

DOES THE REDUNDANCY PRINCIPLE OF MULTIMEDIA LEARNING HOLD IN THE  
SECONDARY SCIENCE CLASSROOM?

BY

ROBERT C. WALLON

THESIS

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Master's Committee:

Professor Margery Osborne, Chair  
Associate Professor David Brown  
Associate Professor Wen-Hao Huang

## ABSTRACT

This study examines the extent to which the redundancy principle of multimedia learning holds in the context of a secondary science classroom. Previous research has identified circumstances when eliminating redundant information improved learning outcomes, but those studies were conducted in laboratory and workplace settings rather than secondary science classrooms.

Therefore the goal of this study is to further clarify the boundaries of the redundancy principle.

This study used a pretest-posttest quasi-experimental design during the enactment of a curriculum unit in three periods of a non-introductory high school biology class. Fifty students were tested before and after watching either the redundant or nonredundant version of a video clip and at the conclusion of the curriculum unit. Comparison of student scores shows a redundancy effect on measures of retention but no redundancy effect on measures of transfer.

Future research should explore the applicability of the redundancy principle using more authentic measures of transfer.

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# CHAPTER I

## THE PROBLEM

### **Introduction**

Multimedia learning is, quite simply, "learning from words and pictures" (Mayer, 2009). Although commonly associated with computers, the term multimedia does not necessarily involve digital technologies. Because of the recent rise in the availability of educational video content via the internet, this research focuses on learning from multimedia video supported with digital technologies.

As American public school systems have expanded access to broadband technologies and computers, teachers have been presented with unprecedented opportunities to select from a variety of educational videos on many desired topics. In a recent national survey, 46% of teachers reported that they use the internet to find videos to include in their curriculum materials (Project Tomorrow, 2014). Teachers, until recently, did not have the options that are conveniently available today. A textbook may have formerly provided the only available pictorial representation of a concept. Now that teachers can select from among many options for visual content in the curriculum, they could potentially improve learning outcomes for students by applying research-supported multimedia learning principles as selection criteria.

Teachers have not only experienced increased access to educational video content, they have also been increasingly creating educational videos. In a recent national survey, 16% of teachers reported that they regularly create educational videos for their students (Project Tomorrow, 2014). A popular movement called "flipped learning" involves teachers authoring videos for students to watch at home so that they could provide more individual attention to

students during class time. In a recent national survey, teachers who had not flipped their classrooms reported feeling that they "needed instruction on how to 'make' or 'find high quality videos'" (Project Tomorrow, 2014, p. 2). An understanding of research-supported multimedia learning principles could also help teachers create effective videos when they seek novel ways to instruct their students.

The Cognitive Theory of Multimedia Learning uses established ideas from cognitive science to explain how people learn from words and pictures. Richard E. Mayer has developed associated multimedia learning principles based on research conducted with rigorous experimental designs. This large body of research has been able to make causal claims about the effects of multimedia learning principles, but the conditions needed to make causal claims have also limited the environments in which the multimedia learning principles have been studied. Most of this research has been done with multimedia related to scientific concepts such as how lightning forms, how plants grow, how mechanical systems such as brakes and pumps function (Mayer, 2009). While they can be important in instruction in any domain, multimedia representations are especially relevant to science instruction because they relate to several scientific practices that are a part of the *Next Generation Science Standards* (NGSS Lead States, 2013).

The redundancy principle is one multimedia learning principle that has been supported by Mayer as well as other researchers. Stated concisely, the redundancy principle says, "people learn better from graphics and narration than from graphics, narration, and printed text" (Mayer, 2009, p. 118). The redundancy principle has been supported by studies in laboratory settings (e.g., Mayer, Heiser, & Lonn, 2001) and workplace settings (e.g., Kalyuga, Chandler, & Sweller, 1999). Having clear significance in instructional multimedia design, testing the principle in

instructional settings seems relevant. Studies to date have not explored the extent to which the redundancy principle applies in classroom settings.

### **Statement of the Problem**

The redundancy principle has been supported in numerous research studies, but none of the studies took place in the environment of a secondary school classroom. This situation may be problematic if secondary school teachers want to apply the redundancy principle when creating or selecting multimedia in an attempt to improve learning in their classrooms. Harskamp, Mayer, and Suhre (2007) succinctly state the problem: "If design principles can be demonstrated in controlled lab environments but cannot be demonstrated in authentic school environments with students, their practical value for education and their theoretical value for multimedia learning are limited" (p. 446).

The redundancy principle has been studied in environments that primarily involve interactions between a learner and the content. Much of the learning that takes place in classrooms also involves interactions between teachers and learners and interactions between many learners as a group. The social interactions within a secondary science classroom create a complex environment different than the controlled laboratory setting. Research on other multimedia learning principles stated the limitation, "these studies were conducted as short laboratory experiments, but future work is needed to determine whether the findings generalize to more realistic educational settings" (Mayer & Johnson, 2008, p. 385).

The redundancy principle is especially important to study in the classroom setting because it contradicts common practices that suggest to present the same information in multiple formats to appeal to students' multiple learning styles. John Sweller (2005) elaborates on this issue: "It is easy to assume that presenting the same information in multiple forms or presenting

additional explanatory information could be advantageous and at worst, will be neutral. Such an assumption ignores what we now know of human cognitive architecture" (p. 166).

### **Purpose**

This study aspires to contribute to the research on the redundancy principle of multimedia learning. By studying if the redundancy principle holds in a secondary science classroom environment, this study will further clarify the boundary conditions on the contexts in which the redundancy principle can be usefully applied.

### **Significance of the Study**

Research must seek boundary conditions for the application of the redundancy principle to determine whether it holds implications for the design and use of multimedia video to teach science in secondary classrooms. Secondary science classrooms are complex environments in which dynamic interactions between and among students, teachers, and instructional materials frequently occur. Aspects of these social environments are difficult to control but nevertheless can affect student learning.

The results of this study may support the body of literature on the redundancy principle, or the results would further define the boundaries when the redundancy principle may not apply. If the redundancy principle is found to hold in authentic secondary classroom settings, then teachers can use this principle as a selection criterion when designing lessons that incorporate visual media such as videos. If the redundancy principle does not apply, then future research can aim to further clarify differences in the efficacy of the redundancy principle in different contexts.

## CHAPTER II

### LITERATURE REVIEW

#### **Introduction**

The purpose for this literature review is to provide a background for research into video use in the secondary science classroom as well as to provide information with practical significance to science teachers, science teacher educators, trainers, and curriculum designers who wish to maximize student learning outcomes resulting from video use. After all, video promises several important benefits especially in the context of science teaching if it is used in effective ways that are consistent with research. Harwood and McMahon (1997) indicate that "the use of video media in education is not new; however, its strengths have yet to be maximized" (p. 619). Moreno and Mayer (1999) cite research that shows that "despite its power to facilitate learning, multimedia has been developed on the basis of its technological capacity, and rarely is it used according to research-based principles (Kozma, 1991; Mayer, in press; Moore, Burton & Myers, 1996)" (p. 358). Using research-based findings in the design and use of video can maximize the strengths of multimedia in science education.

Improvements in information and communication technology (ICT) have expanded student access to video content on devices such as computers, tablets, and cell phones. Teachers also have increased access to video content as a result of the rising popularity of streaming video services such as YouTube, Discovery Education Streaming, Khan Academy, TeacherTube, and SchoolTube. However, expanded access to video does not necessarily mean effective educational use of video.

It is necessary to explain the term *video multimedia* before proceeding. Multimedia refers to the combination of text and graphics. Since the scope of the term multimedia is broad, I have narrowed the scope to video multimedia for the purposes this literature review (Mayer & Chandler, 2001). Video multimedia uses pictorial, auditory, and textual means to convey information. The pictorial component can include filmed footage or graphical illustrations sometimes called animations. This variety of pictorial representation allows the content presented in video to range from concrete to abstract. Limited interactivity differentiates videos from simulations, which have higher interactivity with displays that respond to user input. The ability to interact with video is limited to selecting segments to play, altering playback speed, rewinding, fast forwarding, or pausing.

I started my literature search using Google Scholar with the phrase "video media science classrooms." I had to carefully go through the results to find articles that related to my topic of interest. Common topics I excluded dealt with video games, using video as a method of doing research, and having students create videos as an instructional strategy. Once I found some articles related to the topic of the use of video to teach science, I used citation indexes to find other relevant articles. I found that I needed to change the term "media" to "multimedia" in order to find more relevant studies. I also searched using ERIC, which allowed me to filter articles by grade. I interpreted the meaning of "secondary science" to mean grades 6 through 12 based on U.S. use of the term, but I also reviewed research conducted in other countries. In order to review information about multimedia learning principles, I had to include studies that were done with college students because of the lack of research with secondary students. My main focus is not on college learners, and therefore the reviewed literature on the multimedia principles is not

exhaustive. Rather, I review enough literature to convey the main ideas of the theories supporting multimedia learning principles, and I review multiple studies on the redundancy principle.

This review is organized into sections that describe theoretical work and empirical studies on multimedia. Each main section of this review includes literature that addresses the following questions:

1. How can video be designed to promote student learning?
2. What are findings about learning from video in different scientific disciplines?

The first section, "Theoretical Foundations for Multimedia Learning," describes psychological theory on learning from multimedia and designing multimedia. The concluding section of the literature review examines studies of video use divided by the disciplines of biology, chemistry, earth science, and physics.

### **Theoretical Foundations for Multimedia Learning**

Before exploring literature that deals with the use of video in the secondary science setting, I discuss theoretical models for learning from multimedia using work from the field of cognitive psychology.

#### **Cognitive Load Theory**

*Cognitive load theory* is a useful starting point for considering how multimedia learning functions. Cognitive load theory conceptualizes human memory as working memory and long-term memory, and the theory states that information can only be stored in long-term memory after it has been processed by working memory (Cooper, 1998). According to cognitive load theory, working memory is limited in the amount of information that it can process at one time while long-term memory is relatively unlimited. Meaningful learning happens when information is stored in schemas in long-term memory, but new information must first be processed by the

limited working memory before being stored in long-term memory. Therefore the term *cognitive load* describes "the load imposed on working memory by information being presented" (Sweller, 2005, p.28).

Cognitive load theory conceptualizes cognitive load as being composed of (a) extraneous cognitive load, (b) intrinsic cognitive load, and (c) germane cognitive load. Extraneous cognitive load results from instructional strategies or materials unnecessarily overloading working memory. Intrinsic cognitive load is based on the inherent complexity of the information being learned. Germane cognitive load refers to the productive effort put toward building a schema in long-term memory (Sweller, 2005). Because cognitive load is made up of the sum total of the three categories of cognitive load, the instructional implications of cognitive load theory are especially relevant when the information to be learned is complex (i.e., has a high intrinsic cognitive load). When information to be learned is complex, learning can be improved by reducing extraneous cognitive load to free resources of working memory to process intrinsic and germane cognitive load.

### **Cognitive Theory of Multimedia Learning**

Mayer (2010) describes a model for learning from multimedia that is called the *cognitive theory of multimedia learning (CTML)*. The CTML accounts for the type of learning that enables people to form a mental model of a concept that they can manipulate such as a causal system. The CTML is based on three assumptions. First, the dual channels assumption posits that humans have two distinct channels for processing auditory information and visual information. Second, the limited capacity assumption uses cognitive load theory to suggest that each channel is limited in the amount of information that it can process in a given time. Third, the active processing assumption states that "humans engage in active learning by attending to relevant incoming

information, organizing selected information into coherent mental representations, and integrating mental representations with other knowledge" (Mayer, 2009, p. 63).

The CTML model, summarized in Figure 1, includes five cognitive processes: (a) selecting words, (b) selecting images, (c) organizing words, (d) organizing images, and (e) integrating. An example can be used to summarize these processes. A student uses her ears and eyes to input words and pictures from a multimedia presentation into sensory memory. The student uses cognitive processes of selecting words and selecting images to input sounds and images into working memory. Then the student uses the cognitive process of organizing words to create a verbal model. In an analogous way, the student uses the cognitive process of organizing images to create a pictorial model. Finally, the student uses the cognitive process called integrating to join the verbal model with the pictorial model and prior knowledge from long-term memory.

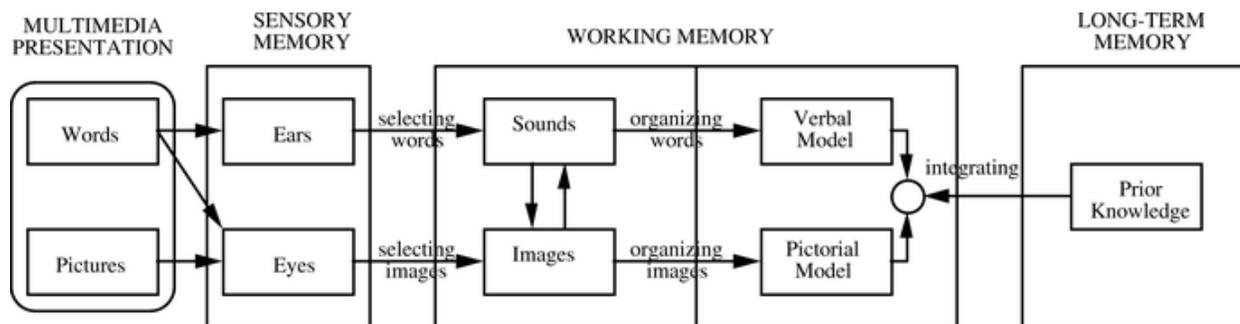


Figure 1. Cognitive theory of multimedia learning. From "Constraints on Multimedia Learning: When Presenting More Material Results in Less Understanding," by R. E. Mayer, J. Heiser, and S. Lonn, 2001, *Journal of Educational Psychology*, 93, p. 190. Copyright 2001 by the American Psychological Association.

Mayer (2009) articulates that the two goals for multimedia learning are remembering and understanding. Remembering is the "ability to reproduce or recognize presented material" (p. 20). Understanding is the "ability to use presented materials in novel situations" (p. 20).

Remembering can be measured with retention tests, and understanding can be measured with transfer tests (Mayer, 2009).

### **Principles of Multimedia Design**

The aforementioned theories have been used to develop multimedia learning principles that improve learning from multimedia. With reference to cognitive load theory, the principles are intended to reduce extraneous cognitive load, manage intrinsic cognitive load, or foster germane cognitive load. From Mayer, 2009, the multimedia learning principles intended to reduce extraneous cognitive load are:

- (a) the coherence principle,
- (b) the signaling principle,
- (c) the redundancy principle,
- (d) the spatial contiguity principle, and
- (e) the segmenting principle

The multimedia learning principles intended to manage intrinsic cognitive load are:

- (a) the segmenting principle,
- (b) the pre-training principle, and
- (c) the modality principle.

The multimedia learning principles intended to foster germane cognitive load are:

- (a) the multimedia principle,
- (b) the personalization principle,
- (c) the voice principle, and
- (d) the image principle.

Each of the multimedia learning principles is interesting in its own right, but for the purposes of this literature review I continue by focusing on one, the redundancy principle.

## **Redundancy**

In broad terms, "the redundancy effect occurs when additional information presented to learners results in learning decrements compared to the presentation of less information" (Sweller, 2005b, p. 159). This explanation of redundancy can involve either the same information in multiple forms or a larger quantity of information intended to elaborate on an idea. Mayer's research uses the former explanation of the redundancy effect. More specifically, the redundancy principle of multimedia learning states that "People learn more deeply from graphics and narration than from graphics, narration, and onscreen text" (Mayer, 2005, p. 193). This definition assumes that the onscreen text repeats the audio narration verbatim as is the case with subtitles on a film.

From a theoretical perspective, redundancy in multimedia overloads working memory in two ways. First, "the visual channel can become overloaded by having to visually scan between pictures and on-screen text" (Mayer, 2009, p. 118). Second, "learners expend mental effort in trying to compare the incoming streams of printed and spoken text" (p. 118). In both cases extraneous cognitive load is increased, leaving fewer resources for intrinsic cognitive load and germane cognitive load.

Mayer, Heiser, and Lonn (2001) conducted two experiments in which they found evidence of a redundancy effect. College students watched an animation about the formation of lightning and listened to audio narration explaining the process. In the first experiment, 22 students in the nonredundant group watched the animation with audio narration and no text, and 19 students in the redundant group watched the animation with audio narration and text. Students

in the nonredundant group scored significantly higher than students in the redundant group on retention tests and transfer tests. In the second experiment, 36 students in the nonredundant group watched the animation with audio narration and no text, 37 students in redundant group 1 watched the animation with audio narration and text summaries, and 36 students in redundant group 2 watched the animation with audio narration and full text. Students in the nonredundant group scored significantly higher than students in redundant group 1 and redundant group 2 on retention tests and transfer tests. There were no significant differences in retention scores or transfer scores between redundant group 1 and redundant group 2.

Moreno and Mayer (2002a) conducted an experiment in which they found a redundancy effect when text information was presented simultaneously with graphics, but they found the opposite to be true when text information was presented sequentially before the graphics. College students watched an animation about the formation of lightning. Text and animations were presented sequentially in the first experiment of this study, and redundant groups scored significantly higher than nonredundant groups on retention tests, transfer tests, and matching tests. Text and animations were presented sequentially and simultaneously in the second experiment of this study, and the researchers found an interaction between redundancy and presentation order in which redundant groups scored significantly higher than nonredundant groups on retention tests and transfer tests only when the presentation was sequential but not when it was simultaneous.

Moreno and Mayer (2002b) investigated the redundancy principle in the context of a virtual reality science game environment. College students learned about how plants grow in different environmental conditions. Students learned in one of three groups: (a) narration, (b) text, or (c) narration and text. Students in the text group scored significantly lower on retention

tests and transfer tests than students in the narration or narration and text groups. There were no significant differences in retention test scores or transfer test scores between the narration group and the narration and text group, indicating that no redundancy effect was found. The researchers explained this result by stating, "when students are exploring an environment (either by moving the computer mouse or by moving their head), it is less likely that they will read a box containing text if they can obtain the same information by listening to a narration" (pp. 608-9).

Kalyuga, Chandler, and Sweller (1999) also found a redundancy effect in their study of 34 first year trade apprentices. The trade apprentices learned about soldering using self-paced multimedia tutorials. The tutorials were provided to 12 participants with printed text and narration, 11 participants with printed text only, and 11 participants with narration only. The narration only group scored significantly better than the other groups in a transfer test.

Kalyuga, Chandler, and Sweller (2000) performed another study in which inexperienced trade apprentices learned about how to read a specialized diagram to determine an appropriate rpm for cutting. The apprentices were divided so that 15 learned with a diagram and printed text, 15 learned with a diagram, printed text, and narration, 14 learned with a diagram and narration, and 15 learned with a diagram only. The group of apprentices with the diagram and narration performed significantly better than the other groups, showing evidence for a redundancy effect. The researchers repeated the experiment with 38 of the apprentices who participated in the first experiment after 2.5 months had passed. The group was divided so that 19 subjects learned using a diagram with narration and 19 subjects learned using only a diagram. The group that learned with only the diagram performed better than the group that learned with the diagram and the narration. The researchers explained this result by stating, "the auditory explanations may also become redundant when presented to more experienced learners" (p. 135).

Craig, Gholson, and Driscoll (2002) conducted a study in which college students learned about lightning formation from an animation that included a pedagogical agent. A total of 71 students participated with 24 students learning from narration, 23 students learning from printed text, and 24 students learning from narration and printed text. There was no significant difference between groups on a retention test. The students who learned from narration scored significantly better than the students who learned from printed text and the students who learned from narration and printed text on a transfer test.

Jamet and Bohec (2007) also found a redundancy effect in a study in which college students learned about memory models. A total of 90 students participated in the study with 30 students learning from animated slides with no text, 30 students learning from slides with full text, and 30 students learning from slides with sequential text. The group that learned with no text performed significantly better than groups that learned with full text and groups that learned with sequential text on retention tests and transfer tests.

Mayer and Johnson (2008) revised the redundancy principle after conducting two experiments that showed redundancy could actually promote learning of how brake systems function if the text was short key words rather than complete replication of the audio and if the text was placed near the relevant images rather than far away at the bottom of the screen. As a result of these experiments, Mayer and Johnson added the limitation to the aforementioned definition of the redundancy principle to exclude “when the on-screen text is short, highlights the key action described in the narration, and is placed next to the portion of the graphic that it describes” (p. 385).

In revising the redundancy principle, Mayer and Johnson (2008) also expected other boundary conditions to apply: “We also suspect that other boundary conditions include when the

spoken text is complex, contains unfamiliar words, or is not in the learner's native language; when the pace of the presentation is slow or under the learner's control; or when no graphics are presented (Mayer, 2001, 2005c)" (p. 385).

## **Summary**

Research in the field of cognitive psychology has provided theoretical models for how people learn from multimedia. Some of the most notable work in this field is cognitive load theory and the cognitive theory of multimedia learning. These theories have enabled the research and development of several multimedia learning principles. The redundancy principle is one of the multimedia learning principles that has been supported in several empirical studies. However, the research does not show simple and unproblematic support for the redundancy effect. Some studies did show that adding redundant text hurt learning outcomes on retention tests and transfer tests (e.g., Jamet & Bohec, 2007; Mayer, Heiser, & Lonn, 2001). Other studies showed this result only for transfer tests (e.g., Craig, Gholson, & Driscoll, 2002). Other studies highlighted confounding issues. One study found no redundancy effect based on the idea that students may voluntarily ignore the text when they can rely on audio in an immersive environment (Moreno & Mayer, 2002b). Another study found that what is considered redundant may depend on the prior knowledge and experience of the learners (Kalyuga, Chandler, & Sweller, 2000). In revising the redundancy principle, Mayer and Johnson (2008) concluded that multimedia learning principles "are not rigid laws that must be followed in all circumstances" (p. 385). Instead, they emphasized the need to use cognitive load theory and the cognitive theory of multimedia learning in order to make instructional decisions that lower extraneous cognitive load, manage intrinsic cognitive load, and promote germane cognitive load.

## Studies of Video Use

In this section I review empirical studies about the learning outcomes of video multimedia use in the classroom. First I review a study that examined barriers to effective use of video. Then I review empirical studies of video use divided by the disciplines of biology, chemistry, earth science, and physics.

### Barriers to Effective Use

Hobbs (2006) found that video use in the classroom is not as effective as it could be because of prevalent non-optimal teaching behaviors. From conducting surveys with teachers, Hobbs synthesized common non-optimal uses of video in the classroom that include

- no clearly identified instructional purpose;
- no use of pause, rewind, or review;
- large-group viewing experiences give teachers a "break;"
- teacher mentally disengages during viewing experiences;
- teacher uses TV viewing as a reward;
- teacher uses media only as an attentional hook; and
- teacher uses video to control student behavior (p. 40-44).

All of the non-optimal uses were behaviors that could potentially reduce how much students learned from video.

### Video Use in Scientific Disciplines

In the sections that follow I review empirical studies of video use in classroom environments.

**Biology.** Kombartzky, Ploetzner, Schlag, and Metz (2010) investigated the learning of sixth grade German students. Some students watched an animated video clip about honey bees

with a designated strategy while others did not, and the researchers found that the strategy group scored significantly higher than the essay group on a post-test of conceptual and rule-based knowledge but not of factual knowledge.

Yadav, Phillips, Lundeberg, Koehler, Hilden, and Dirken (2011) used three case studies of biological infections to teach university students. The case studies were presented on web sites with three different formats of (a) text only, (b) video only, or (c) video and text. The format of the presentation did not significantly affect students' recall after six weeks. Students who saw the video format recalled details in some of the case studies better than those who saw text only. More students were engaged by the formats that included video than the format that included only text.

Alvarado and Maskiewicz (2011) used episodes of the television program *House M. D.* in two units of a high school general biology class. Some classes learned in the unit while watching the program, and other classes did not watch the program. The researchers found that students who watched the program during the nervous system unit scored higher on a delay-test than students who did not watch the program. In the immune system unit the researchers found there was no significant difference in scores on a delay-test between students who did and who did not see the program.

**Chemistry.** Rodrigues, Smith, and Ainley (2001) used data loggers to study how 11-13 year old Australian students selected video clips that explained molecular events. The researchers found that the majority of students did not skip the order in which the videos were presented on a CD-ROM. They also found that students preferred to watch actual footage over animated footage of the same concept. The majority of students reported on a survey that video with text helped them understand the content the best.

Wu, Krajcik, and Soloway (2001) studied how viewing animations of chemicals helped students manipulate representations. Comparison of pre-tests and post-tests showed that the activity significantly improved students' abilities to make translations of chemical structures. The researchers concluded that the animations were helpful because they provided a way to visualize scientific concepts that would otherwise be too abstract or too difficult to see because of microscopic size. The researchers suggested that the use of computerized models of chemicals helped students develop their own mental models of chemicals.

Harwood and McMahon (1997) investigated the effects that integrating video multimedia in a high school chemistry class had on student achievement and attitudes toward chemistry. They found that in a study of 450 first-year general chemistry high school students, the classes with integrated videos showed significantly higher scores on a standardized test and researcher-designed quizzes. The students in classes with integrated video also showed a significantly more positive increase in scores on a survey of attitudes toward chemistry.

Velázquez-Marcano, Williamson, Ashkenazi, Tasker, and Williamson (2004) studied whether the order of macroscopic and submicroscopic videos explaining diffusion affected university first-year chemistry students' learning outcomes. The researchers found that students improved their predictions after watching videos, but the order did not matter.

**Earth Science.** Deutscher (2010) conducted an evaluation of a commercial curriculum that included video multimedia. When comparing pre-test scores and post-test scores of middle school students, the researcher found that students performed significantly better on the post-tests than the pre-tests. Classes that reported using all of the provided multimedia performed significantly better on the post-tests than classes that reported not using all of the multimedia.

**Physics.** Kearney and Treagust (2001) studied how Australian university students' use of the predict-observe-explain technique with videos of physics demonstrations affected students' perceptions of learning from digital video. The researchers used questionnaires to find that students perceived the opportunity to use a strategy while viewing multimedia videos was helpful in learning physics content.

## **Discussion**

Although findings from one content area may or may not generalize to other content areas, dividing the empirical studies showed a difference in the amount of research about learning from video multimedia in different disciplines. Relatively more research on video use has been done in biology and chemistry than in earth science and physics. This is especially important to note if the findings in one content area do not generalize to other content areas. More research on video use is needed in all science content areas, but these studies highlight the largest need in earth science and physics.

A common theme that developed from the research is that there are not always clear improvements in learning outcomes from multimedia use. A study of one teacher's technique showed significantly improved results from video use in one unit of study while the technique showed no significant difference in another unit of study (Alvarado & Maskiewicz, 2011). This result indicates that there may be many complex factors that are involved in the effective use of video for science learning. If one teacher's findings did not generalize from one of her own units to another, then there is concern about findings generalizing to other classrooms, communities, and disparate learning environments.

Some studies that showed improvements from pre-test scores to post-test scores did not consider if the gains would have been made with instructional materials besides multimedia

(Deutscher, 2010; Wu et al., 2001). Perhaps the same learning gains could have been made in a variety of formats. A study that did explore differences in learning gains between multimedia and non-multimedia materials found no significant difference in recall after six weeks (Yadav et al., 2011). This highlights the need for future research to focus on video multimedia in comparison with other formats.

Many of the studies reviewed do not show conclusive support for learning from multimedia in science classrooms (Swarat et al., 2012). This raises important questions about the role of student interest and motivation in learning because multimedia in and of itself does not necessarily improve learning outcomes.

### **General Discussion**

Research in cognitive psychology has provided principles for the effective design of multimedia, including the redundancy principle. When looking at how multimedia learning principles generalize, it is important to note that support for these principles has been demonstrated most often in settings other than authentic classrooms.

Yet the empirical studies that were conducted in authentic classrooms only sometimes implicitly referred to multimedia learning principles. For example, Alvarado and Maskiewicz (2011) said that "the value of teacher-scheduled interruptions into a media presentation allows for processing time and discussion of ideas..." (p. 327). This is a description of the segmenting principle, but it is not explicitly named as such (Mayer & Chandler, 2001). The example also relates to the research on non-optimal uses of video that included not using the pause button (Hobbs, 2006). The lack of connection to prior research in an empirical study co-investigated by a practitioner points to a disconnect between theory and practice. The research findings should be made accessible to practitioners so that a common language can be used when discussing the

effective use of video multimedia in science classrooms. At the same time, researchers need to investigate established principles of multimedia learning in the context of real secondary classrooms if the findings are to have practical implications for educators.

The multimedia principles were researched with a focus on science instructional multimedia that dealt with causal systems. It is important to note that teachers may have diverse learning goals for students that extend beyond causal systems. For example, Yadav et al. (2011) used case studies to teach students about the societal effects of biological infections rather than how the infections are caused. The multimedia principles should be explored in the context of the other types of learning goals that science teachers have for students. This would clarify the degree to which the principles apply or do not apply to broad science learning goals.

It is unfortunate that little demographic information was provided about the teachers when empirical studies did show gains in student learning, (Deutscher, 2010; Harwood & McMahon, 1997; Kombartzky et al., 2010; Wu et al., 2001). It would be helpful to identify characteristics of the teachers and their training so that information could be used to help improve practice for other teachers.

Another interesting point to emphasize is the nature of technology as it relates to showing video multimedia. One of the empirical studies used videos on CD-ROMS (Rodrigues et al., 2001). This is a relatively outdated technology exemplified by the rise in popularity of tablets, smart phones, and laptops that are not equipped with CD-ROM drives. It is now more common for video multimedia to exist in other digital formats. Even when video is used in the classroom, it may be used in different ways that may support or constrain discourse about the videos. For example, a teacher may assign videos to be watched independently as homework or collectively

as a group during class time. Future research should include this contextual factor when examining learning outcomes from using video to teach science.

## CHAPTER III

### RESEARCH PROCEDURES

#### **Research Methodology**

My research question is: Does the redundancy principle of multimedia learning hold in the secondary science classroom? In order to investigate my research question, I reached out to teachers who participated in a summer professional development workshop who had received training on using a particular curriculum unit. The curriculum unit included a video that explained a technique in molecular biology that enables the visualization of stem cells in planarians. The teacher who participated in this study taught three sections of a high school level, non-introductory biology course.

I used a quasi-experimental design in order to investigate my research question in the regular classroom environment. Because students were already grouped in classes, disrupting the established classes would introduce new dynamics and thus new variables. Randomly assigning each student into a group would have been logistically more challenging. One class period was randomly assigned to the nonredundant condition, and two class periods were randomly assigned to the redundant condition.

#### **Development of Pre-Tests, Post-Tests, and Delayed Post-Tests**

I developed the test questions based on similar structures found in the literature (Moreno & Mayer, 2002a). All tests asked students to self-rate their understanding of six biological terms that were important in understanding the video. The pre-tests also asked students to define each of the six terms as a way to measure students' prior knowledge. The post-test asked students to define the same six terms and asked students to answer five additional open-ended questions.

Asking students to define terms was designed to measure students' recall, and asking students to answer the open-ended questions was designed to measure students' transfer. The delayed post-test was identical to the post-test.

### **Description of School, Classroom and Curriculum**

I conducted this study at a mid-sized high school in a town located near a small Midwestern city. The majority of the school's student population was white, with no federal race and ethnicity subcategory larger than 5%. The school low-income level was around 25%. My study took place in the context of an entire curriculum unit in three periods of a second level biology class taught by the same teacher. Students in the classes ranged from grade ten to grade twelve.

I obtained a complete data record of pre-tests, post-tests, and delayed post-tests from 50 students. One class of 20 students served as the nonredundant group. Two classes of 30 total students served as the redundant group.

The teacher attended summer professional development workshops to learn how to use Project NEURON curriculum materials. During this study the teacher used the curriculum unit titled "What can I learn from worms? Regeneration, stem cells, and models" (Project NEURON, 2013). The curriculum unit is described as follows from the Project NEURON web site:

This unit is grounded in a cost-effective and student-driven investigation that teachers love! Intrigued by the fascinating behavior of regeneration, students examine the process of cellular division and visualize the process of planarian flatworm regeneration with fluorescent images from the University of Illinois. While students collect and analyze their own experimental data, students use computer models to simulate how DNA and

protein affect behavior and explore applications of what they've learned to disease and stem cell research. (Project NEURON, 2013)

The curriculum unit was enacted over sixteen days of instruction. A timeline of curriculum enactment can be found in *Table 1*.

### **Specific Procedures**

Near the beginning of the school year, students in all three class periods were invited to participate in the research study. I provided parents with letters of consent, and I provided students with letters of assent. I used data only from students who assented and whose parents consented to participating in the research.

All pre-tests, post-tests, and delayed post-tests were printed on 8.5 X 11 inch paper. The video was projected from a ceiling-mounted LCD projector onto a SMARTboard screen at the front of the classroom.

Students took a pre-test on instructional day 8 (*Table 1* provides a timeline of instructional days in the unit). Students were allowed 10 minutes to take the pre-test, and all students finished within the allocated time. The pre-test can be found in *Appendix A*. The pre-test consisted of one page where students could rate their understanding of six terms and an additional page where students explained each of the six vocabulary terms. The pre-test was administered to measure students' prior knowledge.

During the next class period, instructional day 9, students watched the BrdU video clip (available online at <http://neuron.illinois.edu/videos/brdu>). The BrdU video clip was presented in either a redundant or nonredundant version. Both versions were identical except the redundant version displayed text redundant with all of the spoken audio at the bottom of the screen (*Figure 2*).

Table 1. Timeline of instructional days in curriculum unit.

| <b>Instructional Day</b> | <b>Summary of Lesson</b>  |
|--------------------------|---|
| 1                        | -Introduction of planarian unit with discussion of regeneration<br>-Regeneration jigsaw readings              |
| 2                        | -Mini-lecture on planarian anatomy<br>-Planarian observations and feeding with bloodworms                     |
| 3                        | -Planarian cutting  |
| 4                        | -Planarian observations, Day 1  |
| 5                        | -Planarian observations, Day 2<br>-Journey to Neoblast Division packet handed out                             |
| 6                        | -Planarian observations, Day 5<br>-Journey to Neoblast Division packet continued                              |
| 7                        | <b>-Pre-test for video</b><br>-Planarian observations, Day 6<br>-Cell cycle modeling activity                 |
| 8                        | <b>-BrdU Video</b><br><b>-Post-test for video</b><br>-Planarian observations, Day 7<br>-BrdU packet started   |
| 9                        | -Planarian observations, Day 8<br>-BrdU packet continued  |
| 10                       | -Planarian observations, last day<br>-BrdU packet continued<br>-RNAi reading                                  |
| 11                       | -Lecture on constructing scientific explanations<br>-Notes on RNAi<br>-NetLogo RNAi modeling activity started |
| 12                       | -NetLogo RNAi modeling activity continued   |
| 13                       | -NetLogo RNAi modeling activity finished<br>-Poster project introduced  |
| 14                       | <b>-Delayed post-test for video</b><br>-Letter to a family member explaining future of regenerative medicine  |
| 15                       | -Planarian posters<br><b>-Follow up interviews were conducted with 1 group from each class</b>                |
| 16                       | -Unit Test  |

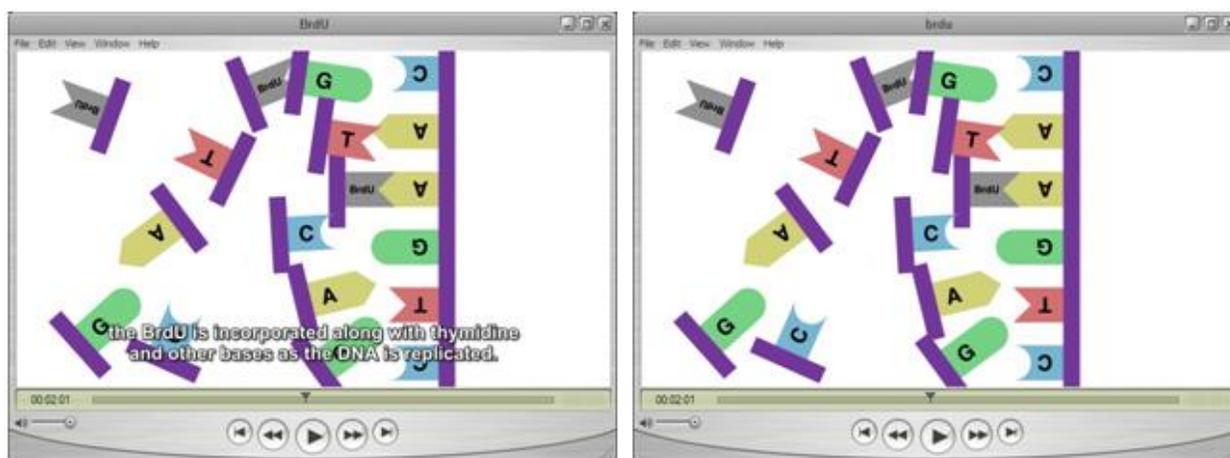


Figure 2. Screenshots of redundant video (left) and nonredundant video (right).

The video clip was developed in an iterative process that was initiated when teachers piloting the curriculum unit requested materials to help students understand how scientists visualize regeneration. The curriculum developers interviewed a scientist at the University of Illinois at Urbana Champaign in order to film him explaining how his laboratory visualizes regeneration using a chemical called BrdU. That footage was combined with custom animations, and teachers provided feedback on early drafts of the video. The developers did not explicitly apply multimedia learning principles during the development of the video. A version of the video with captions was made available after a request from a teacher who works with English language learners (although there were no English language learners in this study), and this made the video available in both redundant (with captions) and nonredundant (without captions) formats.

The video clip lasted approximately 5 minutes. Immediately after watching the video clip students completed the post-test. Students were allowed 15 minutes to take the post-test, and all students finished within the allocated time. The post-test can be found in *Appendix B*. The first two pages of the post-test were identical to the pre-test. The second page was administered to

measure students' retention from the video. An additional third page included five open-ended questions that were administered to measure students' transfer from the video.

Students completed the delayed post-test near the end of the curriculum unit on instructional day 14. Students were allowed 15 minutes to take the delayed post-test, and all students finished within the allocated time. The delayed post-test was identical to the post-test, and it can also be found in *Appendix B*.

A follow up interview was conducted with one group of students from each class period on instructional day 15. The teacher was asked to identify three typical students, and interviews were conducted outside of the normal classroom while other students reviewed for the unit test. Students were asked to collaborate on a delayed post-test so that I could observe some of their thought processes. Students were also asked some general questions about their perceptions of the curriculum unit.

### **Data Analysis**

Field notes from classroom observations were reviewed and served as the basis to write the vignette.

Student responses to 67% of retention items on pre-tests, post-tests, and delayed post-tests were independently scored by the author and a colleague using the scoring guides found in *Appendix C*. Scores were compared and any discrepancies were resolved by discussion. Each of the six retention items could be scored up to 5 points, with a maximum score of 30. Student responses to transfer items on post-tests and delayed post-tests were scored by adding up the number of acceptable responses, up to a maximum of 5 points per item for a maximum total of 25 points.

I ran ANOVAs using R software to determine if there were significant differences between scores for students in the redundant and nonredundant conditions.

I selected example student responses from redundant and nonredundant groups to show various progressions from the pre-test to post-test to delayed post-test. I also included example responses from group interviews.

## CHAPTER IV

### FINDINGS

The test scores serve as the primary data source for answering my research question. However, I start the findings section with a vignette to illustrate the classroom environment on Instructional Day 2. The vignette is written from my perspective as an observer in the class, and it is a synthesis of events from the three class periods. Student and teacher names are pseudonyms to protect confidentiality. Lastly, I present sample student responses that highlight strengths and limitations of learning from the multimedia video used in this study.

#### **Vignette**

"Today is probably going to be one of the best days in here," Heather says to three other students as she slings her backpack off of her shoulder and pulls out a notebook. The other three students seated at the front table, a cluster of four desks, have already settled in. At the back corner of the room Chris holds up a magnifier from a bin of equipment on his desk and peers at the ceiling through it. The bell rings. Around the room the sound of shuffling to seats and rummaging through backpacks dies down. One more student enters the classroom, hugging a binder, and scuttles to her seat.

"Hellllloooo!" Mrs. Manzella's voice booms as she enters from the hallway where she had stood propping the door open and greeting students individually as they entered the classroom. In an enthusiastic tone she asks the class, "Why are planarians *awesome*? Stephanie." As quickly as she called on her, Stephanie responds matching the teacher's tone, "Uh, because they can *regenerate*!" While the student responded, Mrs. Manzella had moved swiftly to the side counter and placed small jars and containers of equipment onto student desks. The teacher reminds

students that they read about regeneration yesterday, and then she directs their attention to the front board to take down some notes about planarians, the flatworms that students would soon observe.

Most students are diligently copying down diagrams from the board into their notebooks. One diagram highlights the planarian nervous system, and the other diagram describes the planarian digestive system. One student raises the small jar in the air and inadvertently scowls as she strains her eyes to see the jar's contents. Heather, who had shown such excitement when she entered the room, props her head up with one hand as she finishes copying notes from the board. The teacher concludes the notes, "Get going on your observations!"

Instantaneously a wave of energy spreads throughout the room as conversations erupt at each of the six clusters of three to four students. What a difference from a moment ago when the sound of the air conditioner could be heard. Now nothing could be heard unless I move closer to focus on an individual group. "What are we supposed to do first?" One student asks the student seated next to him while she skims the guidelines for the activity. At another group a student says to her partner, "We need more water in the Petri dish. What's the right amount?" Around the room pairs of students are huddling around small containers of planarians and watching what happens when they add bloodworms, or mosquito larvae, to their containers. About half of the groups have placed their containers on the stage of their dissecting microscopes to get a better view of the planarians. One student looks through the eyepiece of the microscope while giving directions to his partner on which direction to move the container on the stage. At another group one student asks his partner, "How do you focus this thing?" No response. A few seconds later he tries again, "Does this thing have a focus?" Again no response. He repeats the question. This

time his partner looks up, snaps his fingers, and motions to move the microscope closer so he can manipulate the knobs.

At another table Heather offers to her partner, "Here, you want to see him? You have to be quick to follow him under the microscope." Across the table another student inquires, "Why do you automatically call it 'he'? We don't know if it's male or female." The entire table continues a conversation about the gender of planarians. Mrs. Manzella is crouched down at the adjacent table. "He ran away from the light when he was under the microscope," a student relays his observation. "Would you really want to say 'ran'? What does that imply?" the teacher challenges. The student rephrases his response and reasons that the planarian showed "negative phototaxis" because it moved away from the light. Across the table a student asks, "Does yours have orange spots now?" A student at another table quickly jumps in, "My planarian turned orange after eating!" I check in with students to see how the activity is going at another table. "Mine is a stupid one. It isn't eating the food." And just as soon as she finished her sentence she continues, "Oh! He's eating it! He's eating it! Ewww! He's like wrapped around it." I glance at a student's paper with his observations. In the space designated for drawing observations he has reproduced what looks like the diagram that was on the board for notes at the beginning of the period. Chris at the back table does not have his paper nor a pen. His chin is resting on the desk as his eyes follow the planarian gliding in his container.

Some students have started putting equipment back in the bins at their tables. "They're hermaphrodites! Did you hear her?" Heather exclaims to her group, settling their previous argument, after she overheard Mrs. Manzella talking to another group about the planarians' gender. Some students have retrieved their book bags, and then the bell rings. Students file out.

## Test Scores

For this research study the dependent variable was test scores. The independent variable was the condition of watching either the redundant or nonredundant version of the video. Statistical comparisons between scores for the redundant and nonredundant groups are provided below. Statistical significance is reported, and when results are statistically significant effect sizes are reported as  $\eta^2$ . Cohen (1988) suggests using the following guidelines to characterize effect sizes: 0.01 is a small effect size, 0.059 is a medium effect size, and 0.138 is a large effect size. The results of all tests are summarized in Figure 3, and then each test is described in detail below.

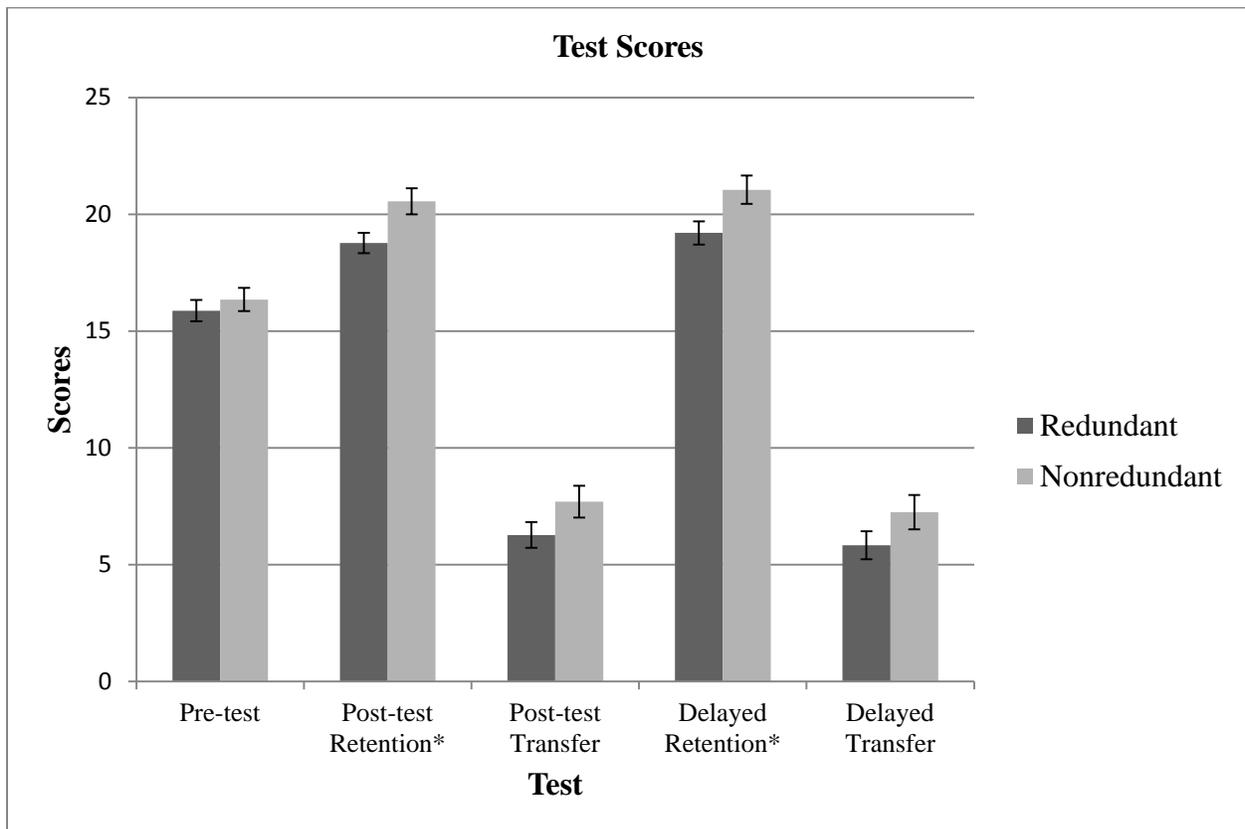


Figure 3. Mean test scores for redundant group (N=30) and nonredundant group (N=20) with standard error bars. \* indicates statistically significant difference.

### **Pre-test Scores**

The means and standard deviations are presented in Table 2. Average scores on each item are presented in Table 7. An analysis of variance indicated that there are no significant differences among the two treatments,  $F(1,48) = 0.49, p > .05, \eta^2 = 0.01$ .

### **Post-test Retention Scores**

The means and standard deviations are presented in Table 3. Average scores on each item are presented in Table 7. The analysis of variance indicates that there are significant differences among the two treatments,  $F(1,48) = 8.83, p < .01, \eta^2 = 0.12$ . The difference between scores for the nonredundant group and the redundant group were even more statistically significant when factoring in pre-test scores,  $F(1,48) = 18.81, p < .001, \eta^2 = 0.25$ .

### **Post-test Transfer Scores**

The means and standard deviations are presented in Table 5. Average scores on each item are presented in Table 8. The analysis of variance indicates that there are no significant differences among the two treatments,  $F(1,48) = 2.69, p > .05, \eta^2 = 0.05$ .

### **Delayed Post-test Retention Scores**

The means and standard deviations are presented in Table 4. Average scores on each item are presented in Table 7. The analysis of variance indicates that there are significant differences among the two treatments,  $F(1,48) = 6.93, p < .05, \eta^2 = 0.10$ . The difference between scores for the nonredundant group and the redundant group were even more statistically significant when factoring in pre-test scores,  $F(1,48) = 13.03, p < .001, \eta^2 = 0.19$ .

### **Delayed Post-test Transfer Scores**

The means and standard deviations are presented in Table 6. Average scores on each item are presented in Table 8. The analysis of variance indicates that there are no significant differences among the two treatments,  $F(1,48) = 2.26, p > .05, \eta^2 = 0.04$ .

*Table 2.* Pre-test means and standard deviations of retention scores for redundant and nonredundant groups. There is no significant difference between treatments,  $F(1,48) = 0.49, p > .05, \eta^2 = 0.01$

|           | Redundant | Nonredundant |
|-----------|-----------|--------------|
| <i>M</i>  | 15.87     | 16.35        |
| <i>SD</i> | 2.50      | 2.21         |

*Table 3.* Post-test means and standard deviations of retention scores for redundant and nonredundant groups. There is a significant difference between treatments,  $F(1,48) = 18.81, p < .001, \eta^2 = 0.25$

|           | Redundant | Nonredundant |
|-----------|-----------|--------------|
| <i>M</i>  | 18.77     | 20.55        |
| <i>SD</i> | 2.39      | 2.50         |

*Table 4.* Delayed post-test means and standard deviations of retention scores for redundant and nonredundant groups. There is a significant difference between treatments,  $F(1,48) = 13.03, p < .001, \eta^2 = 0.19$ .

|           | Redundant | Nonredundant |
|-----------|-----------|--------------|
| <i>M</i>  | 19.20     | 21.05        |
| <i>SD</i> | 2.73      | 2.70         |

*Table 5.* Post-test means and standard deviations of transfer scores for redundant and nonredundant groups. There is no significant difference between treatments,  $F(1,48) = 2.69, p > .05, \eta^2 = 0.05$ .

|           | Redundant | Nonredundant |
|-----------|-----------|--------------|
| <i>M</i>  | 6.27      | 7.70         |
| <i>SD</i> | 3.02      | 3.05         |

*Table 6.* Delayed post-test means and standard deviations of transfer scores for redundant and nonredundant groups. There is no significant difference between treatments,  $F(1,48) = 2.26, p > .05, \eta^2 = 0.04$ .

|           | Redundant | Nonredundant |
|-----------|-----------|--------------|
| <i>M</i>  | 5.83      | 7.25         |
| <i>SD</i> | 3.26      | 3.27         |

*Table 7.* Average scores on retention items for redundant (R) and nonredundant (NR) groups.

| Item         | Pre-tests |      | Post-tests |      | Delayed Post-tests |      |
|--------------|-----------|------|------------|------|--------------------|------|
|              | R         | NR   | R          | NR   | R                  | NR   |
| Stem cells   | 3.42      | 3.90 | 3.61       | 3.75 | 3.90               | 3.95 |
| Regeneration | 3.73      | 3.95 | 3.81       | 4.15 | 3.97               | 4.35 |
| Fluorescence | 2.13      | 1.80 | 2.81       | 3.25 | 2.90               | 3.25 |
| BrdU         | 1.13      | 1.20 | 2.81       | 3.50 | 2.81               | 3.35 |
| DNA          | 2.97      | 3.25 | 2.68       | 3.10 | 3.16               | 3.45 |
| Antibodies   | 2.53      | 2.25 | 3.00       | 2.80 | 2.52               | 2.70 |

*Table 8.* Average scores on transfer items for redundant (R) and nonredundant (NR) groups.

| Item       | Post-tests |      | Delayed Post-tests |      |
|------------|------------|------|--------------------|------|
|            | R          | NR   | R                  | NR   |
| Question 1 | 2.17       | 2.70 | 1.93               | 2.20 |
| Question 2 | 0.63       | 1.00 | 0.80               | 1.25 |
| Question 3 | 1.73       | 1.80 | 1.80               | 2.10 |
| Question 4 | 1.10       | 1.35 | 0.87               | 1.00 |
| Question 5 | 0.63       | 0.85 | 0.43               | 0.70 |

### Sample Student Responses

Below I have listed example student responses from the redundant group and the nonredundant group to show the wide variety of student responses on the tests. I list responses to retention items where students defined the terms BrdU and antibodies. I decided to show responses to the term BrdU because it was expected that students were unfamiliar with this word before watching the video. I decided to show responses to the term antibodies because it was expected that students were familiar with this word from prior experiences.

## Definitions of BrdU

### **Redundant group.**

*Student 1.*

Pre-test: A type of DNA.

Post-test: Planarians eat it, it goes into their stem cells, antibodies attach and the fluorescence is on the antibody.

Delayed post-test: A thing that is feed (*sic*) to planarians that fluorescence attaches to that allows scientists to see the stem cells.

*Student 2.*

Pre-test: (student left blank)

Post-test: A chemical scientists feed planarians and other animals to see certain parts in their body.

Delayed post-test: Chemical that makes changes to your RNA and Proteins (*sic*).

### **Nonredundant group.**

*Student 1.*

Pre-test: I do not know what this is.

Post-test: This is a chemical compound that replaces thymine in the process of DNA replication that allows specific antibodies to target stem cells.

Delayed post-test: This is a compound that takes the place of thymine and is used to help tag stem cells in planarians.

*Student 2.*

Pre-test: (student left blank)

Post-test: A chemical that is injected in organisms to help regeneration.

Delayed post-test: A chemical that gives us a better understanding of stem cells in planarians.

### **Group interviews.**

Redundant group 1: Ingested by planarians AND when the stem cells divide it integrates [*sic*] into the stem cells so when an antibody with a fluorescent [*sic*] property is integrated [*sic*] it can attach to the BrdU so scientists may view it.

Redundant group 2: Chemical used in fluorescence used to see stem cells in planarians. BrdU is what antibodies attach to create the green glow.

Nonredundant group: BrdU's are compounds that can take the place of thymine in a nucleotide strand in DNA. The purpose of this is to attach a fluorescent antibody to the BrdU so scientists can track the movements of the stem cells.

### **Definitions of antibodies**

#### **Redundant group.**

*Student 1.*

Pre-test: These are things that fight off infection or illness in your body that are produced by your body.

Post-test: This is where an unidentified thing in your body is detected like a virus or illness and your body creates to fight off the illness or whatever is in your body.

Delayed post-test: Things that come in to contact to the BrdU that cause the fluorescence to see the stem cells.

*Student 2.*

Pre-test: When you take medicine there are antibodies and these help you get better faster.

Post-test: A Y-shaped protein.

Delayed post-test: What you use when you get sick and it fights it off.

**Nonredundant group.**

*Student 1.*

Pre-test: Antibodies are the things in medicine which help you to fight of [*sic*] sicknesses and diseases.

Post-test: Naturally occur in immune systems of animals, can be used to attach to BrdU so that it is visible.

Delayed post-test: Attach to BrdU to create green glowing stem cells that are visible to scientists.

*Student 2.*

Pre-test: Antibodies are (good) bacteria that kill other (bad) bacteria.

Post-test: Bacteria produced by animals, they attach to cells.

Delayed post-test: Antibodies are good bacteria that kill off harmful bacteria.

**Group interviews.**

Redundant group 1: Cells in your body that will attack pathogens.

Redundant group 2: They are used to attach to BrdU. Organisms create antibodies to defend its self from virus's [*sic*].

Nonredundant group: Antibodies are cells that are able to detect cellular markers that allow them to find and bond to cells with matching bases. This is why fluorescent antibodies can attach to BrdU's.

## CHAPTER V

### DISCUSSION AND CONCLUSIONS

In this discussion, I first examine comparisons of test scores. Then I use the vignette based on classroom observations to highlight aspects of the classroom context that were not captured by the test scores alone. Finally, I use the sample student responses to identify issues with applying the redundancy principle broadly in classroom contexts.

Does the redundancy principle hold in the secondary science classroom? The quantitative test scores showed that the redundancy principle held for retention test items but not for transfer test items. Because there were significant differences and large effect sizes between redundant and nonredundant groups on retention tests for the post-tests and delayed post-tests, it appears that the redundancy effect for retention items persisted over time and after additional instruction. There was no detected redundancy effect on transfer tests because there were no significant differences between scores for redundant groups and nonredundant groups on either the post-tests or delayed post-tests.

Because this was a quasi-experimental study, it is possible that there were differences between groups that contributed to my results. However, I tried to detect any relevant differences by administering the retention items as a pre-test to all participants. The result of no significant difference in pre-test scores between redundant and nonredundant groups suggests that there were no differences between groups in scientific content knowledge relevant to understanding the video.

The test score results are different from the majority of studies on the redundancy principle I reviewed, which showed a redundancy effect either for both retention tests and

transfer tests or a redundancy effect for transfer tests but not for retention tests. Mayer and Johnson (2008) also did not find a redundancy effect in their study. Similar to my results, they found a significant difference on retention tests but not on transfer tests. However, my results differed because Mayer and Johnson found the redundant group outperformed the nonredundant group on measures of retention. Their outcome could be supported by other multimedia learning principles such as the signaling principle and the spatial contiguity principle because the text in their multimedia was short phrases and was located close to the relevant images rather than at the bottom of the screen. This comparison highlights the difficulty of researching one multimedia learning principle in isolation because multiple principles may apply to one multimedia representation. Using the signaling principle would suggest including some redundant text for key terms, and using the spatial contiguity principle would suggest that placing words closer to the content being described is better than placing words at the bottom of the screen. Therefore multimedia learning principles are best applied as part of a strategy to reduce or manage cognitive load rather than as hard and fast rules.

In trying to explain my results, I have followed Mayer and Johnson's (2008) advice to examine instructional materials in terms of cognitive load theory. I may have obtained my results if the content of the video did not involve a high intrinsic cognitive load for students based on their background knowledge. The study took place in a non-introductory biology course so higher levels of student background knowledge may have affected the results. Another possibility is that students in the redundant group did not attend to the text displayed on the bottom of the screen and instead relied on the audio narration as the students in the immersive virtual reality environment did (Moreno & Mayer, 2002b). As an observer I could tell that all students were looking at the screen at the front of the room when the video was projected. I

could not, however, discern whether or not students in the redundant group were attending to the text on the screen.

The vignette painted a picture of the classroom environment in which students were actively engaged in scientific practices of observation, analysis, and experimentation. The vignette also captured the social dynamics of the classroom in which students worked in groups of three or four at desks clustered around the room. The vignette can be contrasted with the classroom environment when the video was shown and when the pre-tests, post-tests, and delayed post-tests were given. At these times, the visible activity in the room was drastically lower, and the lack of student interactions made these times seem abnormal. The retention tests and transfer tests were constructed based on examples found in the literature (Moreno & Mayer, 2002a). However, my time spent as an observer in the classroom showed me that I could have attempted to measure transfer in ways that were more authentic, and admittedly more difficult, by using an observation protocol during specific activities. For example, students needed to use the ideas discussed in the video on instructional days 8-10 while they worked on the “BrdU packet.” While students worked on the packet, they solved problems and talked with one another while they worked. This activity was much more consistent with other classroom activities like the planarian observations. It would have been interesting to use an observation protocol to try to measure transfer during the interactions that were more genuine. Previous research would not have used such observation protocols because the studies did not take place in classroom settings where students were expected to solve problems with their knowledge.

The vignette also illustrated how students were interested in the lesson and motivated to think deeply about the topics within the lesson. It is difficult to identify how motivated students were to elaborate on items on the transfer test. The transfer test directions indicated that students

could use the space on the back of the paper if needed. However, no students used this space. Many students wrote until they filled up the space provided, and then they stopped. This is problematic because scoring the transfer test items followed protocols similar to those in the literature in which any acceptable responses were counted up to a ceiling limit. I question whether students really provided exhaustive responses of all possibilities they could think of. Rather, student responses seem to indicate that they often provided one idea or wrote until they filled the provided space and then stopped. Students were also aware that the various tests would not affect their class grades. Therefore student lack of motivation to elaborate on the transfer test items could be another reason why my instrument did not measure any significant differences between redundant and nonredundant groups.

The sample student responses show that the grain size of interest for the teacher may be different than the grain size of interest for the researcher. The researcher may be interested in comparing class averages. However, the teacher must be concerned with differences in student learning within her classroom. The sample responses of definitions of "BrdU" from redundant student 1 and nonredundant student 1 showed examples of students in both groups who improved their understanding. The sample responses of definitions for the same term from redundant student 2 and nonredundant student 2 showed examples of students in both groups who learned little to nothing about the term. These examples showed the variability of student learning regardless of whether redundant or nonredundant video was presented.

The group response definitions of "BrdU" from the interviews showed that students in both conditions were able to learn the term, especially when they could consult one another. By instructional day 15 when the interviews were conducted, students had additional opportunities to learn the term, even if they initially had not learned it from the video. Students could have

learned the term more deeply during group problem solving on the “BrdU Packet.” The curriculum presented multiple opportunities to learn the target concept, which is different than presenting a concept simultaneously in ways that would be redundant. This highlights another important way in which classroom contexts are different than clinical contexts. In classrooms, students often have more opportunities to learn a target concept because they can ask questions and try to apply their knowledge during other activities. Students may be more motivated in classroom settings because of social influences that may not affect clinical settings.

I also want to highlight sample student responses of definitions of “antibodies.” This term was of interest because students indicated that they were already familiar with it. However, examples from redundant student 2 and nonredundant student 2 showed that some students held misconceptions that persisted throughout the instructional unit. The group interview responses showed that at the end of the curriculum unit students from both the redundant group and nonredundant group held the misconception that antibodies are cells. This is an issue because retention scores were compared by adding up scores for individual items. However, students may have differed in learning outcomes for different terms based on prior knowledge and the assumptions about student prior knowledge embedded within the design of the curriculum materials.

### **Implications for Future Research**

Future research should continue to pursue the extent to which the redundancy principle holds in secondary science classrooms by implementing more rigorous research designs. One possible direction is to try to enact experimental designs within classrooms. There are challenges to this approach related to logistical concerns. Another possible direction is to use quasi-

experimental designs that seek differences between groups in areas other than prior scientific content knowledge such as interest in science or motivation to learn science.

Future research should also pursue more meaningful measures of transfer of student learning. The collaborative, hands-on nature of the classroom described in this study would have allowed observation of students applying their learning to authentic tasks. Of course, these authentic tasks may be more difficult to measure than scoring test responses. However, those authentic tasks may also provide more useful information about students' transfer because students may be more motivated to show what they have learned with hands-on tasks. Just as other areas of study in science education have distinguished cold and warm approaches, the cognitive theory of multimedia learning could benefit from a warm approach that takes account of student interest, attitudes, motivation, etc.

Despite mixed results from this study, it may also be worthwhile to educate teachers on how to apply the redundancy principle as a criterion when selecting media for curricular use or how to apply the redundancy principle as a guideline when designing multimedia for classroom use. Research could explore the effectiveness of these interventions to determine if the topic would be worthwhile for in-service and pre-service teachers. When designing multimedia, teachers should avoid duplicating the audio as text at the bottom of the screen. When selecting multimedia for classroom use, teachers should seek a feature that allows them to turn off captions. Otherwise when presented with multiple choices for selecting multimedia video, teachers should select the video without captions if all other things are equal. Of course, all other features of two possible videos may not be equal, and this could be a good reason for teachers to learn more about cognitive load theory, CTML, and multimedia learning principles. This knowledge could allow teachers to flexibly apply theory to the design and selection of

multimedia. As Mayer and Johnson (2008) have indicated, “design principles for multimedia messages...are not rigid laws that must be followed in all circumstances. Rather, decisions about appropriate instructional design should be based on an understanding of how people learn from words and pictures” (p. 385).

The partial presence of a redundancy effect in a secondary science classroom suggests that it may be worthwhile to do more research on the redundancy principle and other principles of multimedia learning in school settings.

### **Limitations**

This study was done with a quasi-experimental design. Although student prior knowledge was measured and factored into comparisons, other factors may have influenced differences in scores between classes. Future research in school settings that utilize an experimental design could control for more of these factors. The challenge is how to enact an experimental design without introducing confounding variables such as novel group dynamics.

Results from this study may not generalize broadly to all contexts. Recognizing the complexity of a school classroom as a learning environment means that factors in each environment may influence the extent to which the redundancy principle applies. Some of these factors involve different levels of prior knowledge and whether or not students attend to redundant parts of video.

The instruments used in this study were created based on the expertise of the author, and a limitation is that the instruments were not subjected to pilot study or follow up interviews with individual students. Future research can be improved by iterative design of the instruments used to measure learning. The instruments can also be improved by measuring broad science learning goals in addition to measuring gains in scientific content knowledge.

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## APPENDIX A: Pre-test

Pre Test for “How do scientists visualize the regeneration of cells?” Video

**Directions:** Rate how familiar you are with each of the listed terms by placing a check in each row of the table below. The rating scale ranges from 1 to 5. Checking 1 means you are not at all familiar (have never heard the word), while checking a 5 means you are very familiar (understand the word and can use the concept in your thinking).

| <b>Term</b>  | <i>Not at all familiar</i><br><b>1</b> | <b>2</b> | <i>Somewhat familiar</i><br><b>3</b> | <b>4</b> | <i>Very familiar</i><br><b>5</b> |
|--------------|--|----------|--------------------------------------|----------|----------------------------------|
| Stem cells   |  |          |                                      |          |                                  |
| Regeneration |  |          |                                      |          |                                  |
| Fluorescence |  |          |                                      |          |                                  |
| BrdU         |  |          |                                      |          |                                  |
| DNA          |  |          |                                      |          |                                  |
| Antibodies   |  |          |                                      |          |                                  |

**Directions:** In the space below, define each of the following terms in your own words to the best of your ability.

**Stem cells:**

**Regeneration:**

**Fluorescence:**

**BrdU:**

**DNA:**

**Antibodies:**

## APPENDIX B: Post-test and Delayed Post-test

Post Test for “How do scientists visualize the regeneration of cells?” Video

**Directions:** Rate how familiar you are with each of the listed terms by placing a check in each row of the table below. The rating scale ranges from 1 to 5. Checking 1 means you are not at all familiar (have never heard the word), while checking a 5 means you are very familiar (understand the word and can use the concept in your thinking).

| Term         | <i>Not at all</i> |   | <i>Somewhat</i> |   | <i>Very</i> |   |
|--------------|-------------------|---|-----------------|---|-------------|---|
|              | <i>familiar</i>   | 1 | 2               | 3 | 4           | 5 |
| Stem cells   |                   |   |                 |   |             |   |
| Regeneration |                   |   |                 |   |             |   |
| Fluorescence |                   |   |                 |   |             |   |
| BrdU         |                   |   |                 |   |             |   |
| DNA          |                   |   |                 |   |             |   |
| Antibodies   |                   |   |                 |   |             |   |

**Directions:** In the space below, define each of the following terms in your own words to the best of your ability.

**Stem cells:**

**Regeneration:**

**Fluorescence:**

**BrdU:**

**DNA:**

**Antibodies:**

**Directions:** Based on watching the video (“How do scientists visualize the regeneration of cells?”) please answer the following questions as thoroughly as possible. Feel free to use the back of the paper if you need additional space.

1. Please write down a list of as many steps you remember of how scientists visualize the regeneration of cells.

2. What could you do to increase the intensity of fluorescence while visualizing cells?

3. Suppose you do not see any fluorescence when you go to visualize cells. List as many ideas as you can think of for why you might not see any fluorescence.

4. What is the purpose for mixing BrdU with pureed beef liver?

5. What causes stem cells to fluoresce or glow green?

## APPENDIX C: Scoring Rubrics

### Scoring Guide for Student Definitions of “BrdU”

The criteria outlined below establish the minimum components required to assign a score to each response. Adding positive features of responses cannot raise a score if the criteria outlined are otherwise not met (in many cases additional components of a response would qualify it for a higher score based on the criteria). However, negative features of responses such as misconceptions can lower a score by **one point** (e.g., If a response would have been scored a 5, except BrdU was referred to as “a cell,” then the response should be recorded as a 4.). The score is lowered one point regardless of the number of misconceptions that are included. When assigning scores, keep track of any point deductions. Do not penalize students for personification (e.g., saying “your” rather than relating to planarians). Do not penalize students for misspellings that do not affect meaning (e.g., spelling protein as “protien”).

Please read through the criteria for each score several times before beginning to score student responses.

Score of 5 = Response references both the structure of BrdU and the purpose for using BrdU.

Examples of acceptable references to structure can include one or more of the following: replacement for thymine, replacement for thymidine, [chemical, base, nucleotide, or nucleoside] integrated in DNA (binds in DNA or attaches to DNA are also acceptable).

Examples of acceptable references to purpose can include one or more of the following: label stem cells, locate stem cells, visualize or see stem cells, track where stem cells go, allow scientists to visualize or watch regeneration, allows antibodies to target stem cells.

Score of 4 = Response only references either the structure *or* purpose of BrdU.

See above for examples.

Score of 3 = Response is vague or includes limited details. These responses are generally brief and may have been scored higher if the student elaborated.

Examples: A chemical. Observe changes in planarians. Gives a better understanding of stem cells. Scientists put it in cells to study regeneration. It goes into their stem cells. Planarians eat it. They feed it to planarians. Attaches to antibodies. Bromodeoxyuridine.

Score of 2 = Response includes mostly misconceptions.

Examples include: a cell, an antibiotic, a protein, an amino acid, a sequence or strip of DNA code, a gene, a dye, is food or nutrients for planarians, BrdU is injected, BrdU *attaches* on the *outside* of the cell, attaches to RNA, is fluorescent or glows green, freezes or kills planarians, directs stem cells where to go, stops the growth of proteins, changes your proteins.

Score of 1 = Response is blank, or the student explicitly states “I don’t know.” Responses that do not include any relevant details should also be scored in this category.

## Scoring Guide for Student Definitions of “Antibodies”

The criteria outlined below establish the minimum components required to assign a score to each response. Adding positive features of responses cannot raise a score if the criteria outlined are otherwise not met (in many cases additional components of a response would qualify it for a higher score based on the criteria). However, negative features of responses such as misconceptions can lower a score by **one point** (e.g., If a response would have been scored a 5, except antibodies were referred to as “a cell,” then the response should be recorded as a 4.). The score is lowered one point regardless of the number of misconceptions that are included. When assigning scores, keep track of any point deductions. Do not penalize students for personification (e.g., saying “your” rather than relating to planarians). Do not penalize students for misspellings that do not affect meaning (e.g., spelling protein as “protien”).

Please read through the criteria for each score several times before beginning to score student responses.

Score of 5 = Response references both the structure of antibodies and the function of antibodies.

Examples of acceptable references to structure can include one or more of the following: Y-shaped protein, U-shaped protein, chemical created by the immune system.

Examples of acceptable references to function can include one or more of the following: specifically targets/attaches to/"grab"/"hold on to" cells, [proteins, foreign matter, bacteria, viruses, etc.], attach/match up/link to/connect to/contact BrdU, attach fluorescent dyes to BrdU.

Score of 4 = Response only references either the structure *or* function of antibodies.

See above for examples.

Score of 3 = Response is vague or includes limited details. These responses are generally brief and may have been scored higher if the student elaborated.

Examples: helps fight [cells that don't belong, foreign matter, bacteria, viruses, etc.], “thing”, help with proteins, fight off disease, good things that prevent disease, Y figures, make stuff glow, chemicals,

Score of 2 = Response includes mostly misconceptions.

Examples include: a cell, an antibiotic, medicine, bacteria, microbes, organisms, produced from the planarians.

Score of 1 = Response is blank, or the student explicitly states “I don't know.” Responses that do not include any relevant details should also be scored in this category.

## Scoring Guide for Student Definitions of “Stem Cells”

The criteria outlined below establish the minimum components required to assign a score to each response. Adding positive features of responses cannot raise a score if the criteria outlined are otherwise not met (in many cases additional components of a response would qualify it for a higher score based on the criteria). However, negative features of responses such as misconceptions can lower a score by **one point** (e.g., If a response would have been scored a 5, except for a misconception, then the response should be recorded as a 4.). The score is lowered one point regardless of the number of misconceptions that are included. When assigning scores, keep track of any point deductions. Do not penalize students for personification (e.g., saying “your” rather than relating to planarians). Do not penalize students for misspellings that do not affect meaning (e.g., spelling protein as “protien”).

Please read through the criteria for each score several times before beginning to score student responses.

**Score of 5** = Response references both the description of Stem Cells and the function of Stem Cells.

Examples of acceptable references to description can include one or more of the following: unspecialized/undesignated cells; cells with no specific job; “blank” cells; cells without a defined role;

Examples of acceptable references to function can include one or more of the following: help in regeneration/regrowth of lost limbs; help repair damaged tissues; can potentially differentiate into/become/turn into other types of cells;

**Score of 4** = Response only references either the description *or* purpose of Stem Cells.

See above for examples.

**Score of 3** = Response is vague or includes limited details. These responses are generally brief and may have been scored higher if the student elaborated.

Examples: cells that can turn into other things; cells that regenerate; special cells; cells that have yet to receive a purpose (function would be appropriate); cells that help the growth of specific parts;

**Score of 2** = Response includes mostly misconceptions.

Examples include: can become anything; cells *with* a defined role; can duplicate cells nearby; helps cancer; make copies of cells; cells all connected in some way; cells that hold water to support plant stems;

**Score of 1** = Response is blank, or the student explicitly states “I don’t know.” Responses that do not include any relevant details should also be scored in this category.

## Scoring Guide for Student Definitions of “DNA”

The criteria outlined below establish the minimum components required to assign a score to each response. Adding positive features of responses cannot raise a score if the criteria outlined are otherwise not met (in many cases additional components of a response would qualify it for a higher score based on the criteria). However, negative features of responses such as misconceptions can lower a score by **one point** (e.g., If a response would have been scored a 5, except DNA was referred to as “a cell,” then the response should be recorded as a 4.). The score is lowered one point regardless of the number of misconceptions that are included. When assigning scores, keep track of any point deductions. Do not penalize students for personification (e.g., saying “your” rather than relating to planarians). Do not penalize students for misspellings that do not affect meaning (e.g., spelling protein as “protien”).

Please read through the criteria for each score several times before beginning to score student responses.

Score of 5 = Response references both the structure of DNA and the function of DNA.

Examples of acceptable references to structure can include one or more of the following: molecule/chemical (in cells); nucleic acid; strand of nucleotides/acids; sequence of genes;

Examples of acceptable references to purpose can include one or more of the following: provides genetic instructions for creating protein products; codes for proteins/genes/RNA; influences traits/characteristics/features such as some appearances and some behaviors

Score of 4 = Response only references either the structure *or* function of DNA.

See above for examples.

Score of 3 = Response is vague or includes limited details. These responses are generally brief and may have been scored higher if the student elaborated.

Examples: Genetic code/ material/information/makeup/blueprints; **What your genes are made of**; In every living thing; makes you, you/ makes us, us; makes everyone different/makes an organism unique; double stranded; ATGC; Deoxyribonucleic acid; Tells our cells what to do; The data of a given organism; Where cell info is stored; Contains traits;

Score of 2 = Response includes mostly misconceptions.

Examples include: makes up everything; describes everything about who we are; makes up a human; make up your body; amino acids; proteins; directed by RNA; mixed with RNA; doubled during mitosis; Cells divide then new DNA is created; contains uracil; Contains protons, neutrons, electrons; contains neurons;

Score of 1 = Response is blank, or the student explicitly states “I don’t know.” Responses that do not include any relevant details should also be scored in this category.

## Scoring Guide for Student Definitions of “Fluorescence”

The criteria outlined below establish the minimum components required to assign a score to each response. Adding positive features of responses cannot raise a score *if the criteria outlined are otherwise not met* (in many cases additional components of a response would qualify it for a higher score based on the criteria). However, negative features of responses (misconceptions from the score=2 category) can lower a score by **one point** (e.g., If a response would have been scored a 5, except there was a misconception, then the response should be recorded as a 4.). The score is lowered one point regardless of the number of misconceptions that are included. When assigning scores, keep track of any point deductions in the right column of the scoring sheet. Do not penalize students for personification (e.g., saying “your” rather than relating to planarians). Do not penalize students for misspellings that do not affect meaning (e.g., spelling protein as “protien”).

Please read through the criteria for each score several times before beginning to score student responses.

**Score of 5** = Response references both the description of Fluorescence and the purpose for using Fluorescence.

Examples of acceptable references to description can include one or more of the following: giving off light/glowing green under a specialized/fluorescent/UV light/microscope;

Examples of acceptable references to purpose can include one or more of the following: used to locate stem cells/regeneration/mitosis/BrdU

**Score of 4** = Response only references either the description *or* purpose of Fluorescence.

See above for examples.

**Score of 3** = Response is vague or includes limited details. These responses are generally brief and may have been scored higher if the student elaborated.

Examples: dye; glowing; light; green pigment; help see planarians; determine location of cells

**Score of 2** = Response includes mostly misconceptions for how Fluorescence is used in this context.

Examples include: light bulb; light fixture; black light; BrdU; effect of BrdU; food for planarians; changes DNA sequence; fluoride; a virus; unresponsive cell;

**Score of 1** = Response is blank, or the student explicitly states “I don’t know.” Responses that do not include any relevant details should also be scored in this category.

## Scoring Guide for Student Definitions of “Regeneration”

The criteria outlined below establish the minimum components required to assign a score to each response. Adding positive features of responses cannot raise a score *if the criteria outlined are otherwise not met* (in many cases additional components of a response would qualify it for a higher score based on the criteria). However, negative features of responses (misconceptions from the score=2 category) can lower a score by **one point** (e.g., If a response would have been scored a 5, except regeneration was referred to as “initial growth of an organism,” then the response should be recorded as a 4.). The score is lowered one point regardless of the number of misconceptions that are included. When assigning scores, keep track of any point deductions in the right column of the scoring sheet. Do not penalize students for personification (e.g., saying “your” rather than relating to planarians). Do not penalize students for misspellings that do not affect meaning (e.g., spelling protein as “protien”).

Please read through the criteria for each score several times before beginning to score student responses.

**Score of 5** = Response references both the description of Regeneration and the mechanism of Regeneration.

Examples of acceptable references to description can include one or more of the following: process in which damaged tissue regrows

Examples of acceptable references to mechanism can include one or more of the following: results from the activity of stem cells

**Score of 4** = Response only references either the description *or* mechanism of Regeneration.

See above for examples.

**Score of 3** = Response is vague or includes limited details. These responses are generally brief and may have been scored higher if the student elaborated.

Examples: production of new cells; replacing old cells; process of new body parts forming; when cells form into something missing; bringing new life into something already dead; mitosis; to generate something again; bringing new life to something dead;

**Score of 2** = Response includes mostly misconceptions.

Examples include: initial growth of organism

**Score of 1** = Response is blank, or the student explicitly states “I don’t know.” Responses that do not include any relevant details should also be scored in this category.