' conceptual understanding of the process of DNA digestion using restriction enzymes, while learning from an animation I developed. When I classified the propositions that students has drawn in their pre-watching as well as in their post-watching maps in terms of structural versus functional type of propositions, I revealed there was a significant increase in the number of functional propositions. Within the pre-watching concept map, structural propositions such as: "restriction site is composed of nucleotides" or "palindrome sequence is inside the DNA strands" were mostly common. In the post-watching concept maps on the other hand, 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".

To sum up, in both cases, analyzing students' discourse while learning the PCR method, as well as analyzing students' concept maps while learning the DNA digestion process, the use of the animation has enhanced students' explanations which can be classified as mechanistic. A mechanistic explanation is “An explanatory account of observed results by describing the mediating process by which the target factor could have produced the effect” (Koslowski, Okagaki, Lorenz, & Umbach, 1989). Hung & Jonassen (2006), who focused on ways to enhance conceptual understanding of physics, have showed that students who learned using a mechanism-based approach significantly outperformed the other two experimental groups. Since we were able to show in two independent cases that mechanistic aspects were significantly enhanced while learning two biotechnological methods using animations, we can state that the use of the animation had enabled the students to achieve a conceptual understanding of the biotechnological methods being taught, in terms of the acquisition and application of new knowledge resulting in concepts and symbolic representations (Maclellan, 2005).

The role of students' prior knowledge while learning from animations

The role of students' prior knowledge, while learning PCR using dynamic or static visualization tools, was another aspect investigated in the course of this study. Students' prior content knowledge was found to be an indispensable factor for students who learned about PCR using still images. In contrast, the level of students' prior content knowledge did not appear to have any notable effect on their understanding of PCR while learning using animation. Accordingly, a low level of prior knowledge did not serve as an obstacle to students from the animation group, as opposed to those from the still images group.

One explanation might be that since animations help in mentally visualizing a process or a procedure, they reduce the cognitive effort required in comparison to static pictures, in which the process has to be reconstructed from the pictorial information (Hoffler & Leutner, 2007). This might explain our finding that students' prior content knowledge was a crucial factor for students who learned about PCR using still images. The dynamic display of a process by animation can also compensate for a student’s insufficient knowledge in imagining some relevant motions (Salomon, 1979).

Looking at this issue from an alternative point of view, Lewalter (2003) claimed that since dynamic visuals may reduce the load of cognitive processing by directly supporting the construction of a mental model, this might result in learners having less control of their cognitive processing. Mayer et al. (2005), in a study examining the use of annotated illustrations versus narrated animations, found that static illustrations with printed text promote germane processing as compared to narrated animations. Germane processing is the cognitive processing that involves deeper processing of the key material by mentally organizing it into a coherent cognitive representation and integrating it with other representations and prior knowledge (Sweller, 1994). According to Mayer et al. (2005), the advantage of the static-media presentation is that it encourages generative processing, such as mentally animating or self-explaining the key changes from one static frame to the next. In view of that, I suggest that animations should be constructed or used in ways that tap the positive features of static illustrations, besides the intrinsic advantages of the dynamic display. For example, learners could be encouraged to engage in active processing through activities, such as generating explanations or answering questions, during learning using the animation. In light of my results and the relevant studies described above, I also suggest a learning model according to which students initially engage in learning using still images, in order to promote generative processing, and subsequently use animation in order to complete the mental model, and enhance the mechanistic understanding of the phenomena being visualized.

The role of prior knowledge as a central element of active cognitive construction is well known from the constructivist perspective (Ausubel, 1963; Glasersfeld, 1998). According to this perspective, learning is the product of self-organization (Glasersfeld, 1998), in which prior knowledge is one of the major building blocks. This study shows that prior knowledge is not an essential factor when learning using animation. Indeed, there are several benefits, mostly at the initial stages of learning, with the presentation of an explicit, "ready-made" "expert-like" external representation, as it appears in the animation. But for the sake of the long-term benefits, I think that effort should be made in making the visual exploration while watching animations more active in terms of students' use, specifically in involving the students' prior knowledge in a more significant way. For that purpose, I believe that the way in which a teacher enacts the animation in class plays a crucial role.

7. 3. Teaching aspects of enacting animations in class

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 use further prompting to support students' regulative processes. Thus, the role of the teacher while enacting the animations in class seems extremely important.

Teachers' perceptions and reflections concerning the enactment of animations in class

Through this research I wished to shed light on biotechnology teachers' perceptions concerning their practice of animations in class. Teachers' perceptions and reflections concerning the enactment of animations in class were raised during a professional development workshop for biotechnology teachers, in which the teachers were exposed to the new developed animations in genetic engineering.

From analyzing teachers' statements trough their professional development workshop, it can be noticed that the teachers have reflected a complexed reality of enacting animations in class while teaching biotechnological methods. This complexed 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 of using animations, the optimal format of the animation, as well as finding the optimal teaching strategy to use animations in class.

Data indicate that the biotechnology teachers in this study appeared to 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 they can demonstrate the work that is carried out in the lab, the teachers have recommended to use animations while teaching biotechnological methods. In the study of Zacharia (2003), which dealt with enacting computerized learning tools in class while teaching physics, the teachers have also acknowledged computerized demonstrations since they reduce ambiguity by demonstrating or modeling correct options as well as help the learner identify the cause - effect relationship that might be obscured by time or bulk of material. According to the teachers’ responses in Zacharia's study (2003), as well as teachers' responses in this study, the use of computer demonstrations as animations or simulations offer options when other alternative approaches are not available (owing to cost, danger or context). The disadvantages reported were mostly focused on the fact that those tools did not reflect reality (ideal conditions or circumstances). In my study, the teachers have also reported that the representations in the animations might effect the evolvement of misconceptions, concerning the nature of chemical bonds and the accurate structures of molecules.

The contribution of the teacher to the enactment of the animations in class

In a study on the attitudes of prospective high-school mathematics teachers toward integrating computers into their future classroom teaching (Hazzan, 2003), teachers were asked to present arguments that would influence their use of computers in future mathematics teaching. In didactic and cognitive terms, the teachers' major concern was that learners may progress without understanding the previous stages (Hazzan, 2003).

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 watch animations alone (Kelly & Jones, 2007). In this study I explored what might be the contribution of the teacher to the enactment of animations in class, by analyzing two exemplary case studies. 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 while studying biotechnological methods from animations, helping students comprehend with the cognitive load that accompany the use of animations and implementing constructivist aspects of knowledge construction while studying using animations. I have recognized two alternative constructivist approaches of teachers in terms of supporting students' knowledge construction while studying from animations. Those two approaches, concerning teachers' position while enacting animations in class, were in fact being recognized initially during the teachers' focus group. During this focus group, while some teachers indicated they control the activity with the animations and lead it, others said they tend to work in a mode in which the students are more independent.

Those two teaching approaches were exposed during the case studies once again. One of the teachers, Ravit, supports her students' knowledge construction while studying from the animations by explaining and expanding the meaning of concepts she believed are crucial for their understanding the biotechnological method being taught using the animation. According to Soderberg and Price (2003), teacher's role while studying from computer representations is to structure tasks and questions in ways that prompt students thinking about underlying concepts and relationships being introduced in simulations and animations. It involves being available when learners are most receptive to guidance, helping them to reformulate their thinking, for instance, by rationalizing explanation 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 she was exposed to during the enactment of the animations. This approach was also held by Hennessy, Deaney and Ruthven (2006), who claimed that teachers should be encouraged to employ mini-plenaries to quickly identify and address misconceptions and to use pupils' 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 to reach consensus and approach normative views. In light of the fact that Dora had planned the activity with animation which is accompanied by a worksheet, aimed to focus the students on certain issues in the animation while watching, it can be said that such instructional design sequence integrates both socio-pedagogical and material supports (Krajcik, Blumenfeld, Marx, & Soloway, 2000).

