

Descriptive account

Guided Practice Software for Teaching DNA Replication to Senior High School Students

Eric C. Woods¹, Alan E. McKinnon², Jonathan G.H. Hickford³ and Walt A. Abell²

¹*MindSpace Solutions, Christchurch, New Zealand;* ²*Applied Computing Group, Lincoln University, New Zealand;* ³*Cell Biology Group, Lincoln University, New Zealand.*

Date received: 02/07/2008

Date accepted: 01/08/2008

Abstract

The prototype of a guided practice application was developed to instruct year 13 biology students in the process of DNA replication. The application uses a high degree of interaction to engage the student in a guided exploration and problem solving exercise. An evaluation revealed that the students showed considerable enthusiasm and significant educational benefit.

Keywords: DNA replication, teaching software, interactive learning, guided practice

Introduction

Educationalists have recognised that the learning process is enhanced when a *constructivist* approach is taken in contrast to the more traditional *instructivist* approach (Parr, 2001). *Constructivist* activities require students to use their pre-existing knowledge as a base on which they construct new knowledge. A potential danger with constructivism is that individual students construct knowledge differently, due to different interpretations. "If students are not allowed to state and test their own models, hypotheses, ideas, and issues, their understanding may remain partial" (Oliver, 2000). It is therefore important that any computer-based learning software that takes a constructivist approach allows students to confirm their knowledge. One way of doing this is to provide activities that promote reflection between what the student knows, thinks or predicts and the resulting outcome.

Although there are a number of examples of interactive educational software in disciplines such as mathematics (Vienna University, 2001) and chemistry (Jackson, 2000), the number of interactive and engaging applications in biology is relatively few although there are some examples in molecular modelling (WaveFunction, 2008; MDL Information Systems, 2008). The applications focussing on DNA replication (such as Science Media, 2007; Hartwell *et al.*, 2000) do not encourage a reflective approach, or have low quality graphics.

We have developed prototype software to help students learn about DNA replication. The emphasis is on interaction that engages the students and encourages them to discover and reflect on knowledge in an active manner.

Objectives

Our objective was to develop a system that covered all the relevant educational objectives from the curriculum for year 11 to year 13 biology students in New Zealand Secondary Schools (Ministry of Education, 1994).

In particular our system is intended to convey:

- the importance and nature of enzymes involved in DNA replication.
- the importance of DNA strand separation and that existing strands act as templates for DNA synthesis.
- the anti-parallel structure of the DNA strands.
- that DNA is synthesised by the addition of nucleotide precursors that are added by the enzyme DNA polymerase .
- an understanding of RNA polymerase and primers.

We have set out to:

- present information both graphically and as text, to suit different types of learners.
- create sufficient interaction so the student becomes fully engaged in the activity.
- ensure the student has a correct understanding at each stage before proceeding.
- integrate the questions that confirm this knowledge seamlessly into the application.
- make the student discover knowledge, rather than just receive it.
- ensure that feedback is clear and encouraging.

Details of the Prototype

A working version of the prototype can be accessed at:

<http://www.mindspacesolutions.com/html/dnact.html>

The Work Area

The students are set the task of using the interface to replicate a strand of DNA. They are presented with a 2D representation of the inside of a cell. It contains the original strand of DNA as well as the components such as enzymes which make replication possible (Figure 1). The student must use these components in the right way and in the right order to complete the task. To use a component, a student must drag and drop it onto the correct part of the DNA strand.

