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ABSTRACT

This study explores the instructional impact of using computer multimedia to integrate metaphorical verbal information into graphical representations of biotechnology concepts. The combination of text and graphics into a single metaphor makes concepts dual-coded, and therefore more comprehensible and memorable for the student. Visual stimuli help the learner establish semantic connections between the abstract and the concrete, and it is hoped that metaphoric stimuli can facilitate analogical links between the unfamiliar and the familiar. In this study, six versions of instructional materials were developed: non-graphics without metaphors (control group), static graphics without metaphors, animated graphics without metaphors, non-graphics with metaphors, static graphics with metaphors, and animated graphics with metaphors. Participating college students (n=120) were randomly assigned into the six groups and studied the materials independently. A criterion-referenced test was used to assess students' learning performance, while the Instructional Material Motivation Survey (IMMS) was used to gather attitudinal responses. Interviews and observations yielded information about how students employed graphics and metaphors for mental elaboration. Quantitative results suggested that animated graphics plus metaphorical treatment enhanced motivation the most, although metaphorical treatment seemed to be received positively regardless of what accompanied it. Furthermore, the results of the interviews and observations shed light on, among other things, how students process and interpret graphical displays and how the pace of animated presentations influences learning. As a sample of the metaphorical technique, an appendix offers a series of sequential drawings and accompanying verbal information that depict strands of genetic materials as "screwed zippers." (Contains 36 references. (BEW)

Computer Graphics and Metaphorical Elaboration for Learning Science Concepts

by

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Abstract

The study explores the effect of integrating metaphorical strategies in various graphic representations for learning biotechnology concepts. Six versions of instructional materials with following design were developed: Non-graphics without metaphors (control). static graphics without metaphors. animated graphics without metaphors, Non-graphics with metaphors, static graphics with metaphors, and animated graphics with metaphors. One hundred and twenty participants were randomly assigned into six groups and studied the instructional materials independently. A criterion-referenced test was used to assess students' learning performance. Instructional Materials Motivation Survey (IMMS) (Keller, 1987) was used to gather attitudinal responses. In the study, interviews and observations were also conducted to obtain in-depth information about how students employed graphics and metaphors for mental elaboration. Implications for integrating these two instructional strategies are provided.

Introduction

The technology of computer graphics has great potential for multimedia application. The useful feature of linking verbal and nonverbal visuals together permits easy modification of the materials and adaptation of various applications. In the earlier days. computer graphics were designed mainly to deal with numbers or letters. for instance. statistical graphs and letter softwares. In recent years. graphic techniques have been extensively used in various forms to satisfy different instructional needs (Brown. 1992: Rieber. 1995: West. 1992). As the field of computer graphics widens its scope. it becomes an important concern whether the use of graphics can actually facilitate the process of human-computer interaction as expected (West. 1992). This paper provides a case for combining metaphors and graphics to help students in relating to unfamiliar concepts.

Related Literature

Pictures can take many different forms to serve a wide variety of instructional purposes. The use of metaphorical explanation is one of the strategies to make the concept and idea more comprehensible and memorable to convey through graphics, especially when graphics are complex and when the central concepts of the graphics are difficulty to capture. In learning scientific concepts, graphics are designed based on the visual representation of an expert's interpretation (ChanLin, 1993). Whereas, how these representations can actually help relating knowledge that students already have is a very important concern. Literature suggests that students with less experience require the use of various presentation techniques to help them interact with the visual materials, such as dissecting pictures into smaller pieces or presenting pictures which can be controlled by learners to satisfy their different learning needs (Alesandrini, 1985; Fleming, 1987; Hannafin & Peck, 1988).

Visualization and Memory

The best support for the use of visual representations, dual coding theory suggests two functionally distinguishable symbolic systems in semantic memory - one verbal and the other non-verbal (Paivio, 1990). When information is dual-coded, it is easier to retain in memory. Evidence shows that learning increases when verbal information and pictures are presented correspondingly in time and space (Mayer & Anderson, 1992). Modern technology, such as computer-generated animation, offers a potentially powerful medium that allows learners to mentally construct connections for processing information (Mayer & Sims, 1995). The increased availability of design tools also permits the design of instructional materials that incorporate unlimited variations and forms of verbal and visual information for presentation (Rieber, 1995).