Both Ravit and Dora implemented elements of constructivist teaching (Perkins, 1993) while they used animations in class, namely establish clearly the activity with the animation on students' prior knowledge, as well as connect it explicitly to other activities on 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 & Akaygun, 2005; Hennessy et al., 2006; Kelly & Jones, 2007). Accordingly, the role of the teacher while enacting animations in class is critical in order to make it more meaningful. I suggest that students and teachers work together in transforming knowledge while studying from animations, as in other lessons and activities in school (Scardamalia & Bereiter, 1991).

7.4 Overview of the main study limitations and possible future directions

Learning biotechnological methods is a complex process, which involves the use of various teaching strategies and learning tools, including hands-on labs, guided tours in industrial factories, as well as animations. It was my purpose to focus on the episodes of learning biotechnological methods through the use of animations, as well as still images, and to investigate the impact of those visualization tools in the course of the relevant learning episodes. Therefore, a delayed post- intervention questionnaire was not conducted in this study, since it is impossible to separate the impact of the use of the visualizations tools from that of the other above-mentioned teaching strategies. Another concern to consider is that watching an animation or equivalent still images is usually quite a short procedure. However, in this study the intervention of viewing the alternative visualization tools was expanded to three class periods (135 min) in each of the two groups, by means of including in it the filling of the two questionnaires, in order to make the learning activity most meaningful.

The lack of establishment of content validity might be also considered as one of the limitations of this study. Therefore it is suggested to replicate and widen the research to include additional animations of biotechnological methods in the future. Still, it is to mention that the results regarding the unique contribution of the animations while studying biotechnological methods were already obtained while studying two interrelated animations, the PCR and the restriction enzyme animation. Another limitiation that should be noted is that the results regarding the teachers' contribution to the enactment of animations in class were obtained using a *qualitative* research approach, using two case studies. Nevertheless, the external validity of these findings could be considered due to the fact that the two exemplary teachers, and their two biotechnology major classes that participated in this study, can be considered as 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 considerable to assume that in the case of less motivated classes the teacher's contribution might be most significant. I suggest that in the future the use of animations will be mediated to the students by their biology/ biotechnology teachers, and teachers' input should be studied in practice using an experimental design and a quantitative approach.

7.5 Educational implications

Through this research I was able to show the unique contribution of animations, and their advantage over still images, for the acquisition of certain kinds of information, namely the mechanistic aspects of biotechnological methods. Those finding could have educational implications in the learning of various scientific disciplines, in which mechanistic understanding and reasoning causality is crucial. In fact the findings regarding the effectivness of animations while studying biotechnological methods could have important educational implications in higher education of scientific disciplines, in which such kind of processes are being taught as well. Concerning the burden of abstract scientific concepts, and the large conceptual frameworks students in higher education are required to comprehend (Yarden, Marbach-Ad & Gershony 2004), it seems that the use of dynamic visualizations such as animations in higher education courses could have an important impact.

It was also showed in this study the unique contribution of animations to certain kinds of learners, namely students with low prior content knowledge. This finding could be important in the case of undeveloped countries' education, where students have low prior content knowledge in the various scientific disciplines; still learning from animations could be applicative for them.

I have also put a spot light in this study on teachers' contribution to the enactment of animations. Those results might have universal implications to enacting animations in class in diverse disciplines, such as helping students comprehend with the cognitive load involved while studying from animations in general. It is important to emphasize at this point that this study was done in the natural setting of classrooms within the context of intensive biology or biotechnology majors' lessons, not an isolated experience, thus adding additional validity to the findings.

Keeping the study's limitations in mind, I believe my findings regarding the effectiveness of animations when visualizing processes can be extended beyond the context of biotechnological methods, to other diverse topics and processes that involve motion and include interactions between different key factors. Such processes might include macroscopic interactions, for instance, from the disciplines of ecology or mechanics, as well as molecular processes, which are not visible in the real world.

There are several aspects of this study, which can be further studied, in order to learn more about students' cognitive processes while studying from animations, as well as the role of the teacher while enacting animations in class. For instance, I have learned though analyzing students' discourse while studying the PCR animation that the students who watched the animation pay more attention to the images that appear in the animation, while the students who watched the equivalent still images pay more attention to the text that accompany the still images. According to the Limited capacity assumption (Baddely, 1998), only a few pieces of information can be actively processed at any point in time in each channel of processing information. It will be interesting to study in terms of brain activity what exactly happens when a student is viewing a picture in an animation, as opposed to viewing the same picture as a still image. We might find out that the common sentence of "one picture worth 1000 words" is true only in the case of using the dynamic ones.

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Appendix 2

מכון ויצמן למדע

המחלקה להוראת המדעים

שם פרטי ומשפחה: ____________________

מין: זכר/ נקבה

בי"ס: __________________

כתה: __________________

<u>**שאלון הכנה לקראת למידת שיטת ה-**PCR</u>

סמן ליד כל משפט אם הוא נכון/ לא נכון. <u>הסבר בכל משפט מדוע החלטת שהמשפט נכון או לא נכון.</u>

1. בתהליך השכפול של מולקולת **DNA** בתא נוצרים מגדיל <u>יחיד</u> של **DNA** שני גדילים <u>יחידים</u>. נכון/ לא נכון.

____

2. הנוקלאוטידים משלימים זה לזה באופן הבא- **A** ל-**G**, **T** ל-**C**. נכון/ לא נכון.

____

3. **DNA** פולימראז הוא אנזים שאחראי על פתיחת הסליל הכפול של מולקולת ה-**DNA**. נכון/ לא נכון.

____

4. בתהליך השכפול של מולקולת **DNA** בתא נפתח הסליל הכפול של ה-**DNA** ולכל גדיל נוצר גדיל <u>**DNA**</u> משלים. נכון/ לא נכון.

____

5. הנוקלאוטידים הם אנזימים שאחראים על שכפול ה-**DNA**. נכון/ לא נכון

____

רשום ב4-5 משפטים כיצד מתרחש תהליך שכפול ה-DNA **בתא.**

____

Appendix 3

המחלקה להוראת המדעים

שם פרטי ומשפחה: ____________________

מין: זכר/ נקבה

בי"ס: ________________

כתה: ________________

שאלון לאחר למידת שיטת ה-PCR

סמן ליד כל משפט אם הוא נכון או לא נכון. <u>הסבר בכל משפט מדוע החלטת שהמשפט נכון או לא נכון.</u>

1. שיטת ה- **PCR** מאפשרת קבלת כמות כפולה (פי 2) של **DNA** במבחנה ביחס לכמות ההתחלתית. נכון/ לא נכון

2. ____

האנזים **DNA** פולימראז מבצע את הפרדת גדילי ה-**DNA** ב-65º צלסיוס. נכון/ לא נכון

3. ____

האנזים **DNA** פולימראז נקשר לתחלים בטמפ' של 95º צלסיוס. נכון/ לא נכון

4. ____

התחלים הם מקטעי **DNA** קצרים המשלימים אחד לשני . נכון/ לא נכון

____

5. ארבעת הנוקלאוטידים: **G**, **C**, **A**, **T** מוספים למבחנה עם תחילת תהליך ה-**PCR** ומשמשים כאנזימים בתהליך. נכון/ לא נכון

____

6. "מצא את ההבדלים"

רשום ליד כל אחד מהמרכיבים הבאים האם הוא דומה או שונה כשמשווים בין שכפול ה-**DNA** <u>בתא</u>, לשכפולו במסגרת <u>שיטת ה-**PCR**</u>. **<u>הסבר ונמק את החלטתך!</u>**

מקום ההתרחשות ____

הטמפרטורה בה מתרחש התהליך ____________________________________

האנזים המשתתף ____

שימוש בנוקלאוטידים ____

שימוש בתחלים ____

התוצר הסופי ____

ענה בפירוט על השאלות הבאות:

7. מדוע חשוב לדעת מראש את רצף הגן על מנת לתכנן שכפול שלו בעזרת שיטת ה- **PCR**?