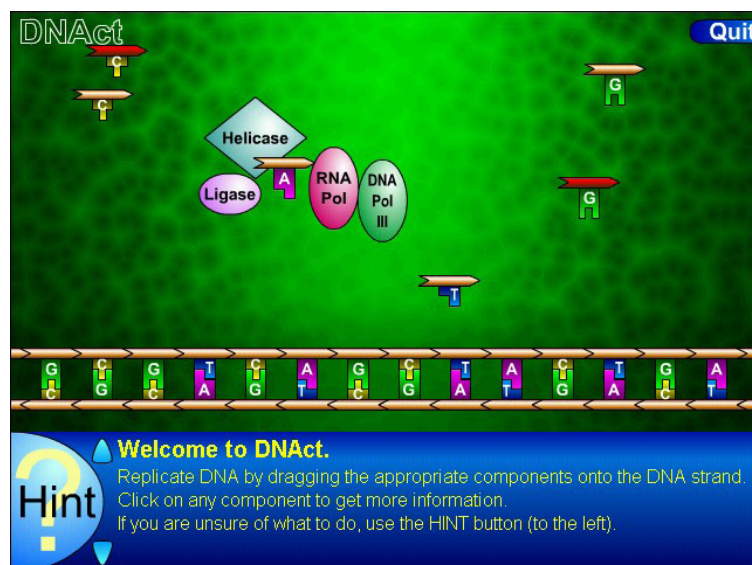


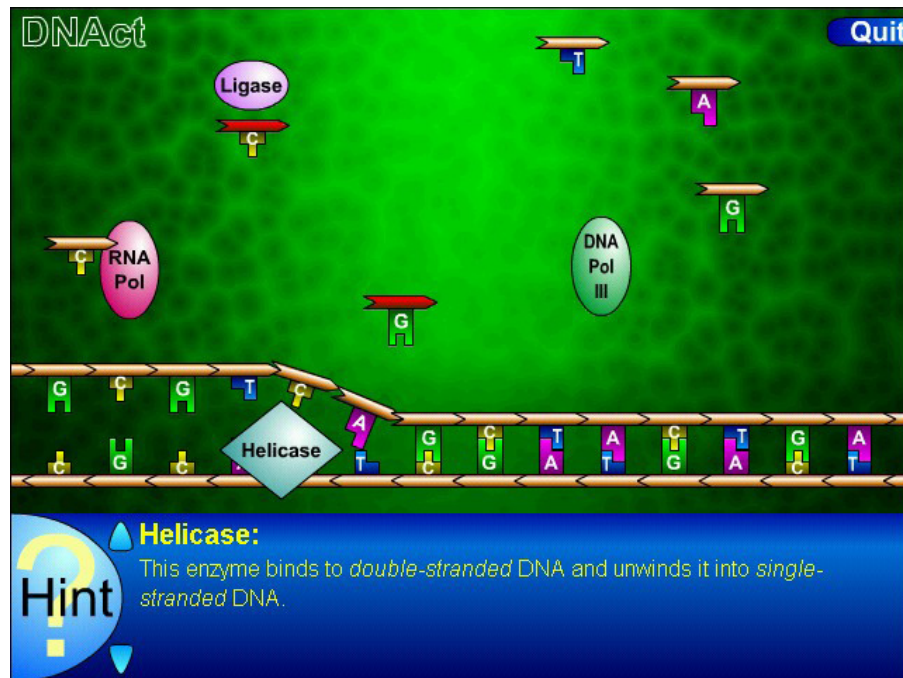
Figure1 The work area and text. The DNA strand is shown at the bottom of the work area. The other components randomly drift around the work area

The stages that a student needs to go through are:

Stage 1: Place helicase anywhere on the DNA strand to trigger the separation process (Figure 2).

Stage 2: Correctly place RNA polymerase on the RNA strand. An animation of the formation of a short strand of RNA primer is shown.

Stage 3: Correctly place DNA polymerase at the site on the strand where the next nucleotide should be added.



Stage 4: Move all of the nucleotides into place in the correct sequence.

Figure 2 The description for helicase is shown in the text area. The work area shows a snapshot part way through the animation of strand separation

The Nucleotides

Figure 2 shows the shapes of the nucleotides used. The backbone *points* to one side (from the 5' to 3' direction, although the students don't need to know that). The backbone is distinguished from the rest of the nucleotide to represent structural reality and also to make it possible to distinguish DNA (brown backbone) from RNA (red backbone). Because prior knowledge of the nucleotide pairings (A–T and C–G) was assumed, the depiction of these bonds was made very obvious by using complementary colours and shapes. The two or three interlocking “teeth” represent the two or three hydrogen bonds that exist between the A–T and C–G pairs respectively.

The Components

The required components are nucleotides (2'-deoxyribonucleotides), RNA nucleotides, helicase, RNA polymerase and DNA polymerase III.

Each component is interactive and responsive, so that if a student clicks on it, some text is displayed giving information about the role of that component. Figure 2 shows the text describing helicase activity.

Text Messages

There are three types of text message:

- 1) *Component text* gives information about a selected component.
- 2) *Hint text* gives information on what must be done next to proceed, but not how to do it.
- 3) *End text* is presented after a student has successfully completed one of the stages.

In contrast to *component text* and *hint text*, *end text* is “compulsory” reading with the remainder of the display dimmed to focus the student’s attention on the message.

Component Drifting

To reinforce the notion that the inside of a cell is a dynamic environment, the components drift around the work area. This drifting also provides for very clear feedback. If an incorrect component is dragged to a proposed site of action, it simply drifts away. Another benefit of using drifting, is that only one copy of each free nucleotide needs to be in the work area at a time. For example, when a nucleotide is used, a replacement drifts into the work area and after the helicase is used to separate the double-strands of the original DNA, one of the separated strands drifts away out of the work area.

Software

The application was developed using *Macromedia Flash™*.

Evaluation

A class of 19 students from a local high school was involved in an evaluation of the prototype as follows:

Pre-Test

Each student was given a multi-choice test to determine his or her prior knowledge before using DNAct. This is shown in Appendix 1.

Post-Test

Three to seven days after using DNAct, the students were given the same test again, to determine if their knowledge had changed.

Post-Questionnaire

At the same time as the post-test was administered, the students filled out a questionnaire (Appendix 1) to gauge their opinion about the experience of using DNAct.

Remote Data Logging

Because DNAct can run as a web application, remote data logging was used to record every time a student clicked on an object. In this way, it was possible to record the actions of the students unobtrusively.

Evaluation Using Experts

In addition to the evaluation with students, three experts (a high school biology teacher, an educational software developer and a university lecturer experienced at managing groups of teenagers), were asked for their views in a structured interview situation.

Evaluation Results

Pre- and Post-Tests

While 19 students took the Pre-Test (Table 1), only 11 were able to take the Post-Test and Post-Questionnaire because not all the students who were pre-tested subsequently used DNAct. Also, because two of the students had independently studied DNA replication between using DNAct and the Post-Test, their results were not included.

Table 1 Results from pre and post testing of year 13 biology students

Question	% Correct Answers	
	Pre-Test (26 students)	Post-Test (11 Students)
What is the first thing to be done in DNA replication?	96%	100%
What are the primers needed in DNA replication for	50%	64%
What does cytosine pair with?	100%	100%
What is needed to attach free nucleotides to a growing DNA strand?	23%	73%
What is template DNA?	58%	91%

These results indicate that the students' knowledge and understanding improved, especially in relation to what is needed to attach free nucleotides to a growing DNA strand and the definition of template DNA. The result for question 3 confirmed the assumption that Year 13 students already know the base-pairing rules of A–T and C–G.

Post-Questionnaire

Table 2 shows the average rankings calculated from all 13 student responses to a question about which technique they would prefer when learning about DNA replication. This indicated a slight preference for DNAct over Teachers and Tutors, which all ranked considerably higher than books and finally videos.

Table 2 The average ranking for students' preferred technique to learn about DNA replication (1 = most preferred, 5 = least preferred)

Technique	Ranking
Books	2.8
Teacher	1.9
Tutor	1.9
Video	3.2
DNAct	1.4

85% of students answered that they would use DNAct in their own time and that they would recommend it to a friend. Some students commented that using DNAct was “fun” or “good” but they would like to see it cover more areas. There were no negative comments.

Remote Data Logging

Figure 3 shows the progress of a particular student using DNAct from data recorded using the remote data logging function. Clearly this student had difficulty with Stage 2. An overall measure of student's success with DNAct is given by the proportion of correct to incorrect drags, which was 68% to 32% in this case. Surprisingly, students did not use the *Hint* button.

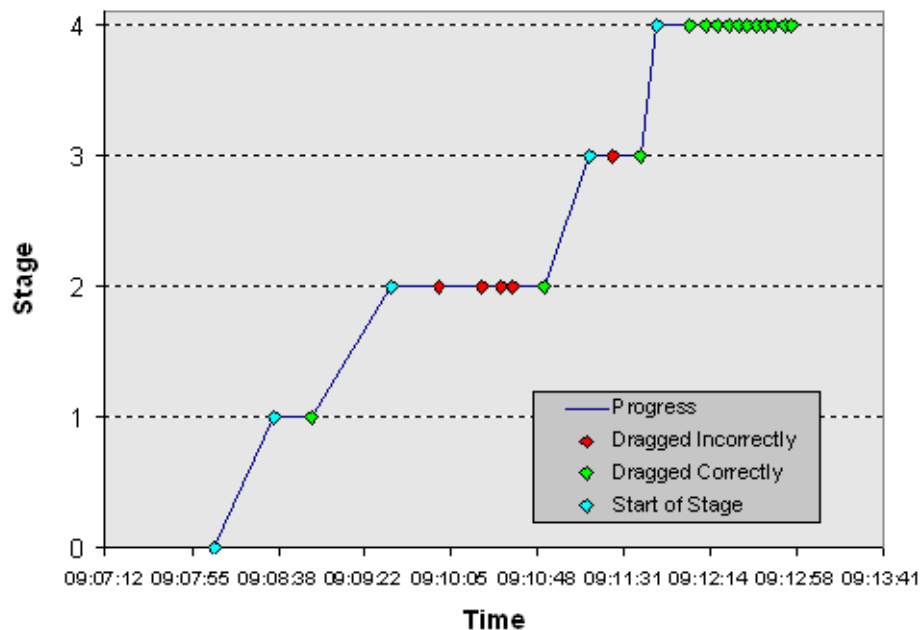


Figure 3 Graph of the actions of a student progressing through the stages of DNAct

Evaluation Using Experts

The three experts interviewed were all impressed with DNAct. The main concern of the biologists was that the prototype did not cover a large enough set of topics to be useful in a general classroom. It was also suggested that it would help if DNA replication was given some context in terms of cell division etc. One expert did not realise the purpose of the *Hint* button which may also explain why the students used it only rarely. One of the biologists pointed out that in reality RNA polymerase can bind at multiple motifs along the template strand, not just at the start, as in DNAct.

Discussion and Conclusions

We have developed a prototype application that meets a set of educational objectives in terms of content and also provides the student with a learning environment that engages him or her in an interactive problem solving process, where at each stage the student's understanding is confirmed. Although DNAct is only a prototype, we have demonstrated that these learning techniques can be implemented and successfully applied to DNA replication. This suggests that these learning techniques can be implemented in other areas. As it stands, DNAct covers too narrow a range of topics to enable a teacher to incorporate it into a class. However, the principles and approach demonstrated can be readily extended, resulting in the development of a full teaching module. Similarly, the use of data logging demonstrated potential that could be expanded in the future. In addition to using this data to analyse the efficacy of the software, it could be presented to the teacher in a structured way that allows for simple identification of a student's learning difficulties.

Another useful extension of DNAct would be to make it scalable so that it could be used by a wide range of students at various levels from junior high school through to first year university. This could be done by developing the system with the level of detail required for the most advanced students and then providing "bridging" animations to simplify the more complex stages for use with more junior students. Now that the learning approach taken by DNAct has shown some promise, its revision to extend the breadth of topics covered and the range of levels is an obvious area for future work.

Communicating Author: Alan McKinnon, Applied Computing Group, PO Box 84, Lincoln University, Canterbury, New Zealand. Email: mckinnon@lincoln.ac.nz, Phone +64 3 325 2811, Fax +64 3 325 3845

References

- Hartwell, L.H., Hood L., Goldberg, M.L., Reynolds, A.E., Silver, L.M. and Veres R.C. (2000) *Genetics: from Genes to Genomes*. Boston: McGraw-Hill
- Jackson, N.B. (2000) Virtually Science, New York: New York Times Article published 9th April, 2000
- MDL Information Systems. (2008) *MDL Chime*. <http://www.mdlchime.com> (Accessed 12 August, 2008)
- Ministry of Education. (1994) *Biology in the New Zealand Curriculum*. Wellington: Learning Media. ISBN 0478057210
- Oliver, K.M. (2000) *Methods for developing constructivist learning on the web*. *Educational Technology*, **40**(6), 5–18
- Parr, J.M. (2001) *A Review of the Literature on Computer-Assisted Learning, particularly Integrated Learning Systems, and Outcomes with Respect to Literacy and Numeracy*. Wellington: New Zealand Ministry of Education.
- ScienceMedia Ltd. (2007) *Biochemical interactions*, <http://www.sciencemedia.com/website/demos/biochem/index.htm> (Accessed 12 August 2008)
- WaveFunction Inc (2008) *Spartan Software*. <http://www.wavefun.com/products/spartan.html> (Accessed 12 August 2008)
- Vienna University (2001) *About Maths Online*. <http://ww2.unime.it/weblab/mirror/moe/ueber.html> (Accessed 12 August 2008)

Appendix 1 Evaluation Test and Questionnaire

Pre- and Post-test

Multi-choice questions. Note: this test is not marked, so if you don't know the answer to a question, *please choose "don't know"* rather than guessing randomly.

1. What is the *first* thing that needs to be done in DNA replication?
 - A primer needs to bind to the DNA strands.
 - The DNA needs to unwind.
 - The cell wall needs to breakdown.
 - Nucleotides need to be added to the DNA strands.
 - Don't know.

2. Primers are needed in DNA replication to:
 - Activate RNA polymerase.
 - Unwind the DNA double-helix.
 - Break the bonds between adjacent free nucleotides.
 - Provide a free end that can be extended into a DNA strand.
 - Don't know.

3. Cytosine base pairs with:
 - Adenine.
 - Cytosine.
 - Guanine.
 - Thymine.
 - Don't know.

4. What is needed to attach free nucleotides to a growing DNA strand?
 - RNA polymerase.
 - DNA polymerase.
 - Helicase.
 - Ligase.
 - Don't know.

5. What is template DNA?:
 - The free DNA nucleotides used to build a strand.
 - Single-stranded DNA that is used to make double-stranded DNA.
 - The primer used to initiate replication.
 - The original double-stranded DNA.
 - Don't know.

Post-Questionnaire

Question: Have you done any study/revision on DNA replication *since* using DNAct?

Yes.

No.

Personal Opinions:

1. When learning DNA replication, which technique would you prefer? Rank the following by placing a number in *each* box (1-Most Preferred, 5-Least Preferred):

- Books.
- In a classroom with a teacher.
- Individual tutor.
- Video.
- DNAct.
- Other: _____

2. Would you consider using use DNAct in your own time?

3. Would you recommend DNAct to a friend?

4. Please include any other comments you would like to make:
