THE EFFECTS OF AN ANIMATION ON STUDENTS’ UNDERSTANDING OF DNA REPLICATION

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ABSTRACT

Research has shown that multimodal learning tools improve students’ ability to construct scientific knowledge. This is particularly because these tools facilitate construction of knowledge through referential connections between verbal and pictorial cognitive channels where information is processed. Although multimodal animations have been shown to improve students’ understanding of scientific concepts, the extent to which these tools are effective and the factors affecting such effectiveness, still remains to be researched. In the current mixed-methods study the effect of a narrated versus an unnarrated animation on students’ understanding of DNA replication was investigated. Two groups of 2nd year genetics students (n = 55 and n = 21) from a South African University participated in a pre-/ post-test design study. Results showed no significant difference in students’ pre-test scores but a significant difference was found in the post-test scores. While the narrated animation improved students’ understanding of DNA replication, the unnarrated animation had a negative effect on students’ understanding of DNA replication. A regression analysis showed that the pre-test scores had an effect on the post-test scores, and that viewing the animation had an effect on the post-test scores. The reported findings are considered in light of multimedia learning and cognitive load theory.

Key words: Animations, cognitive load, DNA replication, external representations, multimedia learning

1. INTRODUCTION

Successful learning is a product of adequate mental processing of information contained in various learning resources (Thompson, 1995; von Glasersfeld, 1995). The manner in which information is presented by these resources has a major influence on how students comprehend information and learn science (Mayer & Anderson 1992; Michael, 2002). Researchers have indicated that improved information comprehension requires suitable teaching strategies which are often accompanied by the use of external representations (ERs), such as animations and graphics (Dori & Barak, 2001; Polhemus et al., 2004).

1.1 Theoretical background

Research has shown that learning from ERs is not always successful due to various factors including poor design and learning difficulties. Consequently students are expected to develop a number of competencies in order to work effectively in this technology-driven education. Such competencies include 21st century skills (Arsad, Osman & Soh, 2011), content literacy (McKenna & Robinson, 1990), academic communication literacy (Spektor-Levy, Eylon & Scherz, 2008), science literacy (Van Eijck & Roth, 2010) and visual literacy (Bottomley, Chandler, Morgan & Helmerhorst, 2006). Mnguni (2014) argues that visual literacy is an important competency for biology students where content knowledge exist at complex molecular and microscopic levels which cannot be visualized with a naked eye.
According to some learning theories, such as constructivism and dual coding in particular, the source of information plays a pivotal role during the learning process (Clark & Paivio, 1991; Thompson, 1995; Wastelinck et al., 2005). Mayer (2003) for example argues that learning from ERs is a cognitive process that involves a number of mental processes as explained in the cognitive theory of multimedia learning (Figure 1). As described by Mnguni (2014), Mayer believes that during the learning process, external information first enters the cognitive system through sensory organs (Figure 1). The student then attends to some aspects of the information which leads to the construction of a mental images and sounds within working memory. These are then arranged to form sets of mental models and coherent mental representations. These cognitive processes involved in the cognitive processing of information include the selection, organisation and integration of images and are commonly referred to as visuo-spatial thinking (Mayer, 2003).

Schönborn and Anderson (2005) also highlight the significance of the source of information by arguing that students’ ability effectively construct mental models through ERs depends on at least three factors namely, students’ conceptual understanding, their reasoning ability as well as the mode in which the ER is presented. They argue that it is important to ensure that the ER is designed and used accordingly in order to maximize learning. To this, Mayer (2001) provides principles for developing and using external visual models in teaching. These principles include, the multimedia, contiguity, coherence, modality, redundancy, interactivity, signalling and personalization principles (Mayer, 2001). The multimedia principle states that deeper learning occurs from words and pictures rather than words alone. In addition, this principle claims that text alone is not effective enough and learning with words alone is not as effective as learning with picture and text in combination. The contiguity Principle states that deeper learning occurs when words and pictures are presented simultaneously rather than successively. The first basis of this principle is that if words and pictures are presented near one another (spatial contiguity), learners do not have to use cognitive resources to visually search the screen and therefore, are likely to hold both pictures and text in working memory at the same time. The second basis is that if narration is presented simultaneously with pictures (temporal contiguity), deeper learning occurs. The coherence Principle suggests that deeper learning occurs when extraneous words, sounds or pictures are excluded rather than included due to the auditory split – attention theory, which suggests that information is processed cognitively, either via the visual or auditory channels, or both, both which can be overloaded if too much information is presented to them. The Modality Principle states that deeper learning occurs when words are presented as a narration rather than as on screen text. The redundancy Principle suggests that deeper learning occurs when words are presented as narration rather than as both narration and on screen text. The interactivity Principle stipulates that deeper learning occurs when learners are
allowed to control the presentation rate than when they are not. According to this principle, an interactive animation is the one that allows the user to control its pace and direction. It argues that such animation presentation improves learning because it allows learners to activate their cognitive processes at their own rates and this reduces the chances of cognitive overload. The signalling Principle states that deeper learning occurs when key steps in the narration are signalled (for instance by changing voice tones) rather than when they are not. This means signalling directs the learner’s attention to key events and the relations among them. This minimizes the chances of the learner to select incorrect information for cognitive storage. The personalization Principle states that deeper learning occurs when words are presented in a conversational style rather than a formal style.

1.2 Aim of the study

While instructional design principles and theories such as Mayer’s are widely accepted in literature, their adoption in practice is not well documented. This especially in molecular biology where the adoption of educational principles is relatively new. For this reason, the current study sought to explore the use of ERs in molecular biology by determining the effect of removing narration on students’ conceptual understanding. In particular the researcher sought to investigate and describe the effect of a narrated and an unnarrated animation on students’ understanding of the process of DNA replication.

2. METHODS

A pre- and post-test experimental design approach was adopted for this mixed-method study, where two forms of an animation displaying the process of DNA replication were played for genetics students, followed by a knowledge test as described below. To ensure validity and reliability the tests were piloted on a student population prior to final data collection. No validity-related problems were identified and the reliability was found to be 0.78 (Cronbach’s alpha).

2.1 Student sample and the research process

A total of 76 second-year genetics students enrolled for a Molecular DNA Technology course at a South African University participated in the study as described in Figure 2. All the students were first given a lecture and study materials such as lecture notes (excluding animations) on DNA replication.

![Figure 2. A diagram depicting the methodology followed in the study to gather data.](image)
Two weeks after the lecture, the students were given a knowledge test on this process (see appendix 1), aimed at testing their level of understanding before being exposed to the animation. This knowledge test was used in this study to probe students’ understanding of DNA replication prior to and after the animation. In the interest of maintaining a user-friendly and familiar test format, the researcher set the knowledge test to follow the format used by lecturers of the Molecular DNA Technology course during exams and assessment tests. The knowledge test (see appendix 1) consisted of descriptive as well as none-descriptive questions. These questions were primarily designed to probe students understanding of DNA replication as described in the animation, by explaining and/or stating specific concepts of replication.

Following the pre-animation knowledge test, the 76 students were divided into two groups consisting of disproportionate number of students i.e. 55 and 21 students respectively (Figure 2). The allocation of students into the two groups followed a convenient, non-probability sampling method as described by Maree and Pietersen (2007). The alphabetical order of students’ surnames determined assignment to the groups. Due to logistical and technical constraints, the sample sizes could not be equal, which limited the randomness of group allocation. In both groups, students were exposed to the animation of DNA replication (Figure 3). The group with 55 students was assigned the animation with narration as an added variable while the group of 21 students did not have the narration. Hereafter, each group is referred to as the narrated (i.e. ‘experimental’) and unnarrated (i.e. ‘control’) group, respectively. For both the groups, the animation was played three times.

2.2 The animation

The animation used in the research represented the process of DNA replication and took 127 seconds to run (Figure 3).

In the animation, enzymes and their functions in relation to their sequence of functioning were shown. In addition, the role of primers which are responsible for the initiation of the process, the template strands as well as new strands were also represented. The animation used graphical conventions of various colours and shapes to represent all the molecules and other biological components relevant to replication. As the animation displayed dynamic pictures, text was also displayed at the bottom of the display corresponding to the visual pictures of replication. This text explained DNA replication by describing what was happening in the animation while it ran. In addition to text, the animation had a narration which expresses the process as it happens. This
narration had similar words as text and both could be independently turned on and/or off depending on the viewers’ interest.

Five minutes after viewing the animation students in each of the groups were given the knowledge test on DNA replication, which was given to them prior to exposure to the animation (Appendix 1). After completing this test, students were given a questionnaire (see Appendix 2) which required closed responses substantiated by free responses. The written questionnaire was used to probe students’ difficulties in understanding and comprehending information from the animation. The questionnaire constituted closed-response questions as well as open-response questions as a follow-up on the closed-response questions.

2.3 Analysis of data

The researcher developed a set of scientifically acceptable responses, against which students’ responses were marked. All the marks were summed to give a total mark for each student, which was expressed as a percentage of the maximum possible score for the test. These scores were analysed to determine difference in average scores for the pre- and post-test, within and between the groups (narrated or unnarrated) by testing the null and alternative hypotheses using SPSS software. The relationship between students’ mean scores on the pre-animation and post-animation test within each group (i.e. with or without narration), was measured using a one-way ANOVA to test the null hypothesis that the two group means were not different. In addition to this, an ANCOVA test was performed that employed regression analysis to compare the two groups by adjusting responses for a covariate.

3. RESULTS AND DISCUSSIONS

3.1 Results from the pre- and post-animation tests

The results reveal a significant difference in student performance in the post-test compared to the pre-test. Here it was found that the unnarrated group performed generally better than the narrated group in the pre-test (Table 1). However it was noted in the post-test that the performance of the narrated group improved by 7%, while that of the unnarrated group decreased by 5%. This observation suggested that the animation affected students; knowledge of DNA replication. According to the analysis of variance, the difference was significant for the post-test scores (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean (%)</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>Minimum (%)</th>
<th>Maximum (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnarrated</td>
<td>21</td>
<td>62.38</td>
<td>14.687</td>
<td>3.205</td>
<td>33</td>
<td>90</td>
</tr>
<tr>
<td>Narrated</td>
<td>55</td>
<td>56.48</td>
<td>13.825</td>
<td>1.864</td>
<td>17</td>
<td>90</td>
</tr>
<tr>
<td>Total</td>
<td>76</td>
<td>58.11</td>
<td>14.219</td>
<td>1.631</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnarrated</td>
<td>21</td>
<td>57.78</td>
<td>14.077</td>
<td>3.072</td>
<td>33</td>
<td>87</td>
</tr>
<tr>
<td>Narrated</td>
<td>55</td>
<td>63.58</td>
<td>10.059</td>
<td>1.356</td>
<td>30</td>
<td>80</td>
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<tr>
<td>Total</td>
<td>76</td>
<td>61.97</td>
<td>11.511</td>
<td>1.320</td>
<td></td>
<td></td>
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<td>Score Diff.</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnarrated</td>
<td>21</td>
<td>-4.60</td>
<td>10.671</td>
<td>2.329</td>
<td>-33</td>
<td>20</td>
</tr>
<tr>
<td>Narrated</td>
<td>55</td>
<td>7.09</td>
<td>10.755</td>
<td>1.450</td>
<td>-13</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>76</td>
<td>3.86</td>
<td>11.889</td>
<td>1.364</td>
<td></td>
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</tr>
</tbody>
</table>
Table 2
Results from an ANOVA that compared the narrated and unnarrated group scores in the pre- and post-tests

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-test score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>528.322</td>
<td>1</td>
<td>528.322</td>
<td>2.671</td>
<td>.1064104</td>
</tr>
<tr>
<td>Within Groups</td>
<td>14634.690</td>
<td>74</td>
<td>197.766</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15.163.012</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Post-test score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>510.883</td>
<td>1</td>
<td>510.883</td>
<td>4.011</td>
<td>.0488793*</td>
</tr>
<tr>
<td>Within Groups</td>
<td>9426.397</td>
<td>74</td>
<td>127.384</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9937.281</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Score Diff.</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>2078.264</td>
<td>1</td>
<td>2078.264</td>
<td>18.044</td>
<td>.0000620**</td>
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<tr>
<td>Within Groups</td>
<td>8522.905</td>
<td>74</td>
<td>115.174</td>
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<tr>
<td>Total</td>
<td>10601.170</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

* p < .05
** p < .01

A linear regression analysis for relating the post-test results with the pre-test results was performed using an ANCOVA (Table 3). This was done to determine whether students’ pre-test scores affected post-test scores and whether exposure to the animation had an effect on students’ post-test scores. In the analysis of covariance therefore the two groups were compared by adjusting the response (students’ post-test scores) for a covariate (students’ pre-test scores). The results suggest that in all cases, the difference between narrated and unnarrated group scores in the pre- and post-tests is significant. This implies that the pre-test scores had an effect on the post-test scores, and viewing the animation affected the post-test scores.