____

____

____

8. בתהליך ה-**PCR**, כאשר מקררים את המבחנה לטמפרטורה של 45º צלסיוס, נצמדים התחלים לגדילים ולא הגדילים אחד לשני. הצע שני הסברים אפשריים לתופעה זו.

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____

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9. לאחר מחזור אחד של **PCR** מתקבלות ממולקולת **DNA** אחת שתי מולקולות **DNA**.

א. כמה גדילי **DNA** קיימים בשתי מולקולות **DNA**?

ב. כמה מולקולות **DNA** יתקבלו לאחר 5 מחזורים? וכמה גדילים? הסבר כיצד הגעת לתשובתך.

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____

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____

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תודה על שיתוף הפעולה! ☺

Appendix 4

המחלקה להוראת המדעים

שם פרטי ומשפחה: ___________________

מין: זכר/ נקבה

בי"ס: _________________

כתה: _________________

<u>שאלון עמדות</u>

<u>חלק א'</u>

1. האם יש לך מחשב בבית?

א. כן

ב. לא

2. אם כן, האם המחשב מחובר לאינטרנט?

א. כן

ב. לא

3. סמן מהו התיאור הנכון ביותר מבחינתך:

א. יש לי ניסיון רב/ בינוני/ מועט/ אין לי ניסיון כלל בעבודה עם מחשב באופן כללי.

ב. יש לי ניסיון רב/ בינוני/ מועט/ אין לי ניסיון כלל בעבודה עם מעבד תמלילים (**Word**)

ג. .יש לי ניסיון רב/ בינוני/ מועט/ אין לי ניסיון כלל בעבודה עם גליון אלקטרוני (**Excel**)

ד. יש לי ניסיון רב/ בינוני/ מועט/ אין לי ניסיון כלל בבניית מצגות (**Power Point**)

ה. יש לי ניסיון רב/ בינוני/ מועט/ אין לי ניסיון כלל בעבודה עם האינטרנט

ו. יש לי ניסיון רב/ בינוני/ מועט/ אין לי ניסיון כלל בעבודה עם אנימציות.

ז.כשאני לומד בסביבה ממוחשבת, אני מפיק הכי הרבה תועלת ממצגות/ אתרים עם משימות/ אנימציות.

חלק ב'

קרא בעיון כל אחד מההיגדים וסמן מהי מידת הסכמתך עם ההיגד לפי המדרג:

1- לא מסכים בכלל..........4- מסכים לחלוטין.

היגדים	לא מסכים בכלל			מסכים מאוד	הערות
1. אני אוהב ללמוד בסביבה ממוחשבת.	1	2	3	4	
2. אני מעדיף ללמוד נושא חדש עם מורה המלמדת את החומר בכיתה, מאשר ללמוד לבד.	1	2	3	4	
3. אני מעדיף ללמוד עם מורה המלמדת את החומר בכיתה, מאשר ללמוד לבד באמצעות סביבה ממוחשבת.	1	2	3	4	
4. אני מעדיף ללמוד לבד באמצעות סביבה ממוחשבת, מאשר ללמוד לבד באמצעות ספר.	1	2	3	4	
5. אני מעדיף לראות הדגמה של תהליך בסרט וידאו לעומת הדגמה במחשב.	1	2	3	4	
6. אני מעדיף ללמוד תהליך כלשהוא באמצעות איור בספר (למשל - תרשים זרימה), מאשר באמצעות המחשה במחשב (למשל- אנימציה).	1	2	3	4	
7. כשאני לומד תהליך חדש אני מעדיף להיעזר באיור בספר <u>ובנוסף</u> בהמחשה במחשב.	1	2	3	4	
8. אנימציות במחשב עוזרות לי להבין דברים.	1	2	3	4	
9. אני מעדיף ללמוד לבד בסביבה ממוחשבת מאשר בזוג.	1	2	3	4	
10. כשאני לומד נושא חדש אני מעדיף ללמוד אותו עם המורה בכיתה <u>ובנוסף</u> להיעזר בסביבת למידה ממוחשבת	1	2	3	4	
11. אנימציות במחשב מבלבלות אותי.	1	2	3	4	
12.אני אוהב ללמוד בזוגות/ בקבוצה	1	2	3	4	
13. למידה בסביבה ממוחשבת מתאימה למי שאוהב ללמוד לבד.	1	2	3	4	
14. למידה בסביבה ממחושבת מתאימה רק לתלמידים שמבינים במחשבים.	1	2	3	4	

היגדים	לא מסכים בכלל			מסכים מאוד	הערות
15. משעמם אותי ללמוד לבד.	1	2	3	4	

תודה על שיתוף הפעולה! ☺

Appendix 5

מכון ויצמן למדע

המחלקה להוראת המדעים

שם פרטי ומשפחה: ___________________

מין: זכר/ נקבה

בי"ס: _________________

כתה: _________________

תלמיד/ה יקר/ה,

נודה לך אם תמלא בתשומת לב ומחשבה את שאלון המשוב הבא. דעתך חשובה לנו מאוד לצורך המשך פיתוח אנימציות בעתיד.

אנא קרא בעיון כל אחד מההיגדים וסמן מהי מידת הסכמתך עם ההיגד לפי המדרג:

1- לא מסכים בכלל..........4- מסכים לחלוטין.

היגדים	לא מסכים בכלל			מסכים מאוד	הערות
1. העבודה עם האנימציה גרמה לי להבין בצורה ברורה את שיטת ה-**PCR**.	1	2	3	4	
2. המשימות שנלוו לאנימציה עזרו לי במיוחד ללמוד ממנה.	1	2	3	4	
3. העדפתי לצפות בהתחלה באנימציה בגרסת "שלב אחר שלב", כשרק התחלתי ללמוד על שיטת ה-**PCR**.	1	2	3	4	
4. העובדה שהאנימציה הופיעה בליווי הסבר כתוב עזרה לי להבין טוב יותר את שיטת ה-**PCR**.	1	2	3	4	
5. המשימות שמלוות את האנימציה מיותרות ואינן תורמות להבנה טובה יותר של שיטת ה-**PCR** .	1	2	3	4	
6. בגרסת "שלב אחר שלב", הייתי מעדיף שההסבר הכתוב ואנימציה יופיעו ביחד ולא כמו שקיים כרגע, שקודם מופיע ההסבר ורק אח"כ האנימציה.	1	2	3	4	
7. העבודה עם האנימציה בלבלה אותי והתקשייתי להבין את שיטת ה-**PCR**.	1	2	3	4	
8.העדפתי קודם לצפות בגרסה הרצופה של האנימציה, ורק אח"כ לצפות ב"שלב אחר שלב"	1	2	3	4	