Visual stimuli facilitate representational connections, referential connections, or associative connections (Paivio, 1990). However, the trigger of these connections and the utilization of these connections by learners does not occur in a linear sequence. Prior learning experiences and existing knowledge representations influence how visual information is processed (Cate, 1993). Instructional strategies used for presenting graphical information also play an important role to facilitate the processing of information among learners (ChanLin, 1993; Mayer, 1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Rieber, 1989; Rieber, 1994).

Prior Case for Learning with Graphics

In scientific area, the use of graphics to establish semantic connections requires active processing among learners (ChanLin, 1993). The levels of processing and elaboration involved among learners might vary based on individual's learning motive. In a case study among veterinary students for learning parasitology lesson, three basic levels of interaction were summarized: interpreting level, memorizing level, and applying level (Figure 1).

From the findings, it is clear that students with more experiences in applying skills and knowledge are more likely to interpret and memorize given information more efficiently, because more related information can be retrieved from the memory to help processing the graphical information. On the other hand, students with less clinic experiences tend to process given visualizations with certain degree of uncertainty, because less information is retrieved from the memory. When knowledge experts employ graphical information for students to learn the concepts, it is more important to analyze beforehand how students deal with the information.

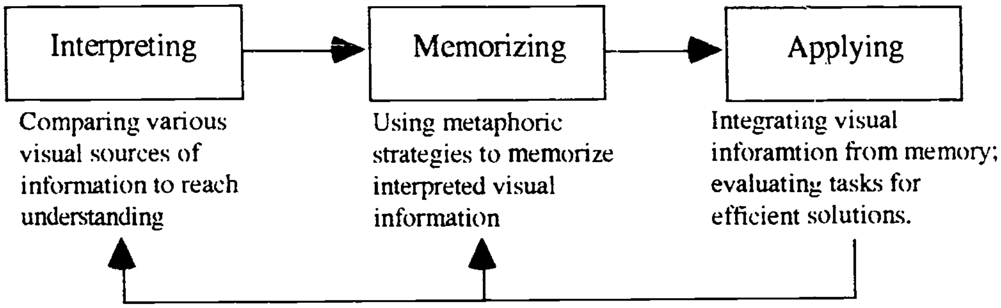


Figure 1. Interplay of Three Interaction Levels for Processing Visual Information

A Case for Metaphors

Knowledge is not only accumulated but also reconstructed (Gagnè, Brigg, & Wager, 1992). Although memory might be considered a "by product" of memory trace (Kobayshi, 1986), perceptual processing often involves analyzing, filtering incoming stimuli for meaningful interpretation. Viewers tend to associate given pictures with text based on their own interpretation of which source is more meaningful to them (Kobayshi, 1986; Pettersson, 1989). Prior experience and knowledge is integrated to connect relevant information for understanding and encoding. When perceiving visual materials, students retrieve the images and pertinent information from memory and analyzed the coming pictorial information by looking for relevant clues to solve given tasks. In scientific learning, most problem solving decisions are often drawn based on a holistic processing (details in ChanLin, 1993). Throughout the whole process, linking relevant information is important to initiate the construction of knowledge.

In an attempt to address the notion of linking relevant information for knowledge construction, integrating metaphors for effective visual learning is anticipated. The use of graphics relies on the recall of a visual memory (Mealing & Yazdani, 1990). However, pictures can communicate more than just their surface contents, because a wide range of prior knowledge and experience is brought to bear on the imagery by the viewers. Visual language and experience can be exploited to enrich the meaning of graphics (Wileman, 1993). Employing metaphors in visual learning aims to enhance the power of graphics in facilitating understanding, memorization, and application of instructional materials.

- A Facilitator for Enhancing Communication

The use of graphics aims at providing connections, actively encouraging an anticipated deeper interaction with pictures. However, not every person who learns a new skill or scientific knowledge possesses the proper prior knowledge. The processes involved in interpreting, memorizing, and applying are interrelated and occur with a non-linear sequence. The paths students would follow might differ from individual to individual . Students who lack repertoire of elaborate learning strategies might rely on rote memorization (Simpson, Supattathum & Tam, 1993). To facilitate a deeper processing and a systemic thinking path, providing facilitators and guidance for interpreting, memorizing, and applying the information is important.

Recent theoretical perspectives suggest that learning of concepts needs to involve domain-specific knowledge and strategic reasoning skills (Rosaen, 1993; Roth, 1992). Scientific instruction has more emphasized on helping a conceptual and practical understanding of information (Lin, Newby, & Foster; O'Connell, 1994). Rich connections among concepts and facts that allow broad exploration will increase the meaningfulness and usefulness of the information to learners (Roth, 1992). Although literature suggests that graphics provide potential impact on learning (Rieber, 1994; West, 1992), visual information sometimes requires learners to invest extra mental effort to digest and encode. Accurate interpretation of graphical information for further application is essential (ChanLin, 1993). Students with limited domain knowledge sometimes view graphics as an excess complexity and incomprehensible information if the connections are not transparent to them (Cate, 1993; Richardson, 1990).

- A Bridge for linking familiarity

Abstractness and unfamiliarity are two factors that tend to reduce curiosity and learning (Keller & Burkman, 1993). Learning is based on employing prior knowledge to understand new situations. Learning is also referred to a process through which prior knowledge reconstructs and changes to deal with new situations (Piaget, 1970). Since one of the important basis for learning is previous knowledge, the student must have previous knowledge to be related to the new information (Thompson, Simonson & Hargrave, 1992). Even with visual learning, existing knowledge and experiences are main considerations for deciphering and encoding visual information. Tying new learning with what is familiar to learners can facilitate comprehension (Gagnè, Briggs, & Wager, 1992).

Analogy and metaphor can help learners relate the new. unfamiliar, abstract knowledge to something that is concrete and familiar, and thereby capture its essence (Alesandrini, 1987). The use of metaphorical explanation in graphics is also intended to relate familiarity so that viewers will be able to accurately decipher the graphics with meaningful representations. If the graphic is familiar and meaningful to learners, it promotes intuitive responding in student's learning processes (Begg, 1983).

Although graphics provide stimuli to help dual coding, learning requires learners construct a meaningful representation for a new concept (Lin, 1993). McGrath (1990) suggests that students with little knowledge background of a learning area are overwhelmed with too much new information at one time and that they used to create analogical representations to keep themselves from losing what they are doing. Due to the lack of correct mental representations, the conceptual analogy that novice students construct for interpreting information might be "fragile" (McGrath, 1990).

Used properly, metaphors can play an important role in the acquisition of new knowledge by linking an analogical model for guided thinking. However, research on the other hand, also suggests that the use of metaphors might lead to misconceptions due to that the learning concepts are often oversimplified by analogical examples provided (Spiro, Feltovich, Coulson, & Anderson, 1989). To help students gain correct concept, this analogical thinking device should first, explicitly identify relevant elements in the metaphorical example, infer relations among elements, and then apply inferring relations to new concepts. The design of metaphors is challenging for instructional designers. Good metaphors should invite students to observe and associate information from different dimensions. They should also encourage thinking of higher order relations (Lin, 1993; Sternberg, 1987).

To facilitate inductive reasoning from visual information, integrating metaphors for elaboration has a great potential for cognitive processes. However, effectiveness of the design needs to be tested on an empirical basis. Much research effort should also be emphasized on how to employ this strategy effectively.

Research Purpose

To examine how metaphors and graphic representations facilitate motivation and cognitive processes, a systematic assessment is required. Within this study, several major areas were explored:

(1). Do various graphic representations (including: non-graphics, static, and animated graphics) used with or without metaphors provide a difference in learning and motivation?

(2). Does the treatment of graphic representations have effect on learning of scientific concepts?

(3). Does the use of metaphors have effect on learning of scientific concepts?

(4). How do students employ their own strategies for processing information with graphics and metaphors?

Method

The subjects were 120 college students, who reported low levels of prior experience with Biology. A computer-assisted lesson, *The Basic Recombinant DNA Technology* was developed for providing a general introduction to biotechnology. With an emphasis on using meaningful representations to help understanding, metaphors were used to enhance graphical information in explaining the concepts of molecular biotechnology. Effectiveness of the design was tested on an empirical basis. Prior to the study, six versions of instructional materials were designed and used among students: non-graphics without metaphors, static graphics without metaphors, animated graphics without metaphors, non-graphics with metaphors, static graphics with metaphors, and animated graphics with metaphors. Students were randomly assigned into six groups and studied the instructional materials independently (Table 1). A criterion-referenced test was used to assess students' performance. Students' attitudinal responses were also gathered.

Interviews and observations were conducted among students to obtain in-depth information about the processes employed by students to interact with visuals and metaphors. The researcher worked with students one by one and encouraged them to respond orally. Students' responses were recorded for further analysis. During the interviews, typically, the researcher stopped at a certain point of the instruction, and asked students to summarize the main point of the information presented on a particular screen. In order to trace the processes during thinking, students were requested to report how they switched their attention on the screen, and how they interpreted what they read and saw. The questions raised by the researcher were based on individuals' previous responses.

Table 1. Arrangement of different treatment groups

	Visual Treatment		
	Non- Graphics	Static Graphics	Animated Graphics
Without Metaphors	20 students	20 students	20 students
With Metaphors	20 students	20 students	20 students

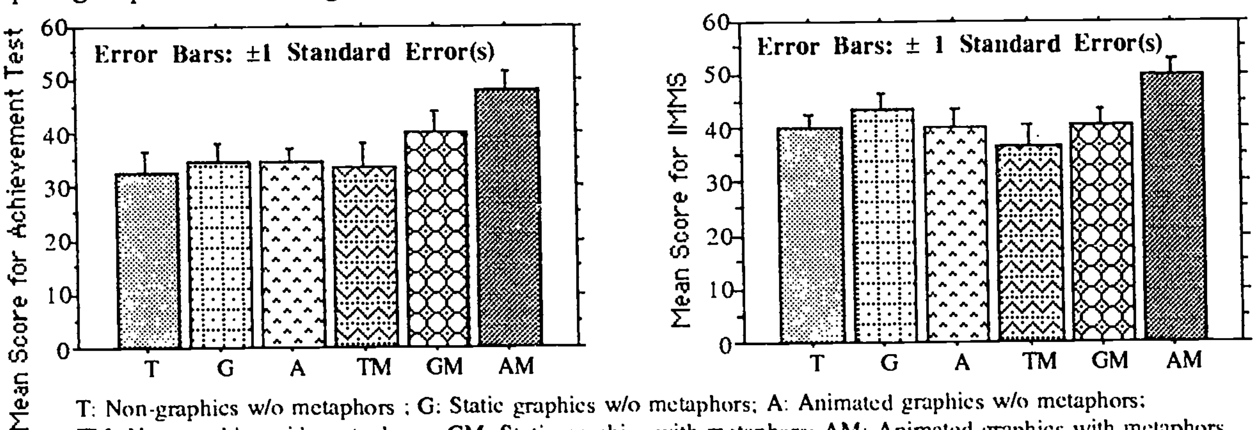
Results and Discussion

Quantitative Results

The criterion-referenced test consists of two major units. Unit one contains 16 multiple choice questions used for assessing students' basic knowledge in this lesson, such as: "What is the human growth hormone composed of?" and "What kind of bacteria DNA is used for substituting human DNA?". Unit two contains three problem questions used for assessing retention tasks. Within each problem question, students were requested to identify the correct steps and sequence related to a concept, such as: "How is human growth hormone produced?" and "How does translation occur?".

Students' test scores were gathered. The left graph in Figure 2 shows the mean score produced on the criterion-referenced test. As can be seen, metaphorical elaboration with animation treatment scored higher than the other groups. An analysis of variance confirmed that the group differed significantly from one another, $F(5,114) = 2.666$, $p<0.05$. A 3 X 2 analysis of variance indicated no significant difference in the first main effect, graphic representation (non-graphics, static graphics, and animated graphics), $F(2, 114) = 2.518$, $p > 0.05$. The second main effect, metaphorical treatment (with or without metaphors) indicated a significant difference, $F(1,114) = 5.420$, $p < 0.05$. No significant interaction was found between two main effects (metaphorical treatment, graphic representation), F(2,114) = 1.436, p >0.05. The results supported the assumption that learners within six different treatment groups differed in the cognitive process. From the study, the use of metaphors substantially improved learning of visual materials. Especially with animated graphics, providing metaphors would make the concepts more transparent to the learners.

The right graph in Figure 2 shows the mean score produced on student's attitudinal responses gathered through Keller's IMMS (Instructional Materials Motivational Survey). Learning with metaphors and animation provided higher motivational scores. An analysis of variance confirmed that the group differed significantly from one another, F(5,114) = 2.304, p < 0.05. A 3 X 2 analysis of variance indicated no significant difference in graphic treatment, F(2, 114) = 0.0969, p > 0.05. The metaphoric treatment also indicated no significant difference, F(1,114) = 0.6536, p > 0.05. There was a significant difference between two main effects (metaphorical treatment, graphic treatment), F(2,114) = 3.276, p <0.05. The results supported the assumption that learners within six different treatment groups differed in motivational responses. From the study, the use of metaphors improved students' attitude for animation treatment, but not for non-graphic and static-graphic treatments. It was hypothesized that metaphors would motivate students to explore the episodic scenario provided by animation. However, additional effort required to learn metaphors for non-graphic and static-graphic groups resulted a negative attitude.



T: Non-graphics w/o metaphors ; G: Static graphics w/o metaphors; A: Animated graphics w/o metaphors;
TM: Non-graphics with metaphors ; GM: Static graphics with metaphors; AM: Animated graphics with metaphors

Figure 2. Mean score on performance test and mean score on attitudinal responses (IMMS) among different treatments.

Interview Results

Students processed on-screen information differently. Some started with text, and some started with graphics. Verbally oriented students considered words contained important information. Graphically oriented students considered graphics provided concrete meaning to the words. When animation subsequently follows the presentation of still textual and graphical information, verbally oriented students were more easily interrupted by animation than graphical oriented students . The presentation of animation often attracted students' attention, however, distracted students from what they were doing too. When concentrating on the screen information, verbally oriented students used to stop and switch attention to graphics. Graphically oriented students did not need to shift focus like verbally oriented students did.

Replay of animation was often found among verbally oriented students. Due to the sudden change of attention from text to graphics, verbally oriented students often missed the beginning of most animation . Consequently, some students re-played the animation to review the content. Although the re-play conditions might be beneficial because more opportunities for comparing the text and animated graphics allowed elaborate processing, not every student would re-read the information, even they knew they might miss something important.

The complexity of the information influenced how students processed on-screen information . Switching attention between different forms of stimuli was a strategic accommodation toward the environment provided. Although literature indicates that the affective and semantic attributes of a specific stimuli have potential influence on how people first perceive (Paivio, 1990), the perceptual sensation or sub-conception toward a particular form of stimuli are also based on the complexity of a visual material. In the case observed, students sometimes switched their starting point for processing screen information based on what they thought were easier, less complex, and shorter (text) for them to handle.

Graphics (in various forms) led to multiple interpretations . A mental representation created by learners was based on the way it was interpreted (which might not be accurate). It was found that novices processed information superficially based on the physical characteristics of the graphics, such as size and ratio, and ignored the conceptual meaning of the graphics. With the use of metaphorical elaboration, students were invited to see the graphics from a different aspect, and to construct a deeper conceptual connection of the information.

The animation provided episodic events that allowed to-be-remembered elements closely connected. In the lesson, animation was often used to illustrate a sequence of procedures and steps for a specific biological reaction. The animated scenario allowed students to connect related components more easily. Students could easily describe how a biological reaction occurred by pointing at the graphic objects. However, recalling the steps by using correct terms was not intuitive for students.

Matching the pace of animation with the presentation of verbal information facilitated effective referential processing, especially for less experienced students. When learning a unfamiliar concept through animation, students used to integrate the scene and text simultaneously and spontaneously for obtaining a holistic understanding. The processes involved, for some students, required much mental effort. Some students constantly pointed at the verbal explanations when viewing animation. This behavior reflected the limited working memory. With limited free memory, students needed frequent access to text and animation so that they could keep these two information sources in working memory and referentially processed the information more efficiently. The provision of metaphorical explanations also slowed dow.ı the pace of animation to allow sufficient time of processing. [Pause keys were provided together with metaphors at certain point of the animation. Students needed to click on the key to proceed the animation.] The finding is consistent with the empirical support in a series of studies which suggest corresponding graphic information with text (e.g. Mayer & Anderson, 1992; Mayer & Gallini, 1990).

When the metaphor could not match with -what was familiar to students, it became distracting to the process of learning. Although the intent of providing metaphors was to connect new information with things familiar to students, some students could not make the connections easily. Consequently, the metaphorical explanations became irrelevant for learning. Under this circumstance, students needed to make an extra effort to decipher and process the metaphors.

Conclusion

The statistical results indicate potential merit for integrating metaphors and animation in instruction. However, as implied from the findings, the significant effect of the instructional treatments might be determined by inherited factors, such as learners' prior experiences, the nature of the retention tasks given, the pace of the presentation, and the learning strategies employed by learners. Furthermore, graphics presented in computer screens are different from how they applied in other media. Students' viewing strategies and interpreting processes are inter-related factors worth for further exploration in the future research.

From the design aspect, the instructional strategies we propose in this paper are to invite instructional designer to carefully examine the designed graphics by adding metaphorical explanations to make the visual representations more concrete to the learners. In scientific learning, many abstract concepts are often materialized through the use of various forms of objects or symbols. Although the manipulation of these visual representations is assumed easier to communicate ideas, whether students can accurately interpret the meaning of the graphic objects or animation is questionable. The combination of metaphors and graphics adds another thinking dimension. Through the provision of a different thinking path, it is expected to extend the level of processing and space for thinking. It is hoped that the impact of this study may encourage more studies to research in this area.

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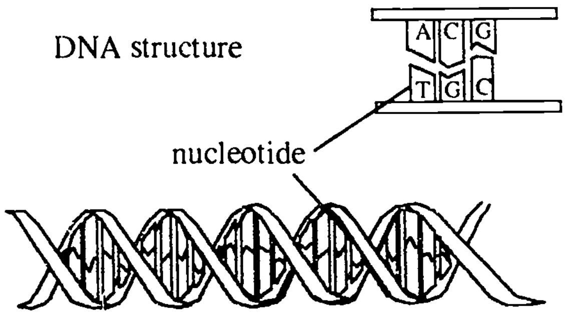
Appendix:
An example of employing metaphors for enhancing graphical information

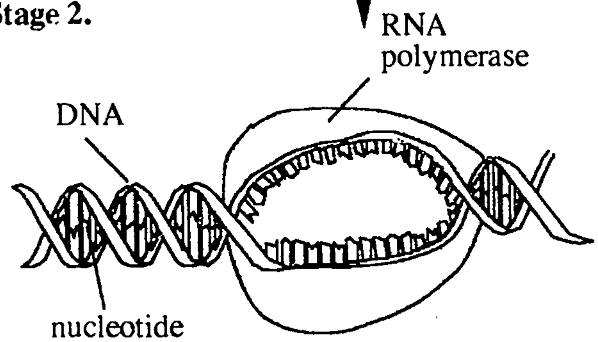
Stage 1.



Verbal Information:
DNA molecular contains a double-stranded structure. Each nucleotide of a single-stranded DNA is correspondent with a specific nucleotide on the other strand.

Elaboration Instruction:
Consider the component of a double-stranded DNA molecular as a screwed zipper. Each nucleotide of a single strand is paired with a specific nucleotide on the other strand.

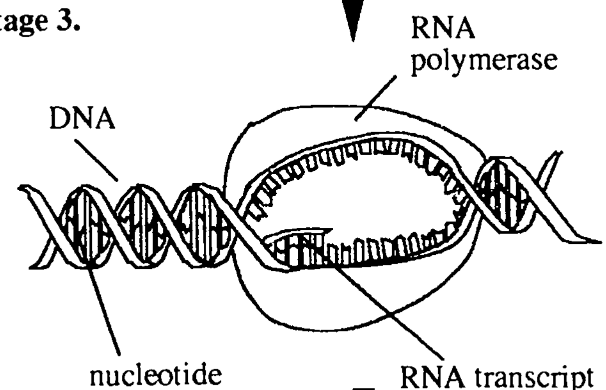
Stage 2.



Verbal Information:
When transcription occurs, the catalyst, RNA polymerase opens the double-stranded DNA.

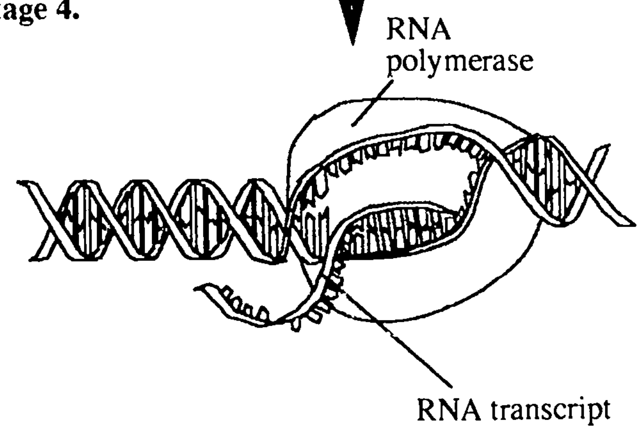
Elaboration Instruction:
Consider the catalyst, RNA polyme:ase as a "Force" that can make the paired DNA structure open. When transcription occurs, the RNA polymerase pulls the double-stranded DNA apart.

Stage 3.



Verbal Information:
RNA polymerase uses a single-stranded DNA as a template to reproduce complementary nucleotides. The reproduced one is called RNA transcript.

Stage 4.



Verbal Information:
The RNA polymerase moves forward to open DNA to reproduce complementary nucleotides. Whenever a complementary nucleotide is reproduced, the paired DNA nucleotides marry together. The reproduced one, RNA transcript releases.