Table 3
Results from an ANCOVA that compared the narrated and unnarrated group scores in the pre- and post-tests

<table>
<thead>
<tr>
<th></th>
<th>Unstandardised coefficients</th>
<th>Standardised coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>(Constant)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>24.662</td>
<td>.531</td>
<td>4.772</td>
<td>.00000198**</td>
</tr>
<tr>
<td></td>
<td>.928</td>
<td>.070</td>
<td>.656</td>
<td>.00000000**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.225</td>
<td>.349</td>
<td>.00014399**</td>
</tr>
</tbody>
</table>

** p < .01; Dependent variable: post-test scores

The effect sizes were also calculated to further determine the significance of the differences between the groups and pre- and post-test scores. It was found here that the differences in the means scores had a relatively medium effect size (Table 4) suggesting that the differences were significant.

Table 4
Effect sizes indicating significance of the mean scores

<table>
<thead>
<tr>
<th>Groups/Tests</th>
<th>Mean score</th>
<th>Standard dev.</th>
<th>Cohen’s d</th>
<th>Effect size r</th>
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</thead>
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<tr>
<td>Pre-test</td>
<td>Narrated</td>
<td>56.48</td>
<td>13.825</td>
<td>0.4136</td>
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<td></td>
<td>Unnarrated</td>
<td>62.38</td>
<td>14.687</td>
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</tr>
<tr>
<td>Post-test</td>
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<td>63.58</td>
<td>10.059</td>
<td>-0.4741</td>
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<td></td>
<td>Unnarrated</td>
<td>57.78</td>
<td>14.077</td>
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<td>14.687</td>
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<td>Post-test</td>
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<tr>
<td>Unnarrated</td>
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<td></td>
<td>Post-test</td>
<td>57.78</td>
<td>14.077</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Sources of students’ difficulties

After showing statistically that not all students benefited positively from the animation, the questionnaire responses were analysed in an attempt to ascertain what could be the cause of the negative effect. In this analysis, a number of student difficulties related to interpretation and comprehension of the information presented in the animation were found.

a) Visual literacy

One of the major causes of the apparent students’ poor performance was that of lack of visual literacy skills required to comprehend and understand concepts presented in the animation. Schonbörn and Anderson (2006) define visual literacy as the ability to read, interpret and present visual images. In this regard, it was found in the current study that some students had poor visual literacy which hindered their ability to comprehend information from the animation. In one case, students had a difficulty differentiating similar symbols (conventions) used in the animation. For instance, student could not differentiate between meaning of round-shaped conventions used to represent enzymes, even though these had different colours and functions. In fact one of the students argued that “The enzymes could’ve been a bit more clearly distinguishable. I would’ve remembered them better if they were more different”.

This problem was also observed as students failed to label their conventions correctly even though these were labelled in animation (Figure 4). This was could partly be due to an inability to memorize labels the meaning of these symbols as shown in the animation (throughout the animation) given per convention. This inability to differentiate between conventions, especially with the un-narrated animation, led to students interpreting the animation incorrectly.

Figure 4. Examples of two diagrams drawn by students after the animation drawn during the post-test animation test. The diagrams in A indicate the tendency of students to mimic what the animation shows. In the same diagram, indicated in red is the student labelling the template strand, leading strand and enzymes involved all as the leading strand. In B, cycled is the students incorrect labelling of the template strands as the leading and lagging strands.