היגדים	לא מסכים בכלל			מסכים מאוד	הערות
לצורך לימוד מפורט.					
9. בגרסת "שלב אחר שלב" עזר לי שקודם הופיע ההסבר ורק אח"כ, כשסיימתי לקרוא, לחצתי ואז הופיעה האנימציה.	1	2	3	4	
10. הייתי מעדיף לאחר צפייה בקטע קצר מהאנימציה כבר לבצע משימות, אח"כ להמשיך לצפות באנימציה, שוב משימות וחוזר חלילה.	1	2	3	4	
11. הגרסה הרצופה טובה לסיכום וחזרה של הנושא, לאחר שכבר הבנתי אותו באמצעות גרסת "שלב אחר שלב".	1	2	3	4	
12. הייתי רוצה שיהיו יותר משימות שבהן עובדים עם פריטים מהאנימציה עצמה- מסדרים תמונות, גוררים וכו'.	1	2	3	4	
13. היה לי קשה להתרכז בסרטון האנימציה בגלל ההסבר הכתוב שהופיע לידו.	1	2	3	4	
14. אני מעדיף ללמוד מאנימציה שבה אני גורם לדברים לקרות, ע"י לחיצה במקומות שונים במסך, גרירת פריטים וכו'.	1	2	3	4	
15. העובדה שבתוך ההסברים הכתובים היו ציורים מהאנימציה (צורתו של האנזים, נוקלאוטיד וכו'), עזרה לי להבין טוב יותר מה אני רואה באנימציה.	1	2	3	4	
16.הייתי מעדיף שיהיו יותר משימות שבודקות הבנה של השיטה עצמה (ע"י שאלות, נכון/ לא נכון וכו'), ופחות משימות שבודקות הבנה של האנימציה (למשל סידור תמונות מהאנימציה וכו')	1	2	3	4	
17.עזר לי לעבוד בזוג כשלמדנו מהאנימציה.	1	2	3	4	
18. אני מעדיף להנות מאנימציה בתור צופה ולא להיות זה ש"מפעיל" אותה.	1	2	3	4	
19. האנימציה של שיטת ה- **PCR** המחישה לי	1	2	3	4	

היגדים	לא מסכים בכלל			מסכים מאוד	הערות
דברים כלליים כמו איך בדיוק משתכפל ה-**DNA**.					
20. אני חושב שאם הייתי עובד לבד עם האנימציה הייתי מפיק ממנה הרבה יותר תועלת.	1	2	3	4	

נשמח לשמוע את הערותיך באופן כללי על הפעילות ועל האנימציות:

Appendix 6

Supporting learning biotechnological methods using interactive and task oriented animations

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Theoretical background

Animations were previously shown to promote understanding and improve learning (Sanger, Brecheisen and Hynek 2001; Mayer and Moreno 2002; Stith 2004; Stromme and Jorde 2005). Recently, the possible contribution of instructional aids or tasks, which are integrated into the animations, was investigated (Kramer, Prechtl and Bayrhuber 2004; Lowe 2004). Those instructional aids were developed to support simultaneous learning of text and pictures, as commonly appear in animations, since simultaneous appearance of text and pictures tends to impose a cognitive load on learners (Mayer and Moreno 2002). Another difficulty that is taken into consideration is whether students' comprehension processes can keep up with the rapidly changing stimuli shown in dynamic displays. It seems that better support for learning occurs when learners can speed up or slow down the display to match their personal rate of comprehension (Hegarty 2004).

Key objectives and Research questions

We attempt to characterize the conditions under which animations are effective in promoting comprehension of biotechnological methods, that are part of adapted primary literature used for learning biology in high schools in Israel (Yarden, Brill and Falk 2001). Since most students usually have no opportunity to experience hands-on the methods described in the Methods section of the adapted research articles, we attempt to use animations as visualization tools in order to support learning.

Here we focus on the following research questions:

1. **What are high-school biology students' experiences, preferences and attitudes towards working in computerized learning environments?**
2. **Is there a correlation between students' prior content knowledge and their understanding of the method being learned using the interventions?**
3. **Which visualization tool (cards, animation or task included animation) is more effective in promoting learning of the biotechnological method?**
4. **What are students' preferences with regards to the interactivity of the animation?**

Methods

The animation

Here we describes the use of an animation we developed in order to visualize the PCR (Polymerase Chain Reaction) method. The animation introduces sequentially the main steps of the PCR method in two alternative versions: a continuous version, which shows the whole procedure continuously and a sequential version, which shows the procedure gradually, or "step by step". An additional version of this animation includes three computerized interactive tasks. Those tasks are aimed to identify students' attention to key issues of the PCR technique, as well as to their understanding of the symbols and images which appear in the animation.

The sample and the research tools

Fifty seven 12th grade high-school biology majors participated in this phase of the study. All the students were from three parallel classes of the same school, and each class was exposed to different visualization tool. At the beginning of the lessons the students in all three classes were asked to answer a written questionnaire. In this questionnaire the students were asked to respond to true/false sentences and answer open questions which were designed to examine their prior content knowledge in topics which are relevant for understanding the PCR technique (e.g. DNA replication). Subsequently, a 4 point Likert-type scale (4 = strongly agree and 1 = strongly disagree) was used to probe students' experiences and attitudes towards learning in computerized learning environments. Once filling the first questionnaires, the students in one class got cards with still images taken directly from the animation and were asked to read the text and watch the still images in order to learn about the PCR technique. The students in the second class watched the PCR animation while the students in the third class watched the animation's version which is accompanied with tasks. Subsequently, the students in all three classes answered a second questionnaire which examined their understanding of the PCR method. The students who used the animations (second & third groups) also answered a Likert-type scale feedback questionnaire about the animation. It should be emphasized that all the students learned about the PCR method for the first time through these activities and their teacher did not discuss this method in advance. During learning with the various alternative visualization tools the students worked in couples and their work was audio-taped. Transcripts were prepared and qualitatively analyzed.

Results

Students' experiences and attitudes towards working in computerized learning environments

Students' previous exposures and experiences with common computer's programs in general, and with animations in particular, were initially examined. Their preferences while learning using computerized learning environments, as opposed to learning from a teacher or textbooks, was also examined. Analysis of the relevant section in the first questionnaires revealed that all of the students in our sample have computers with an access to the Internet at home. Most of the students reported they are familiar with common computer programs, i.e. Word, Excel and Power Point. On the other hand, about 50% of them have no or relatively minor experience with animations. Still, when the students were asked to state their preference for informative presentations, versus computerized tasks or animations, most of them reported to prefer computerized tasks and animations as the most effective learning tools.

Most of students reported they prefer learning with the teacher than learning by themselves or by computerized learning environments. When they do not have the opportunity to learn with their teacher, the students reported they prefer learning using computerized learning environment than learning alone using textbooks. Moreover, the students stated that they prefer learning new processes using computer visualizations rather than visualizations that appear in textbooks. The students also stated they prefer learning in couples than alone.

Students' performances in the questionnaires

Table 1: Mean scores of treatments with alternative visualization tools.

The 1st and 2nd	Mean scores of the alternative groups	

questionnaires	The cards' group (N=19)	The animation's group (N=25)	The task oriented animation's group (N=13)	
Prior content knowledge (1st)	**78.42 (16.07)**	**58.00 (21.4)**	**71.53 (19.51)**	**P< 0.0034**
Understanding of the PCR method (2nd)	**80.45 (14.45)**	**80.85 (19.53)**	**84.06 (14.33)**	
Question No. 7 in the 2nd questionnaire (analytic level)	**47.37**	**80.00**	**92.31**	**P<0.0088**

Analysis of the first and second questionnaires revealed a significant difference between the groups in terms of the prior content knowledge. The mean score of the Animation's group prior content knowledge was significantly lower compared to the other two groups (Table 1). However, the mean scores of the three groups in the second questionnaire, which checked students' understanding of the PCR technique; showed no significant differences between the three groups. In addition, no correlation was found between students' prior content knowledge and their understanding of the PCR method, using each of the visualization tools.

Even though there was no significant difference between the mean scores in the second questionnaires, a significant difference was identified in a particular question, in favor of the animation and the task oriented animation groups. This specific question (No.7) was classified as an analytical question, demanding a higher cognitive level, while the true/ false sentences, in which no difference between the groups were identified, was classified into the knowledge level.

Students' preferences with regards to central features of the animations

One of the most interesting things we learned from students' respondents to the feedback questionnaire (4 point Likert-type scale, 4 = strongly agree and 1 = strongly disagree) was that there was a significant difference between the animation group mean score and the task oriented group mean score in the responses to the statement "Using the animation enables me to understand clearly the PCR method" (2.88 (0.72) and 3.53 (0.66), respectively). The students in both groups found the "step by step" version of the animation more effective than the continuous version, when using it at the initial stages of learning the PCR method. However, the students stated that the continuous version can serve as a summary tool, following learning the PCR technique. The students also stated that the text and the accompanied tasks are important and helpful.

Discussion

Here we focused on comparing learning using three alternative visualization tools: cards with still images, animations and task oriented animations of a biotechnological method. We found that all three visualizations tools were useful for learning about the PCR method, and even though some students (in the Animation's group) lacked relevant prior knowledge, they were able to use the animation, learn from it and close the gap in their knowledge. In an analytical type question, of a higher cognitive level, we could identify a significant

difference in favour of the animation and the task oriented animations. We believe that by enlarging our sample and continue studying the role of the interactivity and the effectiveness of the tasks on students' comprehension, we might be able to determine terms under which the use of animations is valuable in promoting learning.

Reference

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Kramer, B., Prechtl, H., et al. (2004). Using micro-tasks to foster the understanding of signal transduction in a multimedia learning environment. V[th] **meeting of the European Researchers in the Didactic of Biology (ERIDOB) meeting, Patras, Greece.**

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Sanger, M. J., Brecheisen, D. M., et al. (2001). "Can computer animations affect college biology students' conceptions about diffusion & osmosis?" The American Biology Teacher 63**(2): 104-109.**

Stith, B. J. (2004). "Use of animation in teaching cell biology." Cell Biology Education 3**: 181-188.**

Stromme, T. A. and Jorde, D. (2005). The effect of animations on learning in science. A comparative classroom study of Gene technology using Viten.no. ESERA, Barcelona, Spain.

Yarden, A., Brill, G., and Falk, H. (2001). "Primary literature as a basis for a high-school biology curriculum." Journal of Biological Education 35**: 190-195.**

Appendix 7

Supporting learning biotechnological methods using interactive and task included animations

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Abstract

The conditions and the components of animations, under which they are most effective in promoting comprehension of biotechnological methods, are characterized in the course of this study. Here we describe the use of an animation we developed in order to visualize the main steps of the Polymerase Chain Reaction (PCR) method. The animation was developed in two alternative versions: a continuous version, and a sequential and interactive version ("step by step"). The animation is accompanied by three computerized tasks, aimed to identify students' attention to key issues in the PCR method, and to the symbols which appear in the animation. One hundred and twenty three 12th grade biology majors were divided into three groups and were exposed to three different treatments: cards with still images, animation and task included animation. The results indicate that all the three visualizations tools were useful for learning the PCR method, despite a significant difference which was identified between the groups in terms of the prior content knowledge. From observing students' work with the animations we learnt that even though the students were not told to view the animation in any specific order, most of them watched first the interactive version ("step by step").

Theoretical background

Animations were previously shown to promote understanding and improve learning (Sanger, Brecheisen and Hynek 2001; Mayer and Moreno 2002; Stith 2004; Stromme and Jorde 2005). Recently, the possible contribution of instructional aids or tasks, which are integrated into the animations, was investigated (Kramer, Prechtl and Bayrhuber 2004; Lowe 2004). Those instructional aids were developed to support simultaneous learning of text and pictures, as commonly appear in animations, since simultaneous appearance of text and pictures tends to impose a cognitive load on learners (Mayer and Moreno 2002). Another difficulty that is taken into consideration is whether students' comprehension processes can keep up with the rapidly changing stimuli shown in dynamic displays. It seems that better support for learning occurs when learners can speed up or slow down the display to match their personal rate of comprehension (Hegarty 2004).

Key objectives and Research questions

We attempt to characterize the conditions and the components of animations, under which they are most effective in promoting comprehension of biotechnological methods, that are part of adapted primary literature unit in biotechnology, used for learning advanced biology in high schools in Israel (Yarden, Brill and Falk 2001), as well as in an obligatory unit in genetic engineering for biotechnology majors (Israeli Ministry of Education 2005). Since most students usually have no opportunity to experience hands-on biotechnological methods, we attempt to use animations as visualization tools in order to support learning.

Here we focus on the following research questions:

5. **What are high-school biology students' experiences, preferences and attitudes towards working in computerized learning environments?**

6. **Is there a correlation between students' prior content knowledge and their understanding of the method being learned using the interventions?**
7. **Which visualization tool (cards, animation or task included animation) is more effective in promoting learning of the biotechnological method?**
8. **What are students' preferences with regards to the interactivity of the animation?**

Methods

The animation

Here we describe the use of an animation we developed in order to visualize the main steps of the Polymerase Chain Reaction (PCR) method. The animation was developed in two alternative versions: a continuous version, which shows the whole procedure continuously, and a sequential version, which shows the procedure gradually, or "step by step". Those two versions are accompanied by three computerized tasks. The tasks are aimed to identify students' attention to key issues in the PCR method, as well as to the understanding of the symbols and images which appear in the animation.

The sample and the research tools

One hundred and twenty three 12th grade high-school biology majors participated in this phase of the study. All the students were from seven parallel classes; they were divided into three groups and were exposed to three different visualization tools. At the beginning of the lesson the students in all three groups were asked to answer a written questionnaire. In this questionnaire the students were asked to respond to true/false sentences and to answer open questions which were designed to examine their prior content knowledge in topics which are relevant for understanding the PCR technique (e.g. DNA replication). Subsequently, a 4 point Likert-type scale (4 = strongly agree and 1 = strongly disagree) was used to probe students' experiences and attitudes towards learning using computerized learning environments. Once filling the first questionnaires, the students in one group (N=33) received cards with still images taken directly from the animation and were asked to read the text and watch the still images in order to learn about the PCR method. The students in the second group (N=38) watched the PCR animation, using the continuous and the "step by step" versions. The students in the third group (N=52) watched also the two versions of the PCR animation, only this time the animations were accompanied with the computerized tasks. Subsequently, the students in all three interventions answered a second questionnaire which examined their understanding of the PCR method. The students who used the animation (second & third groups, N=90) also answered a Likert-type scale feedback questionnaire about the animation. It should be emphasized that all the students learned about the PCR method for the first time through these activities and their teacher did not discuss this method in advance. During learning with the various alternative visualization tools the students worked in couples. The work of 12 selected couples (24 students) who worked with the animation was audio-taped, and then transcripts were prepared and qualitatively analyzed.

Results

Students' experiences and attitudes towards working in computerized learning environments

Students' previous exposures and experiences with common computer programs in general, and with animations in particular, were initially examined. Their preferences while learning using computerized learning environments, as opposed to learning from a teacher or textbooks, were also examined. Analysis of the relevant section in the first questionnaires revealed that all of the students in our sample have computers with an access to the Internet at home. Most of the students reported they are familiar with common computer programs, i.e. Word, Excel and Power Point. On the other hand, about 50% of them have no or relatively minor experience with animations. Still, when the students were asked to state their preference for informative presentations, versus computerized tasks or animations, most of them reported to prefer computerized tasks and animations as the most effective learning tools.

Most of students reported they prefer learning with the teacher than learning by themselves or by computerized learning environments. When they do not have the opportunity to learn with their teacher, the students reported they prefer learning using computerized learning environment than learning alone using textbooks. Moreover, the students stated that they prefer learning new processes using computer visualizations rather than visualizations that appear in textbooks. The students also stated they prefer learning in couples than alone.

Students' performances in the questionnaires

Analysis of the first and second questionnaires revealed a significant difference ($p<0.05$) between the groups in terms of the prior content knowledge (see Figure 1). The mean scores of the Animation and the Task groups' prior content knowledge were significantly lower in comparison to the Card group .However, in the second questionnaire, which checked students' understanding of the PCR method, no significant differences were found between the mean scores of the three groups.

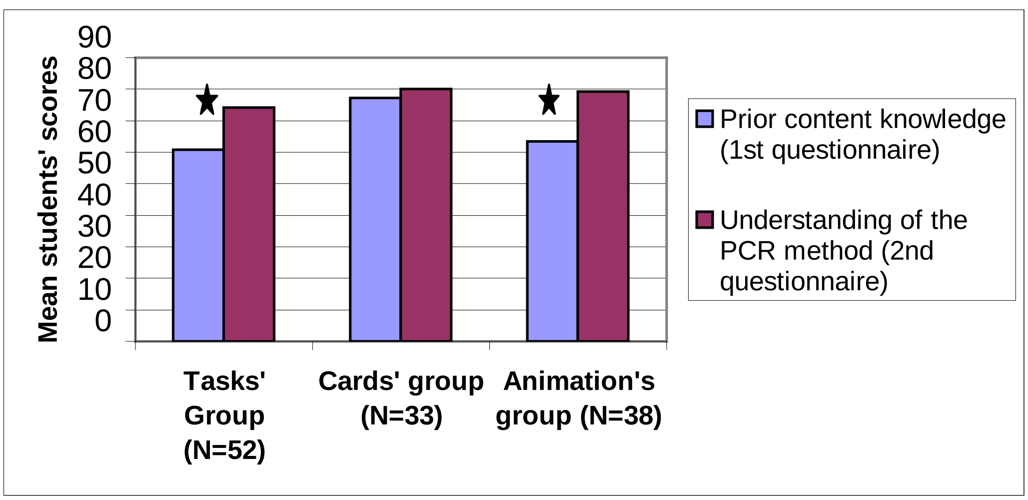

Figure 1: A comparison between mean students' scores, prior and following treatment with various visualization tools.

Students' preferences with regards to central features of the animations

From analyzing students' conversations (N=12) while learning the PCR method using the animation as well as analyzing the feedback questionnaires (N=90), we learnt that the

students in both groups (the Animation's and the Tasks' groups) found the "step by step" version of the animation more effective than the continuous version, when using it at the initial stages of learning the PCR method. However, the students stated that the continuous version can serve as a summary tool, following learning the PCR technique. The students also stated that the text and the accompanied computerized tasks are important and helpful.

Discussion

Here we focused on comparing learning the PCR method using three alternative visualization tools: cards with still images, animation and task included animation. We also learnt about the use of interactive animation (the "step by step" version), versus the non-interactive animation (the continuous version). We found that all three visualizations tools were useful for learning about the PCR method. However, we found that students from the Animation's and the Tasks' groups, who their prior knowledge was significantly lower than that of students' from the cards' group ,were able to use the animation, learn from it and close the gap in their knowledge. From observing students' work with the animations and analyzing the transcripts we learnt that even though the students were not told to view the animation in any specific order, most of them watched first the "step by step" version in order to learn effectively the PCR method. We believe that by studying the effectiveness of the animation's interactivity in a comparative research design, as well as studying the impact of different kinds of tasks included in the animation on students' comprehension, we might be able to determine distinct terms under which the use of animations is most valuable in promoting learning.

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Stromme, T. A. and Jorde, D. (2005). <u>The effect of animations on learning in science. A comparative classroom study of gene technology using Viten.no.</u> Paper presented at the European Science Education Research Association (ESERA) meeting, Barcelona, Spain.

Yarden, A., Brill, G. and Falk, H. (2001). "Primary literature as a basis for a high-school biology curriculum." <u>Journal of Biological Education</u> 35: 190-195.

Appendix 8

Learning a biotechnological method using dynamic and static visualizations: Students' comprehension and conceptual status.

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Abstract The unique contribution of animation in promoting conceptual learning of a biotechnological method, among 12th grade high-school biology majors, is explored in this study. All the students learned about the Polymerase Chain Reaction (PCR) using still images (n=83) or animation (n=90). A significant advantage to the animation treatment was identified following learning. In addition, through analyzing students' discourse in the framework of the conceptual status analysis, we observed that students who learned about PCR using still images faced difficulties in understanding some mechanistic aspects of the PCR.

Key words: Animations, Biotechnology education, Conceptual status, Prior knowledge.

Introduction

The importance of biotechnology education has been recognized in a number of international curriculum frameworks around the world (Conner 2000; Solomon 2001; Israeli Ministry of Education 2003; Steele and Aubusson 2004; Israeli Ministry of Education 2005). Still, less was published about how to teach this topic effectively. Steele and Aubusson (2004) suggested two main obstacles in the teaching of biotechnology: the level of difficulty of this subject matter, and the lack of practical laboratory work that suits the biotechnological content. Falk, Brill and Yarden (2008) reported that one of the most problematic issues in learning biotechnology at the high-school level is comprehending the methods. Accordingly, there is a strong necessity in demonstrating in a more concrete and accessible means the course of action of such biotechnological methods.

Animations are holding a great potential for improving the way people learn (Mayer and Moreno 2002). One of the most unique advantages of animations is that it can provide a virtual alternative to practical work, that would be dangerous, costly, or otherwise not feasible in a school laboratory (Hennessy, Deaney and Ruthven 2006). While the use of animations may be a relatively new technology, the addition of images to text has a much longer history. Many studies which aimed to compare between instructional animations versus static pictures, and their impact on learning outcomes, sometimes yielded contradictory results (Tversky and Morrison 2002; Hoffler and Leutner 2007). Individual differences, such as prior knowledge, can influence whether static pictures or animations within a specific domain are superior (ChanLin 2001). Williamson and Abraham (1995) favour the use of animations because they provide learners a ‘ready-made’ explicit dynamic representation, which can compensate students' little or no knowledge of the domain.

In this study we explored the use of an animation we developed in order to promote high-school biology students' comprehension of PCR, a biotechnological method which allows replicating multiple copies of a specific DNA fragment in a test-tube. We embraced the perspective of conceptual learning as a framework to evaluate the learning process of PCR (Posner, Strike, Hewson and Gertzog 1982). Hewson and Lemberger (2000) claimed that conceptual status, an idea built on the conceptual change foundation, can illuminate deep conceptual learning, whether or not it involves conceptual change. Very few studies who have analyzed students' comprehension of molecular genetics, using the conceptual status technique, reported that it enables them identifying deep conceptual learning (Hewson and Lemberger 2000; Tsui and Treagust 2007).

Research questions

Herein we focus on the following research questions:
1. Is there a difference in the comprehension of PCR between students who learned using animation and those who learned using still images?
2. What are the relationships between students' prior content knowledge and their comprehension of PCR, using animation or still images?
3. What is the difference between students who learned using animation to those who learned using still images in their conceptual status of PCR?

Methodology

Research design

One hundred and seventy three 12th grade biology majors participated in this study. At the beginning of the activity the students answered a written prior content knowledge questionnaire. Subsequently 83 students received cards with still images taken directly from the PCR animation ("Still images"), and 90 students watched the PCR animation ("Animation"). The animation group was originally divided into two sub-groups; both watched the PCR animation, only in one of the groups the animation was accompanied with 3 computerized tasks. Since no differences were found between the sub-groups, they were united into one group. During learning the students worked in couples and their conversations were audio-taped. Following learning, the students answered a second questionnaire, which examined their understanding of PCR.

Students' discourse analysis

Eight transcripts from the animation and the still images groups were qualitatively analyzed based on the conceptual status framework. Each transcript was divided into content episodes. In order to illustrate the inclusion or exclusion of a status element, it was indicated with a "+" or a "-" sign, respectively. For reliability verification those transcripts were also analyzed by another researcher, with an agreement of 95% between the two researchers.

Results

Comprehension of PCR using the various visualization tools

In order to learn about the possible differences in comprehending PCR while learning using still images or animation, a t-test was used. No significant differences were found between the groups in terms of the students' prior content knowledge (Figure 1). However, a significant advantage to the animation group was identified in the post-questionnaires (Figure 1).

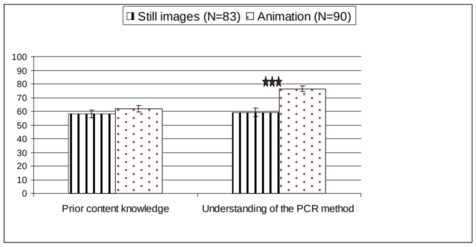

Figure 1: Comparison between students' mean scores in prior content knowledge and understanding of the PCR method following learning using different visualization tools. The significant differences are marked by *** ($p<0.001$).

The relationships between students' prior content knowledge and their comprehension of PCR

In order to learn about a possible correlation between students' prior content knowledge and students' understanding of PCR, a regression analysis was performed. A relatively high correlation was found between students' prior knowledge and their understanding of PCR while learning using still images ($R^2 = 0.412$). In contrast, the level of students' prior content knowledge seems to have no noteworthy effect on their understanding of PCR while learning using animation (Figure 2).

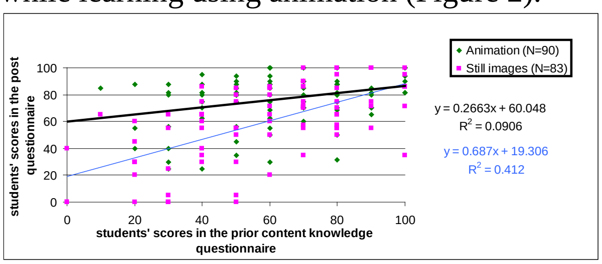

Figure 2: A regression of students' scores in the prior content knowledge questionnaire, with their scores in the post questionnaire, in each of the two alternative groups.

Students' conceptual status

Differences in students' conceptual status, while learning about PCR using animation or still images, were mostly observed in content episodes which dealt with the mechanistic aspects of PCR. In those episodes we discovered that in conversations of students who learned about PCR using still images the status elements of metaphysics and real mechanism were generally excluded. Accordingly, it seems that those students were facing a difficulty in understanding the ontological **function of the different molecules**

involved in PCR (metaphysics), and in which causal mechanism they are involved (real mechanism). For example:
1: I did not understand what DNA polymerase is doing (-metaphysics)
2: It is written [in the text].
1: I did not understand what DNA polymerase is doing (-metaphysics), I mean, do they [the primers] stick by themselves?
2: Here, [reading the text] "The DNA polymerase is synthesizing a new DNA strand"
1: What does it mean? They [the primers] are already attached, so what does it [the DNA polymerase] do? (-metaphysics)
2: Maybe it [the DNA polymerase] is connecting between them [the primers], I don't know…
(-real mechanism).

In contrast, in conversations of students who learned about PCR using the animation, the metaphysics and real mechanism status elements were identified. For example:
1: Does it [the DNA polymerase] separate them [the DNA strands]? [As written in a true/ false statement in the post-questionnaire]?
2: No, it does not (+real mechanism). It does the replication (+metaphysics). Here, [watching the animation], now they [the DNA strands] are separating, you see, it [the DNA polymerase] doesn't do the separation; it makes a new DNA (+ metaphysics).
1: Does it do it at 95^0C [as written in a true/ false statement in the post questionnaire]?
2: No, it does it at 65^0C (+real mechanism).

Discussion

Our research is aimed to study the contribution of an animation about PCR to conceptual learning of the biotechnological method. The use of the PCR animation as a visualization tool was shown here to provide an advantage to the students who used it, as opposed to those who used still images. In addition, students' prior content knowledge was found as an indispensable factor to students who learned about PCR using still images, while to students who learned PCR using animation it did not serve as an obstacle. According to Salomon (1979), the dynamic display of a process by animation can compensate for a student’s insufficient knowledge in imagining some relevant motions.

Through analyzing students' discourse, in the framework of the conceptual status analysis, we identified recurrent inclusions of the status elements metaphysics and real mechanism in conversations of students who learned about PCR using animation. According to Hung and Jonassen (2006), the ability to understand the essential parts, and cause–effect relationships which exist within a system, are the two most important roots for conceptual learning. Since those aspects were repeatedly reflected in conversations of students who learned about PCR using animation, and were absent from conversations of students who learned using still images, we can articulate that the use of the animation did enable the students achieve conceptual understanding of PCR.

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Appendix 10

Teachers' contribution to the enactment of animations in class while studying biotechnological methods

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Abstract

Animations have a great potential for improving the way people learn. A number of studies related to different scientific disciplines have shown that instruction involving computer animations can facilitate the understanding of processes at the molecular level. However, using animations alone does not ensure learning. Students sometimes miss essential features when they watch animations alone, mainly due to the cognitive load involved. In addition, 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 the contribution of the teacher to the enactment of animations in class. Two exemplary biotechnology teachers participated in two case studies, aimed to characterize teachers' contribution to the enactment of animations in class while studying biotechnological methods. Our findings reveal that teachers' contribution is pronounced in the following three aspects: establishing the "hands on" point of view, helping students deal with the cognitive load that accompany the use of animations and implementing constructivist aspects of knowledge construction while studying using animations. We have also recognized two alternative approaches of teachers in terms of supporting students' knowledge construction while studying from animations.

Key words: Animations, Biotechnology education, cognitive load, constructivist teaching,
הוראה בסביבות ממוחשבות

Introduction

Animations have a great potential for improving the way people learn (Mayer and Moreno 2002; Hoffler and Leutner 2007). A number of studies related to different scientific disciplines have shown that instruction involving computer animations can facilitate the understanding of processes at the molecular level (Williamson and Abraham 1995; Sanger, Brecheisen and Hynek 2001; Stith 2004; Yarden and Yarden 2009). However, using animations alone does not ensure learning. It is occasionally linked with simplified models of the scientific process, that can give students the impression that every variable is easily controlled (Hennessy, Deaney and Ruthven 2006). According to Kelly & Jones (2007), students sometimes miss essential features when they watch animations alone, due to the cognitive load involved (Hegarty 2004). In addition, students seem to attribute a great deal of authority to the computer and may develop misconceptions by taking animations of abstract concepts too literally (Wellington 2004). In order for students to learn new concepts and processes they encounter in animations in a meaningful way, according to constructivism (Ausubel 1963) they should relate the new knowledge and information they come across with concepts and claims they already hold. For that purpose, we believe that the way in which a teacher enacts the animation in class plays a crucial role. In this study we attempted to study the contribution of the teacher to the enactment of animations in class, while studying biotechnological methods.

Methodology

Context

In this study we used two animations we previously developed for the use of high school biotechnology majors. Those animations are aimed to introduce the following biotechnological methods: gene cloning and the construction and use of genomic DNA library (http://stwww.weizmann.ac.il/g-bio/geneengine/animations.html). The animations include interactive features and accompanied by computerized tasks.

Sample

Two exemplary biotechnology teachers participated in two case studies, aimed to explore teachers' contribution to the enactment of animations in class while studying biotechnological methods. Two biotechnology major classes (culturally non-deprived population, each class about 25 students) were chosen according to their teachers' initiative and motivation to take part in this study, as well as due to their extensive teaching experience (more than ten years). Both teachers, Ravit and Dora (pseudo names), possess previous formal knowledge in molecular biology and laboratory research.

Procedure

During the lessons being documented, in Ravit's class the animations were viewed simultaneously by all of the students, through the guidance of Ravit. In Dora's class

however, in one lesson the students worked in pairs, while in the other lesson the animations were viewed simultaneously by all of the students, through the guidance of Dora. In both cases, the lessons were based on the animations being used, and both teachers employed specific strategies developed before-hand for using the animations.

Data analysis

The enactments of the animations, in two exemplary biotechnology majors' classes, were audio - taped and fully transcribed. The transcripts were qualitatively analyzed according to the narrative constructivist procedure recommended for multiple-case analysis (Shkedi 2005). Following mapped and focused categorizations, the two teachers were interviewed. In the interviews the teachers were asked to explain representative episodes of the class observations transcripts, illustrating the main categories resulting from the focused categorization. Teachers' interviews were audio - taped and fully transcribed.

Results

The analysis revealed that 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 accompany the use of animations and implementing constructivist aspects of knowledge construction while studying using animations.

Establishing the "hands on" point of view

Both Ravit and Dora emphasized how the biotechnological methods, which were introduced in the animations, are carried out in practice in the lab. In her interview, Ravit explained why it is important to discuss with the students the rationale behind different stages of a biotechnological method, being demonstrated in the animation. She believes the students should understand what is the rationale behind each step they see in the animation, and how it is really done in the lab: "In the animation that demonstrates the creation of a DNA library the stage of blotting is being demonstrated, but the rationale, why it has to be done like that, using a filter, can not be fully described. We want to demonstrate the biotechnological methods dynamically to the students, and we also 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 establishing the "hands on" point of view was by discussing with the students and bringing up to their awareness the existence of some steps that were skipped

from the animation, still important while performing the relevant biotechnological method in the lab. In the next example from classroom observation, Dora is discussing with her students the rationale of a step that is not present in the cloning animation they watch:

Dora: Tell me, what we should do to the bacteria in the lab in order to get an effective transformation?

Student1: We should heat them

Student2: We should heat them more and more

Dora: And in that way we'll create more temporal holes in the cell wall as well as in the membrane, which enables us the transformation with plasmids.

Afterward in her interview, Dora is stating that without the discussion on the steps of the biotechnological method and their rationale, the students might learn incompletely the biotechnological methods as they are being demonstrated in the animations: "Those steps are missing in the animation but it is not terrible at all because we discuss them together. Even if the animations had included all steps, still the students might not think why there is a need to perform each step".

Helping the students deal with the cognitive load

Both Ravit and Dora tend to guide their students while watching the animations. They focused their students' attention on important details in the animation, and kept asking the students different questions about objects in the animation. 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 antibiotics 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 more?

Student: An origin replication site.

In her interview, Ravit explained that by guiding students through watching animations she is making the animation more comprehensible for her students: "look, I could seat, read a book, and let them watch the animation alone till it ends. I believe that in that way they will

lose some important points because they have not noticed them through all the details and changes in the animation".

The importance of identifying exactly what is shown in the animation seems to direct Dora as well. In her interview, Dora summarized the kind of support she believes is essential while watching: "Focus is the key word in order to cope with the load while watching animations. For example, the students could have looked over and over again on the different kinds of bacteria in the animation, but they really need my help to focus on each of the plasmids inside the bacteria, and on its unique elements."

Besides the dynamic changes and the intrinsic 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), that is abstract and complex. According to Ravit, especially in animations of this topic, carefulness is needed during watching 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, in a first look everything looks the same. The student may notice the difference, or not. This small difference between molecules can make a huge difference in understanding".

Implementing constructivist aspects of knowledge construction

Both Ravit and Dora implemented elements of constructivist teaching while they used animations in class. They both considered the activity with the animation as important in the construction of students' knowledge and understanding of the biotechnological methods. For that purpose, one of the things that were done by Ravit was to establish clearly the activity with the animation on students' prior knowledge:

Ravit: Let's see in the animation how to create a recombinant plasmid, but before that, can someone please tell us how it is done? How we link a gene, a fragment of DNA into a plasmid?

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

Dora: Nofar [a student] is asking an interesting question regarding the animation: 'How can we tell who the insert in the end of the cloning is?' Since we cloned here two plasmids, we really can not tell which the insert is and which the recombinant plasmid is.

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 in a plasmid. In that case the insert is the fragment from the virus and the plasmid has received it.

In her the interview, Ravit is stressing why she believes it is so important to link the activity with the animation to the other learning activities the students are exposed to: "It is most important to link the activity with the animation to the tour, to experiences we 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 I work with the animation, I keep going back to what I have already taught in other occasions. The student is curious, if he does not understand something from the animation he can go back to other learning experiences he had."

While the constructivist aspects being introduced so far were common to both Ravit and Dora, 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 studying using animations. In her interview, Ravit explained why, for instance, the conceptualization of processes the students had just watched in the animation is so important: "The students are watching a process in the animation but they must know the name of it, the concept behind what is being demonstrated in the animation. For example, you can not study the process of taking a gene and inserting it into bacteria without the concept transformation, and without the concept that the bacteria who received the gene is a transformant".

While Ravit bases her supporting efforts while enacting the animations on her own pedagogical knowledge, Dora is basing her supporting efforts on students' difficulties and misunderstandings she is exposed to during the enactment of the animations. In her interview, Dora reveals that after examining the animation with her students she became aware to the places where the students needed assistant in order to gain meaningful understanding. Her presence in those points enables her to support the students through studying the animation, whenever they encounter concepts or objects which were not so comprehensible: "When I was exposed to students' specific difficulties through their watch of the animation I had the opportunity to put a spot light on objects and concepts in the animation which are not understandable enough to the students".

Discussion

Learning from animations is not a simple task, even though it might seem like. Although animations can provide learners with explicit dynamic information, the inclusion of a

temporal change introduces additional information-processing demands (Lewalter 2003). In this study we have identified teachers' essential support in universal aspects, such as helping students comprehend while studying from animations, despite the cognitive load involved, as well as in particular aspects for studying biotechnological methods from animations, as establishing the "hands on" point of view. We have also recognized two alternative approaches of teachers in terms of supporting students' knowledge construction while studying from animations. The teacher's role seems critical in terms of promoting students' thinking while studying from animations about underlying concepts and relationships being introduced. 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)

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