On the positive aspect of visual literacy some students were able to represent information in a form of images and diagrams. In this regard, some of the students who prior to the animation could not represent information in both text and diagrams could post the animation. This indicated that the animation assisted students to integrate their verbal and non-verbal knowledge. However, an element of animation mimicking (Chi et al., 1981) was observed accompanying this ability to successfully integrate verbal and non-verbal knowledge (see Figure 4A). Here, some students drew diagrams very similar to what the animation showed when asked to use a diagram to explain concepts. For instance, in the animation (see Figure 3), because there is an enzyme on the 5’ end of
the growing strand (e.g. leading strand), the animation was not able to indicate that at the 5’ end of such a strand the strand has a blunt end. As a result, when students were making their drawings, they failed to observe that there is a blunt end veiled by the enzyme and they drew exactly as the animation represented (Figure 3A), without annotating this.

b) Information retention and cognitive adjustment

On the issue of information retention, it must be stated that one of the aims of educating students is to equip them with necessary skills and/or knowledge, such that if they are faced with new experiences they are able to use such knowledge to interpret and respond accordingly (Doyle, 2005). In the context of the current research, students were expected to use the information presented in the animation when answering test questions. However, it was observed that some students failed to remember throughout the presentation information presented earlier in the animation. One student indicated that “The symbols are not labelled during process, but at the end of the process. Perhaps if labels could accompany the animation all throughout the process, so as to make it easier to connect everything else”. As a consequence of an inability to retain information, some students failed to integrate information presented early in the animation with that presented at a later stage. It is suspected that this may have caused misconceptions about the process as presented in the animation.

In addition to the retention of information difficulty some students failed to keep with the pace of the animation. For example, one student indicated that she “…can’t read & look at the animation at the same time, it was too fast”. In fact even though the animation was played three times, most students argued that the pace of the animation was not suitable for them and hence they missed a lot of information trying to adjust their cognitive processing systems.

c) Cognitive overload

Another commonly observed difficulty was that of cognitive overload. According to the dual coding theory, if information is presented both as text and pictures concurrently, as was the case in the current study, the working memory may be overwhelmed leading to learning difficulties. In this regard, results of the unnarrated group showed that most students failed to comprehend information presented by the animation because they could not use information presented as text and diagrams to formulate sound cognitive schema by integrating new information with prior knowledge and hence ended up losing vital points, which was observed by a decrease in their performance. In fact one of the students suggested that “The explanations below the animation pass too quick while still trying to connect the wording to the animation”. This suggests that students failed to cognitively process all the information presented as narration, text and dynamic pictures simultaneously. As in the failure to keep with the pace of the animation, they failed to identify and comprehend vital points because they were still trying to create mental models of the presented concept via cognitive processing, while still having to integrate the new information at the same time.

d) Integrating information

According to the constructivism theory, prior knowledge is integrated with the new information for creating new mental models (Moreno & Mayer, 1999). This process involves selecting and transforming the information, and making decisions, relying on an already existing cognitive structure to do so (Thompson, 1995). In the current study it was found that some students could not identify critical conceptual points in the animation which they would integrate with prior knowledge. However, a question arises as to how do students know what information is vital and must be selected and integrated with prior knowledge. Usually, teachers or instructors direct students to such information. In the current study however, students were expected to identify such information in the animation by themselves. In this regard, some students had difficulties in...
adequately selecting information. One of the students commented that “...you can’t ask it questions, and you don’t know what is important and what is not”.

d) Misconceptions
It was also found that to some students the animation presented information contrary to what they already knew. For instance, one student previously knew that DNA replication occurs from “left to right” where as in reality it proceeds on the 5’ to 3’ direction as shown in the animation. When answering a question regarding the direction of replication, this student said “the lagging strand is synthesized discontinuously because it’s synthesised from 5’ – 3’ which is not possible because it should be from left to right”. Clearly this student observed in the animation that replication occurs from “5’ – 3’”, however she believes this is not possible because it is not in the “left to right” direction.

e) Affected domain (motivation and attitude)
Another variable which was observed can be explained using Kahneman’s capacity theory of attention (Greene & Hicks, 1984) which argues that motivation is essential for student learning. Based on this understanding, when one is motivated, they are able to perform more effectively in conceptually demanding tasks. In the current research, it was observed that the animation, compared to normal lectures, motivated the students to engage themselves in the study. However, some students were negatively affected by some components of the animation. For example one student indicated that “…the pictures are sweet but the narrator was scary...Narrator’s voice was terrible and very broad”. Another student argued that the animation was “too fast, too serious jokes are needed to easy the understanding”.

4. GENERAL DISCUSSION AND IMPLICATIONS OF THE STUDY

A number of researchers have previously indicated that pictures are more effective in the construction of knowledge than text alone (Tversky et al., 2002). This finding has also been observed with dynamic pictures (animations) which are more effective than still diagrams or text (Dori & Barak, 2001). Many researchers however have cautioned that animations are not always effective, unless some strict principles are followed, both in compiling and using the animation (Mayer, 2001; Reinmann, 2003; Wastelinck et al., 2005). Observations of the current study showed that animations do improve the level of understanding of a genetic process, but there a number of limitations to this. In particular, the current study supports Mayer’s (2001) principles for designing effective multimedia learning tools. These principles include the multimedia effect, temporal-contiguity effect and the modality effect (Moreno & Mayer, 1999). The multimedia effect states that students’ understanding of verbal explanations is improved when coordinated with pictorial ERs. The temporal-contiguity effect suggests that deeper learning occurs when narration is synchronised with animated pictorial information. The modality effect suggests that students’ content understanding improves when receiving verbal input as narration, rather than when presented only visually as textual subscripts (Moreno & Mayer, 1999).

This study also showed that there are a number of factors that could hinder students’ learning through animations. The researcher believes that the observed decreased performance of the unnarrated group could be potentially explained by considering aspects of cognitive load theory (Chandler & Sweller, 1991). For example, the student is required to ‘split’ their visual attention across two visual modes that coordinate visually presented text and pictures when using multimodal visual models. This potentially overloads the visual processing channel, thus inducing a split-attention effect (e.g., Mayer, 1997; Robinson, 2004). As explained by the cognitive load theory, this however may overwhelm the cognitive structures leading to learning difficulties.
The author therefore believes and strongly recommends that scholars and teachers adhere to guiding principles for multimedia learning whenever designing and/or using visual models for teaching and learning. The author however notes the need to further investigate the role and effect of using different visual models in teaching biology.

5. ACKNOWLEDGEMENTS

The author would like to thank Professors John Rogan and Trevor Anderson, Doctor Konrad Schonborn, Colleen Aldous, the Science Education Research Group (SERG) and all staff members and students of the University of KwaZulu-Natal (Pietermaritzburg) who contributed to the success of this work.

6. REFERENCES


Appendix 1

Pre - and post – animation test
The following questions were in the tests that were given to students prior and after the animation. Students were not given an indication of how much information to give in their responses.

1. Besides the different enzymes, name 3 prerequisites of DNA replication.
2. What is the function of a helicase enzyme?
3. DNA replication occurs in what direction, with respect to the growing strand?
4. Why does replication initiation require a free 3’OH?
5. How is a free 3’OH provided for replication?
6. With the aid of a diagram, describe how the leading strand is different from the lagging strand.
7. If the primer is a short RNA strand required to initiate replication, does it mean the end product of replication contains an RNA molecule? Explain your reasoning.
8. With the aid of a diagram, describe the structure of a double stranded DNA molecule. In your diagram show the location of the phosphodiester bonds and the hydrogen bonds.
9. In a short paragraph, discuss the following statement:

“The leading strand is synthesized continuously, while the lagging strand is synthesized discontinuously.”

Appendix 2

Research written questionnaire
Below is an abstract of the written questionnaire given to students after watching the animation. The questionnaire had closed-responses as well as open-response questions. Except for question 1 and 10, this format was similar for all the statements as shown in statement number 2. Students were not compelled to give their personal details on the questionnaire.

ANIMATION ANALYSIS
Study the animation on a genetic process and fill in the questionnaire. Indicate your choice by means of crossing (X) the appropriate box. Give reasons for your choice in the space provided after each statement.

1. At which level(s) did you study the basics of DNA replication?

<table>
<thead>
<tr>
<th>High school</th>
<th>Undergraduate Biochemistry</th>
<th>Undergraduate genetics</th>
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</thead>
</table>

2. The animation is a good representation of replication

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
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<tbody>
<tr>
<td></td>
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</table>
3. The symbols used are easy to follow
4. The speed of the animation is appropriate
5. The animation is easy to understand
6. The narration explains the process clearly.
7. There is good balance between narration and pictures
8. The animation is appropriate for teaching 2\textsuperscript{nd} year genetics students
9. Special skills are required to interpret the animation
10. Give details of any other positive and negative design features of the animation and its ability to communicate the information it is representing
   a. Positive comments:
   b. Negative comments: