Use of Multimedia Games for Biology Vocabulary Instruction

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USE OF MULTIMEDIA GAMES FOR BIOLOGY VOCABULARY INSTRUCTION

A Dissertation Presented

to

The Faculty of the School of Education
Department of Learning & Instruction

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Education

By

Ian Murray
San Francisco
May 2018
Use of Multimedia Games for Biology Vocabulary Instruction

Vocabulary knowledge is considered fundamental to learning. However, students typically find learning scientific vocabulary quite difficult, and that is especially true for biology vocabulary. Games are well established as effective tools for vocabulary instruction. Multimedia instruction is likewise recognized as aiding vocabulary learning. To date, however, there seems have been little examination of the use of multimedia games in biology vocabulary instruction. This study, therefore, compared the effectiveness of digital multimedia games and traditional instruction in teaching biology vocabulary.

A two-group, quasi-experimental study was carried out over the course of 61 days. Participants were a convenience sample of 10 high school biology classes (N = 276). Fixed-effects multivariate analysis of covariance (MANCOVA) was used for three dependent variables: 1) scores on tests of biology vocabulary; 2) scores on tests of biology concepts; and 3) vocabulary feedback and Reduced Instructional Materials Motivation Survey (RIMMS) scores.

The multimedia group put more work into the vocabulary practice at Time 1 (27 days) and Time 2 (59 days) than did the traditional-instruction group, to a degree that was statistically significant. In addition, at Time 2 the multimedia group indicated a greater feeling that the practice was helping them learn the vocabulary, once again to a degree
that was statistically significant. RIMMS data collected after the end of instruction also showed that the multimedia instruction group scored higher on measures of learner satisfaction than the traditional instruction control group, to a statistically significant degree.

Contrary to what previous research would predict, there was no statistically significant difference in vocabulary learning between groups using multimedia games and those using traditional instruction. In keeping with previous research, use of multimedia games for instruction led to higher learner motivation, expressed as a greater level of satisfaction with the instructional materials and a greater willingness to spend more time on task when compared to learners receiving traditional instruction. Thus one implication of this study is that the use multimedia games for biology vocabulary instruction has the potential to increase learner satisfaction and motivation.
This dissertation, written under the direction of the candidate's dissertation committee and approved by the members of the committee, has been presented to and accepted by the Faculty of the School of Education in partial fulfillment of the requirements of the degree of Doctor of Education. The content and research methodologies presented in this work represent the work of the candidate alone.

Ian Murray ________________________________ May 2, 2018
Candidate Date

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Robert Burns, Ph.D. ________________________________ May 2, 2018
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Date
Dedication

The work herein is dedicated to my wife, Yoko Otomi, who made this all possible; and to my son, Eric Otomi Murray, who made this – and so many other things – worth working for.
Acknowledgements

I want to gratefully acknowledge my colleagues at Albany High School, Mr. Loring Barker and Ms. Patricia Fujiwara, whose help was essential to this study. I should also point out that their help has been essential to me throughout the fourteen years we have worked together.

This dissertation would not have been possible without the wisdom and guidance of my advisor, Dr. Robert Burns. I am incredibly grateful for his help, and I suspect he has helped me even more than I am able to realize. I am also extremely thankful for the good nature, flexibility and insight of my dissertation committee members, Dr. Walter Gmelch and Dr. Mathew Mitchell.

I also need to thank my family, starting with my late father, Elwood Murray, and my mother, Ardene Anderson. As a teacher, I have seen enough parents and children over the years to be grateful beyond words for what my parents gave me. By the same token, I need to apologize to my son, Eric Otomi Murray, for what I have not given him – that is, for not being the parent I should have been for at least the last five years. I also want to thank him for giving me the motivation to accomplish far more than I ever would have without him. Finally, I will always be grateful to my wife, Yoko Otomi, for giving me the chance to complete my doctoral studies, as she has given me the opportunity to do so much else in the past.
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CHAPTER ONE

STATEMENT OF THE PROBLEM

Learning scientific vocabulary can constitute a tremendous burden for science students, (Hakuta, Santos, & Fang, 2013), and particularly for biology students (Grillo & Dieker, 2013). Imagine that your child has just started high school. She needs to study a foreign language, so she signs up for first-year French. The two of you were a little worried about all the vocabulary she would need to learn in her French class – but when she comes home with her first round of high school homework assignments, you discover that she has ten times as much new vocabulary to learn for her biology class as she does for her French class. This might be the stuff of nightmares, but it has its basis in reality: one researcher found that a typical high school French textbook introduced 1750 new words; a high school physical science textbook introduced 2,173; and a high school biology textbook introduced 17,130 (Groves, 1995).

The tremendous burden that vocabulary places on biology students is the focus of this study – but that is not to ignore the fact that vocabulary has a major impact on every part of our lives, helping to determine, according to some researchers, “academic success, economic opportunity, and societal well-being” (Gardner & Davies, 2014). It has been widely recognized that difficulties with vocabulary can cause problems for learners in all areas (Blachowicz & Fisher, 2004; Gray & Yang, 2015; National Institute of Child Health & Human Development, 2000). “Learning,” it has been said, “as a language based activity, is fundamentally and profoundly dependent on vocabulary knowledge” (Baker,
Simmons, & Kame’enui, 1998), and researchers have long been focused on how “to narrow the gap between the vocabulary learners know and the vocabulary they need” (Laufer, 2016). In recent years, more and more attention has also been focused on what has been termed the “vocabulary gap” between many students of color and/or lower socioeconomic status and their more privileged peers, and the role that the vocabulary gap plays in the widely recognized achievement gap (David, 2010; Hart & Risley, 1995).

Not surprisingly, given the degree of interest in vocabulary, a number of approaches to vocabulary learning have been developed. Two especially influential methodologies are those of Nation Nation & Gu, 2007; Nation & Meara, 2002), and Stahl and Nagy (Stahl & Nagy, 2006).

Nation has proposed an approach to vocabulary learning that consists of four “strands” that work synergistically to maximize vocabulary learning (Nation, 2006, 2008; Nation & Gu, 2007; Nation & Meara, 2002). The first of Nation’s four strands is meaning-focused input, which involves listening and reading with materials containing only 2% to 5% unfamiliar vocabulary. His second strand, meaning-focused output, entails learning new vocabulary through speaking and writing. The third strand is language-focused learning, which involves a conscious focus by the learner on strategies such as the use of word roots to discover word meanings. The fourth and final strand is fluency development. This strand does not involve learning new vocabulary; instead, it focuses on practicing to make best use of vocabulary already acquired.

Another multipronged approach to fostering vocabulary learning has been developed by Stahl and Nagy (Stahl & Nagy, 2006). Their method involves three components. The first component is the teaching of specific words. Their second
component is increasing learner exposure to rich written and oral language. Stahl and Nagy’s third and final component is increasing learners’ skill in using definitions, word roots, and context, and their interest in and awareness of words.

A major difference between Nation’s and Stahl and Nagy’s approaches is in their level of tolerance for techniques, such as word cards, that separate vocabulary from its context (Nation, 2006, 2008; Stahl & Nagy, 2006). For Nation, use of tools like word cards is a central part of his four-strand approach (Nation, 2001, 2006); Stahl and Nagy, by contrast, emphasize the centrality of developing an understanding of how vocabulary items fit into a context (Stahl & Nagy, 2006). This difference in approach has led to a great deal of heated debate over many decades (e.g., Cobb, 2016; McQuillan, 2016; Nation, 2016).

Despite their differences in approach, both Nation and Stahl and Nagy recognize the usefulness of teaching morphemes (word roots) to allow learners to deconstruct the vocabulary they encounter (Nation, 2006, 2008; Stahl & Nagy, 2006). It has been pointed out that this strategy (e.g., the morpheme bio, “living,” can be combined with the morpheme logy, “study of,” to form biology – “the study of life”) is particularly useful for learning scientific vocabulary (Fang, 2006).

Researchers like Nation or Stahl and Nagy may differ in their degree of tolerance for decontextualized vocabulary instruction, but there has been general agreement for some time that one valuable tool for vocabulary learning is the use of games (Andrade, 2009; Lubliner & Scott, 2008; Manyak, 2012; Stahl & Nagy, 2006).

Games are well-established as instructional tools, and have been used for at least 5,000 years (Dempsey, Haynes, Lucassen, & Casey, 2002). Despite – or perhaps because
of – their long history, there is no single definition of what constitutes a game (Kamil & Taitague, 2011; Plass, Homer, & Kinzer, 2015). Most researchers agree, however, that a game is an activity that involves a goal, rules, and competition – even if that competition is with oneself (Dempsey et al., 2002; Jin & Low, 2011; Mayer, 2011; Randel, Morris, Wetzel, & Whitehill, 1992).

Games seem to aid vocabulary learning in a number of ways (Andrade, 2009; Hitosugi, Schmidt, & Hayashi, 2014). However, despite the obvious need to help science students with the vocabulary load they face, there has been relatively little investigation of the use of games in learning scientific vocabulary. When one turns to the use of games for the learning of biology vocabulary, the lack of research is even worse, as there appear to be almost no investigations done as yet. This is despite the fact that, of all areas of science vocabulary instruction, biology is the discipline where the need for aid in learning vocabulary seems to be the greatest (Grillo & Dieker, 2013; Groves, 1995, 2016; Wandersee, 1988).

There is also a great deal of evidence to support the idea that the use of multimedia, i.e., a combination of words and pictures (Mayer, 2014a), can aid learning in many areas, including the learning of vocabulary (Castek et al., 2012; Clark & Mayer, 2016; Kennedy, Deshler, & Lloyd, 2013; Mayer, 2014a). Mayer’s multimedia principle, part of his cognitive theory of multimedia learning (CTML), states that “people learn more deeply from words and pictures than from words alone” (Mayer, 2014a, p. 43). The multimedia principle has been found to hold true for learning in a wide variety of applications, including learning vocabulary, and so it seems logical to think that the use of multimedia might be helpful in learning biology vocabulary as well. Another of
Mayer’s principles of multimedia learning is the modality principle - “that the words in a multimedia lesson should be spoken rather than printed” (Mayer, 2010, p. 548). Like the multimedia principle, the modality principle has also been shown to be highly beneficial to learning (Clark & Mayer, 2016; Mayer, 2011).

It has been proposed that one way that the use of multimedia can aid in learning is by increasing learner motivation (Mayer, 2010; Mayer, 2014b; Moreno, 2006; Plass et al., 2015; Pedra, Mayer, & Albertin, 2015). Moreno points to what she has termed “affective mediation – the idea that motivational factors mediate learning by increasing or decreasing cognitive engagement” as a possible explanation for this interaction of motivation with multimedia learning (Moreno, 2006). Mayer has theorized that increased motivation may benefit multimedia learning by fostering generative processing (Mayer, 2014b).

Among the various applications of multimedia, the use of multimedia games as an aid to learning has been studied extensively (Tobias, Fletcher, Bediou, Wind, & Chen, 2014). The use of such games in learning vocabulary has been much less thoroughly studied, but what little research has been done is generally encouraging (e.g., Bakar & Nosratirad, 2013; Hitosugi et al., 2014; Vahdat & Behbahani, 2013).

Turning to the use of multimedia games in learning scientific vocabulary, there has been very little research done. One – and perhaps the only – example is Salazar and Carballo’s investigation of the use of the digital Spanish-English vocabulary translation game *Vocabulary*, a Spanish-English vocabulary translation game with students in a nursing program at the Universidad de Costa Rica (Salazar & Carballo, 2009). Unfortunately, the results of the investigation were inconclusive.
Purpose of the Study

When we narrow our focus to the use of multimedia games in learning biology vocabulary, there seems to have been even less research done than for scientific vocabulary in general – that is to say there is apparently none. Given that research indicates that multimedia games can be very effective aids for vocabulary learning, and given the extensive body of research showing that learning science vocabulary – and biology vocabulary in particular – presents a tremendous problem for a large number of students, it seems logical to investigate their use in biology vocabulary learning. As yet, however, this field of inquiry does not seem to have been the subject of any formal research. This study, therefore, reviewed the literature on multimedia gaming and examined the effectiveness of using digital multimedia games to help high school students learn biology vocabulary.

A two-group, quasi-experimental study was used, consisting of one treatment and one control group. The study employed a fixed-effects multivariate analysis of covariance (MANCOVA) for a series of three types of dependent variables. Multivariate analysis of covariance lets the researcher attempt to adjust participants’ results for differences in initial level on a relevant variable, or covariate, when random assignment to treatment and control groups has not been possible. The three types of dependent variables examined using MANCOVA were: 1) scores on tests of biology vocabulary; 2) scores on tests of biology concepts; and 3) vocabulary feedback and instructional materials motivation survey scores. These three types of dependent variables were chosen for three reasons: 1) student scores on the tests of biology vocabulary were used because it was hoped that, as predicted by theory, the use of appropriate multimedia would result in a
statistically significant increase in vocabulary scores; 2) student scores on the tests of biology concepts were used because it was hoped that any increase in vocabulary scores would not occur at the expense of concept learning; and 3) vocabulary feedback and instructional materials motivation survey scores were used because theory predicts that the use of appropriate multimedia will increase student motivation. Participant HMH Reading Inventory (formerly Scholastic Reading Inventory – SRI) Lexile reading scores were used as the covariate for all three analyses of covariance. Lexile reading scores were chosen as the covariate because of the strong relationship between reading ability and vocabulary (Lubliner, 2005; National Institute of Child Health & Human Development, 2000; Shanahan & Shanahan, 2008), which allowed Lexile reading scores to be used as a proxy for participants’ initial level of vocabulary knowledge.

Participants were a convenience sample of 10 college preparatory high school biology classes with a total of 276 students. The classes were taught by three different teachers, one of whom was the researcher. Each teacher taught half of his or her classes using a multimedia game for vocabulary instruction and half using traditional vocabulary instruction. The students, in grades 9 through 12, attend a comprehensive high school in a medium-size suburban school district where all students are required to take and pass biology in order to graduate high school.

Data collection included standardized test scores, curriculum-based measurements, and surveys with Likert-type rating scale. The standardized test was the HMH Reading Inventory, administered to almost all students in the district, which provided the Lexile reading scores used as a covariate in data analysis. The curriculum-based measurements were vocabulary tests developed by the researcher;
concept tests constructed by the researcher’s colleagues; and a final examination, produced by the researcher’s colleagues, from which several questions were selected for use as a posttest. The surveys with rating scale that were given to participants were of two types: one was a short vocabulary feedback survey developed by the researcher; the other was a version of Keller’s Instructional Materials Motivation Survey (IMMS), which has been used extensively to measure learners’ motivation in response to instructional materials (Keller, 2010; Loorbach, Peters, Karreman, & Steehouder, 2015; S. Park & Lim, 2007).

**Significance of the Study**

The problem investigated in this study has both theoretical and practical significance. In terms of theoretical significance, it seemed worthy of examination in part because it could provide further evidence for the validity of Mayer’s multimedia principle as it relates to vocabulary learning, science vocabulary learning, and most particularly, biology vocabulary learning.

The practical significance of this study lies in the guidance may provide for the effective teaching and learning of biology vocabulary, especially in a secondary school setting. It also may provide insight into the training of all science teachers – and biology teachers in particular – in more effective vocabulary instruction strategies. As one researcher puts it, “Teachers are already under the gun to cover more material than time permits and they are stymied by the need to devote extra time to vocabulary” (David, 2010). Few if any studies to date have examined whether using a multimedia game for vocabulary instruction is a more effective and efficient use of instructional time than traditional instruction. This study, by making that examination, may help teachers and
students move towards a more humane match between the material to be covered and the time available to do so.

**Theoretical Framework**

Mayer’s cognitive theory of multimedia learning (CTML) and the principles derived from it serve as the primary theoretical underpinnings of this study. CTML uses ideas originating in cognitive load theory and dual processing theory to predict and explain how words and pictures can be used most effectively to aid learning (Mayer, 2014a).

CTML is based on three assumptions about learning. The first of those assumptions is that our mind has an information processing system that includes two channels, one for visual/pictorial processing, and the other for auditory/verbal processing. CTML’s second assumption is that each of those two channels has a limited processing capacity; only a few words can be held in a listener’s auditory working memory at any one time, for example. The third assumption of CTML is that active learning requires that the learner construct a mental model based on new information, and connect that model with prior knowledge stored in the learner’s long-term memory (Mayer, 2014a).

CTML posits three types of demands that are placed on a learner’s cognitive capacity during learning: a) extraneous processing, i.e., processing not related to the goal of instruction, b) essential processing – that is, processing that is necessary to mentally represent the essential material being presented, and c) generative processing, which has the goal of making sense of the material that is being presented (Mayer, 2014a).

According to CTML, one way to facilitate learning is to facilitate generative processing – and one way to do that is by presenting material in both words and pictures.
Mayer has termed this principle, that “people learn more deeply from words and pictures than from words alone,” the multimedia principle (Mayer, 2014a, p. 43). CTML, and specifically the multimedia principle, predicts that learners should acquire vocabulary more successfully when materials used incorporate the multimedia principle than when they do not. Given the pressing need to reduce the vocabulary burden for biology students, a main goal of this research study is to see to what extent if any application of CMTL and the multimedia principle aids in the learning of biology vocabulary.

**Background and Need**

Vocabulary learning has been studied for many years, and by many researchers (Kame’enui & Baumann, 2012; Lubliner, 2005; Nation, 1990; Stahl & Nagy, 2006). This is not surprising, given the central role of vocabulary in learning any discipline. It is knowledge of vocabulary that gives one access to membership in a community of practice (Hakuta et al., 2013), and that same knowledge of the vocabulary of a discipline is often used as a proxy for competence in that discipline (Nation & Gu, 2007). Some authors have even extended that idea beyond the level of discipline to say that vocabulary knowledge is a requirement for being a competent participant in our society – that vocabulary knowledge is thus a prerequisite for true citizenship (Blachowicz & Fisher, 2004; Larson, 2014).

The intensive study of vocabulary learning by numerous researchers has revealed that vocabulary learning can present a tremendous problem for many learners, particularly when learning academic vocabulary, and particularly when that learning is in the medium of English (Kame’enui & Baumann, 2012; Nation, 1990, 2005, 2008; Stahl & Nagy, 2006). While vocabulary must be learned in any language, no language places
as great a demand for an extensive vocabulary on its users as English (Nation & Meara, 2002). What is more, as Stahl and Nagy (2006, p. 41) point out, the academic version of English differs dramatically from the spoken language, so that “literate or academic English... is likely to be a foreign language to the student whether or not the student comes from a home in which English is spoken.”

In scientific fields, the burden of vocabulary learning can be even greater (Fang, 2006; Graesser, Léon, & Otero, 2002; Hakuta et al., 2013; Snow, 2010; Zhang & Lidbury, 2012). This is largely due to the complexity of the vocabulary that must be learned and the sheer volume of that vocabulary (Fang, 2005; Seifert & Espin, 2012). This vocabulary burden presents what can be an almost insurmountable barrier for many learners (Fang, 2005, 2006; Graesser et al., 2002; Groves, 1995; Zhang & Lidbury, 2012), including both English Language Learners, or ELLs, (Hakuta et al., 2013; Janzen, 2008) and individuals identified as having learning disabilities (Seifert & Espin, 2012).

The issue of learner problems with vocabulary learning is common to all scientific disciplines, but seems to be greatest in biology (Grillo & Dieker, 2013; Groves, 1995), due to the tremendous vocabulary load it presents to learners. For example, an examination by Groves (1995) of the vocabulary load (number of new words presented to the learner) of secondary school science texts found (as shown in Figure 1 below) the lowest load to be 2,173 words for a physical science textbook, and the highest load to be 17,130 words for a biology textbook. By comparison, a high school French text examined had a vocabulary load of less than 1800 new words.

**Research Questions**

This research study addressed the following three questions:
Figure 1. Comparison of vocabulary load for secondary school textbooks (Based on Groves, 1995).
1. Are there statistically significant differences in scores on tests of biology vocabulary knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

2. Are there statistically significant differences in scores on tests of biology concept knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

3. Are there statistically significant differences in ratings of motivation engendered by the learning materials used by students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

**Definition of Terms**

*Cognitive Load Theory* is a theory of instructional design that maintains that we have a very limited working memory, which holds information for a very limited period and processes just a few pieces of that information at a time, and a long-term memory that is basically infinite in size and able to store information on a lasting basis (Kalyuga, 2011; Mousavi, Low, & Sweller, 1995; Sweller et al., 2011).

The **element interactivity** of a learning task is the extent to which it forces the learner to hold several related chunks of the information to be learned in working memory at the same time (Moreno, 2006).

**Essential processing** is cognitive processing that is needed for the learner to construct a representation of the crucial material to be learned in working memory. This has been described as primarily a process of selection: the learner decides what is worth incorporating in his or her mental representation and what can be safely left out (Mayer, 2010).

**Extraneous processing** is cognitive processing that does not support learning (Mayer, 2010). For example, if a learner is reading a text in which a diagram appears on the front side of a sheet and the text that refers to that diagram appears on the back of the sheet, the learner wastes cognitive processing resources repeatedly flipping from one side of the sheet to the other.

A **game** can be defined as an activity that typically involves a goal, rules, and competition – including competition with oneself (Dempsey, Haynes, Lucassen, & Casey, 2002; Jin & Low, 2011; Mayer, 2011).

**Generative processing** is cognitive processing that is focused on making sense of what is being learned. It has been described as consisting of organizing and integrating information, “and is caused by the learner’s motivation to understand the material” (Mayer, 2010, p. 546).

A **morpheme** is defined as the smallest unit of meaning in words (Kieffer & Lesaux, 2007). Morphemes can be bound or unbound. Typical unbound morphemes
include prefixes and suffixes, like “dis-” in “disinterested,” or “-able” in “likeable.”

Typical unbound morphemes include word roots such as “aqua” in “aquatic.”

Multimedia learning has been defined as “learning from words and pictures” (Mayer, 2010, p. 544). The text can be written, like in a textbook, or spoken, as in a lecture presentation. The pictures may be unmoving or static, like a photograph, or they can be moving or dynamic, as with a video.

The multimedia principle states that individuals learn more effectively from a combination of words and pictures than they do from words alone – that is, that multimedia learning is more effective than learning solely from text (Mayer, 2014a). It is the most fundamental of the principles that together constitute Mayer’s Cognitive Theory of Multimedia Learning (Mayer, 2014a).
CHAPTER TWO
LITERATURE REVIEW

This section reviews the literature for this study of the effect of biology vocabulary instruction using a multimedia game versus using a traditional vocabulary instruction. The first section explores the research on vocabulary learning in general, and science vocabulary learning in particular. The second section looks at the research on the use of games in vocabulary learning, and the third section examines relevant theories of multimedia learning. The chapter finishes with a summary of these three areas of inquiry and their significance to the proposed study.

Vocabulary Learning

Some Influential Approaches to Vocabulary Learning

A number of influential theorists have developed approaches to vocabulary learning that are summarized in Table 1 and discussed in more detail below. Nation (2001, 2006) has proposed an approach to vocabulary learning that consists of four “strands” that work synergistically to maximize vocabulary learning. According to Nation, each of these strands should receive equal attention. The first of the four strands is meaning-focused input, which involves listening and reading with materials containing only 2% to 5% unfamiliar vocabulary. The second strand, meaning-focused output, entails learning new vocabulary through speaking and writing. The third strand is language-focused learning, which involves a conscious focus by the learner on strategies such as the use of word roots to discover word meanings. The fourth and final strand is fluency development. This strand does not entail learning new vocabulary; instead, it
focuses on practicing to make best use of vocabulary already acquired (Nation, 2006, 2008; Nation & Gu, 2007; Nation & Meara, 2002).

Table 1

Overview of Influential Vocabulary Learning Theorists and Their Approaches

<table>
<thead>
<tr>
<th>Theorist(s)</th>
<th>In favor of using word root strategies?</th>
<th>Emphasis on rich oral language</th>
<th>Tolerance for decontextualizing techniques</th>
<th>Facilitated by digital and internet technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nation</td>
<td>Yes</td>
<td>Medium</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Stahl and Nagy</td>
<td>Yes</td>
<td>Medium</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Lubliner</td>
<td>Yes</td>
<td>High</td>
<td>High</td>
<td>Yes</td>
</tr>
</tbody>
</table>

One concern for those following Nation’s approach is how to ensure that materials used for meaning-focused input contain only 2% to 5% vocabulary that is unfamiliar to an individual learner. Thankfully, the use of computers and other digital and web-connected learning devices promises to make this a simpler matter than it has been in the past.

Stahl and Nagy (2006) have developed a three-part approach to fostering vocabulary learning: teaching specific words; increasing learner exposure to rich written and oral language; and increasing learners’ skill in using definitions, word roots, and
context, and their interest in and awareness of words – what Stahl and Nagy have termed generative word knowledge (Stahl & Nagy, 2006).

Whereas it may have been difficult in the past to provide the range of materials that would increase exposure to rich written and oral language and capture the interest of a wide range of learners, digital and web-connected learning devices are once again making this simpler with each passing day.

A major difference between Nation's (2006, 2008) and Stahl and Nagy's (2006) approaches is in their level of tolerance for decontextualizing instructional techniques, such as word cards, that separate vocabulary from its context. For Nation, use of tools like word cards is a central part of his four-strand approach (Nation, 2001, 2006); by contrast, Stahl and Nagy emphasize the centrality of developing an understanding of how vocabulary items fit into a context, as well as of how vocabulary items with very similar denotations may have very different connotations – and therefore very different effects when used (Stahl & Nagy, 2006).

Such differences in approach become important considerations when picking tools to aid in learning vocabulary: according to Nation’s thinking, it may be productive to teach vocabulary divorced from context through such means as flashcards or games such as Concentration (Nation, 2001, 2006); Stahl & Nagy (2006), on the other hand, might say that such vocabulary would be better taught using an activity, such as a simulation or role play, that introduced the words or terms to be learned in context. A third influential approach is that of Lubliner (Lubliner & Scott, 2008), who sees vocabulary learning as being like a pyramid (see Figure 2 below). The base of Lubliner’s (Lubliner & Scott, 2008) pyramid is rich oral language – meaningful, extended
From Lubliner & Scott, 2008, p. 1

*Figure 2.* Lubliner’s Pyramid of Vocabulary Learning (Lubliner & Scott, 2008, p. 1)
conversation. Immediately above that base level of the pyramid is wide reading and reading aloud, both of which expose learners to language that does not generally form a part of oral communication. Above the level of wide reading and reading aloud is the level of word consciousness – developing an awareness of the impact of word choice as well as sensitivity to issues of denotation versus connotation. The penultimate level of Lubliner’s (Lubliner & Scott, 2008) pyramid is problem solving, which involves strategies such as breaking down words into their component parts (use of morphemes) as an aid to understanding their meanings, using context clues, and effective dictionary use. At the apex of the pyramid is the explicit teaching of single words (Lubliner & Scott, 2008).


As they did with the approaches of Nation (2001, 2006) and Stahl and Nagy (2006), it is clear to see how the advent of the Internet and digital, web-connected devices have aided teachers and others who wish to implement Lubliner’s (Lubliner & Scott,
approach to vocabulary learning. With the use of digital technology, the wide
text reading that forms such an important part of her approach is far easier to implement and
customize to the needs of individual learners than was the case in the past.

Science Vocabulary Learning

Over the years, a number of researchers have investigated the effective learning of
science vocabulary (Fang, 2005, 2006; Graesser et al., 2002; Snow, 2010; Stevenson,
1937; Taboada, 2012). Taboada (2012) has developed a text-based questioning approach
that relies on learners’ interactions with text, particularly learners’ self-generated,
text-based questions. Learners generate their questions after eight to ten minutes of
browsing the text. This is followed by a twenty-minute period during which they write
questions about thing they want to know concerning the topic or topics of the text. This
seems to increase learners’ science comprehension, perhaps by fostering more thinking
about text topics and content prior to reading. This leads to students being more focused
on the text as a whole, as well as on key concepts within topics.

Taboada's (2012) emphasis on having learners interact with vocabulary in situ is
very much in keeping with Stahl & Nagy's (2006) stress on not decontextualizing
vocabulary. Her approach could also be incorporated as part of Lubliner and colleagues’
(Lubliner & Scott, 2008) problem-solving or word-consciousness steps in vocabulary
learning. While Taboada's (2012) approach does not depend on access to digital
technology, such access might make it somewhat easier to implement.

Fang (2006) has extensively investigated the language demands of science
reading, and techniques he recommends as aids to learning science vocabulary include
noun expansion, sentence completion exercises, paraphrasing, sentence stripping and
developing awareness of signposts. In noun expansion, learners perform elaboration exercises, in which a simple noun is expanded into longer noun phrases by adding pre- and/or post-modifiers. Sentence completion involves learners carrying out a fill-in-the-blanks exercise that requires them to synthesize information in a portion of a text into a noun or noun phrase that can be used as the subject of the next sentence in the text. In paraphrasing, learners translate back and forth between scientific and everyday language. Sentence stripping involves the teacher and students analyzing the ways clauses are combined in scientific text to form complex sentences.

Fang (2006) also recommends direct instruction of learners in the use of Latin- and Greek-derived morphemes – showing students how scientific vocabulary is made by joining together morphemes. For example, the morpheme *bio* ("living") can be combined with the morpheme *logy* ("study of") to form *biology* – “the study of life.”

Fang's (2006) approach fits well with the thinking of researchers such as Nation (2005), who readily accept the sort of decontextualized vocabulary learning Fang (2006) is promoting. It could also be used as part of Lubliner’s (Lubliner & Scott, 2008) problem-solving or word-consciousness steps in vocabulary learning. As with Taboada's (2012), Fang's (2006) approach does not depend on access to digital technology; it is easy to see, though, how access to such technology would make it much easier to implement, especially with any sizeable number of learners.

**Use of Multimedia Games in Vocabulary Learning**

As mentioned earlier, it can be difficult to arrive at a universally-accepted definition of exactly what constitutes a game (Plass et al., 2015). One of the simplest might be Jin and Low’s characterization of a game as being “a type of voluntary,
interactive, mentally/physically challenging exercise by one or more players” (Jin & Low, 2011, p. 395). Similarly terse is Mayer’s description of games as “artificial environments that are rule-based, responsive, challenging, and cumulative” (Mayer, 2011, p. 282). Somewhat more involved is Randel and colleagues’ definition of games as “competitive interactions bound by rules to achieve specific goals that depend on skill and often involve chance and an imaginary setting (Randel et al., 1992, p. 262). At a similar level of complexity is the National Research Council’s statement that "…games are played spontaneously in informal contexts for fun and enjoyment… In addition, games generally incorporate explicit goals and rules" (National Research Council (U.S.), 2011, p. 9). More complicated yet is the definition given by Dempsey and co-researchers. A game, they say, is a “set of activities involving one or more players. It has goals, constraints, payoffs, and consequences. A game is rule-guided and artificial in some respects. Finally, a game involves some aspect of competition, even if that competition is with oneself” (Dempsey et al., 2002, p. 159). For the purposes of this study, a game will be defined simply as an activity that involves a goal, rules, and competition.

Some researchers go to great pains to distinguish games from simulations, which “model a process or mechanism relating input changes to outcomes” (Randel et al., 1992). This, like coming up with a widely accepted definition of a game, can be difficult to do. The National Research Council points out that in contrast to the informal settings in which games are typically played, simulations are usually encountered in a more formal context (National Research Council (U.S.), 2011). Tobias and Fletcher stress that while not all simulations are games, all games are simulations (Tobias & Fletcher,
Games, in their analysis, emphasize competition, interaction, and entertainment, while simulations prioritize realism, accuracy, and task completion (Tobias & Fletcher, 2011b).

Regardless of how games are defined and distinguished, there has been general agreement for many years now that they can be a valuable tool for vocabulary learning (Andrade, 2009; Castek, Dalton, & Grisham, 2012; Huyen & Nga, 2003; Lubliner & Scott, 2008; Manyak, 2012; Stahl & Nagy, 2006; Wright, Betteridge, & Buckby, 2006). One way games seem to help in vocabulary learning is by reducing inhibition, anxiety, and self-doubt, all of which can function as an “affective filter” (Hitosugi, Schmidt, & Hayashi, 2014; Krashen, 1981), impeding language learning of all kinds, including the learning of vocabulary. Games lower that affective filter, giving learners license for the sort of experimentation and risk-taking that fosters vocabulary learning (Andrade, 2009).

Games can also make possible the integration of multiple learning modalities, such as drawing, drama, and movement, into the learning process (Andrade, 2009; Blachowicz & Fisher, 2012; Lubliner & Scott, 2008). In many respects, the most important way that games help with vocabulary learning is that “games are fun, and word games are no exception” (Castek et al., 2012, p. 316). They can be so entertaining, in fact, that learners may not realize how much learning is taking place, and teachers may often need to make their rationale for using games explicit, warns Andrade (2009) – or risk having their students view those games as a meaningless waste of their time.

**Use of Multimedia Games in General Vocabulary Learning**

It should not be surprising, given the longstanding acceptance of games as a tool for vocabulary learning, that in recent years a number of researchers have looked at the
use of digital multimedia games for vocabulary learning. Among the attractions of digital multimedia games is that, in addition to the possible supports for learning that regular games have, they also present new ways to foster interaction and the possibility of essentially unlimited repetition (Hitosugi et al., 2014).

Investigations of the use of digital technologies in vocabulary learning games take four main approaches, which are summarized in Table 2 and discussed in more detail below.

One approach involves adding a game element to an already-utilized digital tool for vocabulary learning. A second approach involves using a traditional game in a digital format to aid in vocabulary learning. Another approach is to use a commercial, off-the-shelf (COTS) digital game to teach vocabulary. A fourth and final approach is to develop a totally new digital game to help with vocabulary learning.

An example of an approach that adds a game element to an already-utilized digital tool for vocabulary learning is the Lex app for mobile devices (Rose, 2012). The Lex app builds on the omnipresence of digital flashcard tools by letting learners import flashcard vocabulary lists from sites such as Quizlet, which has thousands of pre-made lists, and also gives learners the ability to make custom lists as needed. The Lex app can then display vocabulary items from the imported list in a game interface that is cognitively much more engaging than a flashcard interface, such as that of Quizlet. The Lex app also includes multiple ways to track learner progress. No study has been carried out to date to determine the effectiveness of the Lex app as an aid to vocabulary learning.
Table 2

*Main Approaches to the Use of Digital Games to Promote Vocabulary Learning*

<table>
<thead>
<tr>
<th>APPROACH</th>
<th>Researcher(s)</th>
<th>Game</th>
<th>Contextualized or Decontextualized Learning?</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adding a game element to an already-utilized digital tool</td>
<td>Rose, 2012</td>
<td>Lex app for mobile devices</td>
<td>Decontextualized</td>
<td>Not tested</td>
</tr>
<tr>
<td>Using a traditional game in a digital format</td>
<td>Lo &amp; Tseng, 2011</td>
<td>Electronic version of Bingo</td>
<td>Decontextualized</td>
<td>Not tested</td>
</tr>
<tr>
<td></td>
<td>Bakar &amp; Nosratirad, 2013</td>
<td>The SIMs</td>
<td>Contextualized</td>
<td>Gains in vocabulary, positive attitude toward language learning</td>
</tr>
<tr>
<td></td>
<td>Ranalli, 2008</td>
<td>The SIMs</td>
<td>Contextualized</td>
<td>Gains in vocabulary with supplementary material use, positive attitude toward language learning</td>
</tr>
<tr>
<td>Using a commercial, off-the-shelf (COTS) digital game</td>
<td>Miller &amp; Hegelheimer, 2006</td>
<td>The SIMs</td>
<td>Contextualized</td>
<td>Gains in vocabulary with supplementary material use, positive attitude toward language learning</td>
</tr>
<tr>
<td></td>
<td>Hitosugi et al., 2014</td>
<td>Food Force</td>
<td>Contextualized</td>
<td>Gains in vocabulary, positive attitude toward language learning</td>
</tr>
<tr>
<td></td>
<td>Vahdat &amp; Behbahani, 2013</td>
<td>Runaway: A Road Adventure</td>
<td>Contextualized</td>
<td>Gains in vocabulary, positive feelings toward game play</td>
</tr>
<tr>
<td>Developing a totally new digital game</td>
<td>Chen, Lee, &amp; Chou, 2013</td>
<td>My-Pet-Shop</td>
<td>Contextualized</td>
<td>Not tested</td>
</tr>
<tr>
<td></td>
<td>Fisser, Voogt, &amp; Bom, 2013</td>
<td>Word Score</td>
<td>Contextualized</td>
<td>Gains in vocabulary, positive feelings toward game play</td>
</tr>
</tbody>
</table>
An example of an approach that uses a traditional game in a digital format to aid in vocabulary learning is an electronic version of the traditional game Bingo (Lo & Tseng, 2011). In this electronic version, players answer vocabulary questions to win squares. Just like traditional Bingo, the electronic version allows multiple learners to play at the same time. It also lets the players customize the game’s level of difficulty. No research has yet been done to gauge the effectiveness of this electronic version of Bingo.

An example of using a commercial, off-the-shelf (COTS) digital game to teach vocabulary is the utilization of The SIMs for self-directed vocabulary learning by adult English as a Second Language (ESL) students (Bakar & Nosratirad, 2013). The three participants were simply told to play The SIMs, a game in which players organize and manage a neighborhood of 10 houses, create the people living in the houses, and try to keep those people happy. Participants were told to play any time they wanted, for as long as they wanted. The researchers found that the participants exhibited both gains in vocabulary and a positive attitude toward language learning.

The SIMs were also used by Miller and Hegelheimer (2006) in a study that compared the effectiveness of adding support materials to regular game play. The researchers found that only the players for whom use of the support materials was mandatory showed any statistically significant gain in vocabulary scores. They also found that all 18 of the participants had very positive feelings about playing the game.

Ranalli (2008) also used The SIMs in an investigation with nine participants designed to repeat and expand on the findings of Miller and Hegelheimer (2006). He also found, as they had, that support materials were necessary for a statistically significant gain in vocabulary scores, as well as generally positive feelings about game play.
Another investigation of the use of a COTS digital game to aid vocabulary learning was carried out by Hitosugi et al. (2014). They examined the use of the United Nations’ Food Force videogame to increase vocabulary learning and improve learner affect in university Japanese as a Second or Other Language students. In Food Force the player takes on the role of a new member of a United Nations World Food Project mission to fight hunger. Two studies were carried out. In the first, with 11 participants for whom results of testing had no effect on their grades, the students used vocabulary worksheets as an adjunct to game use. In the second study, with nine participants for whom results of testing were part of their grade in the class, the students were given lists of new vocabulary prior to game use, a quiz during game use, and a unit test at the end of game use. Participants in both studies were given vocabulary pre- and posttests and an attitudinal survey after completion of the posttest. The researchers found that use of Food Force seemed to have a positive effect on student vocabulary learning and retention. The effect was greater for those students in the second study. The researchers also found that students exhibited a positive affect regarding the use of Food Force in instruction, although feelings were less positive for those students in the second study, for whom it counted as part of their grade.

Vahdat and Behbahani (2013) also made use of a COTS digital game, Runaway: A Road Adventure, to foster vocabulary learning by adult English as a Foreign Language (EFL) students. In Runaway: A Road Adventure, players must find certain objects within the game, and then use them to build a tool to help the game’s protagonist get out of trouble. There were 40 participants, half of whom received traditional lessons that consisted of readings written by the researchers and based on the plot of the game,
followed by worksheets to teach the new vocabulary. The other participants were simply asked to play the game. The researchers’ results indicated that participants who learned vocabulary through game play acquired more vocabulary than those receiving traditional instruction. The researchers also found that students generally had very positive feelings about the experience of learning vocabulary through video game play.

Instances of the development of digital games for vocabulary learning that are not reworkings of an existing game, do not have a connection with some preexisting application like Quizlet, or a connection with a preexisting digital game, like The Sims, are few and far between. Two examples of such original games are My-Pet-Shop (Chen et al., 2013) and Word Score (Fisser et al., 2013). My-Pet-Shop is a digital management game designed to foster self-regulated learning as well as incidental vocabulary learning from meaningful context (Chen et al., 2013). In the game, the student plays the part of the manager of a pet shop. My-Pet-Shop has not, as yet, been tried with students. Word Score is an online game that is designed to improve players’ vocabulary. In the game, the student acts as the manager of a soccer team. In the study, 82 students used the Word Score game, 46 of whom did so during regular class time, and 36 of whom did so as part of “Educational Time Extension” (ETE), a program in which class time is extended beyond the regular school hours so as to improve learning outcomes for underperforming students. The results on vocabulary pre-and posttests for students using Word Score were compared with a control group of 60 students who did not use Word Score and did not participate in ETE. All participants in the study, including teachers and supervisors, also completed an attitudinal survey when study was completed. The investigators also found that students using Word Score as a part of ETE showed a gain on vocabulary tests when
compared to the control group that had both statistical and practical significance. They also found that student users, teachers, and supervisors were all very enthusiastic about the use of Word Score.

**Use of Multimedia Games in Science Vocabulary Learning**

If one examines the use of digital games in learning scientific vocabulary, there is very little research at present, despite the fact that, as discussed previously, vocabulary learning is a particularly pressing problem in the sciences.

One example of the use of a digital game specifically for learning scientific vocabulary is the digital game Vocabulary, a Spanish-English vocabulary translation game. Salazar and Carballo (2009) investigated the use of the Vocabulary game, which was designed by an unnamed graduate student working on the research project, with eight students in their fifth and final year of a nursing program at the Universidad de Costa Rica. Sadly, the results of the investigation were inconclusive. They were, however, interpreted by the researchers as an indication that it is possible for learners to successfully acquire vocabulary using a context-free computer game.

**Use of Multimedia Games in Biology Vocabulary Learning**

When one turns to the use of digital games for the learning of biology vocabulary, there appears to be no research done as yet, despite the fact that, as mentioned previously, there is an overwhelming need for more effective and efficient ways to teach the enormous amount of vocabulary that biology students need to acquire (Groves, 1995; Grillo & Dieker, 2013). This gap in the research would seem to argue for the need for investigation into the use of digital games to aid in learning biology vocabulary.
Given such a need, the question then arises as to what type of digital game should be used for the investigation. If one feels, as Stahl and Nagy (2006) do, that vocabulary should not be learned divorced from context, then the answer is a game such as The SIMs, as employed by Miller and Hegelheimer (2006), Ranalli (2008), and Bakar and Nosratirad (2013). It is worth bearing in mind that, as Miller and Hegelheimer (2006) have pointed out, the cost of obtaining enough copies of the game to use with a sizeable number of individuals can be quite prohibitive. A free game such as Food Force, used by Hitosugi and colleagues (2014) might be a reasonable alternative in some circumstances.

Those who believe, as do Nation (2006) and Lubliner (Lubliner & Scott, 2008), that it can be effective to teach vocabulary independent of context, might prefer to use a digital game such as Rose's (2012) Lex app, which is easily customizable, and although not free, is relatively inexpensive. It is, however, confined to use on mobile devices such as cell phones, which may limit its application in many classrooms.

A third option exists that is potentially suitable for those of any school of thought, which is to build a game from scratch. That, however, requires a skill set not many educators possess, can be extremely time-consuming and labor-intensive, and may yield little payback on that investment of time and energy (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012).

**Multimedia Learning**

The theoretical foundation for the proposed research is Mayer’s cognitive theory of multimedia learning (CTML), which seeks to explain how we learn from words and pictures – that is, from multimedia (Mayer, 2010, 2014a). The theoretical foundation for Mayer’s theory, in turn, lies in the ideas of a number of his predecessors. Those ideas
include Paivio’s Dual Coding Theory, the Cognitive Load Theory of Sweller and colleagues, and Wittrock’s Generative Learning Theory. All of these will be discussed in this section in regard to their influence on CTML. This section will also look at ideas regarding the relationship between motivation and multimedia learning, including Moreno’s Cognitive-Affective Theory of Learning with Media (CATLM).

**Paivio’s Dual Coding Theory**

Paivio’s Dual Coding Theory (DCT) is a general theory of cognition that holds that there are two separate cognitive systems: a verbal system for dealing with language in all its forms, and a nonverbal system for dealing with everything else (Paivio, 1971, 1986, 1991; Sadoski, 2005; Sadoski, Goetz, & Fritz, 1993). The verbal system codes verbal information into units Paivio calls logogens (Paivio, 1986). The nonverbal system is often referred to as the imagery system since it codes information in the form of image units, which Paivio has termed imagens, but it is important to note that the information it codes can be anything nonverbal, such as the smell of a rose or the anger associated with a parking ticket (Paivio, 1986; Sadoski et al., 1993). “All knowledge, meaning, and memory,” says DCT, “is explained by representation and processing within and between the two codes” (Sadoski, 2005, p. 222).

According to DCT, coding is additive – something that has been coded both verbally and nonverbally (dual coding) is twice as likely to be recalled as something coded in only one form. This leads to a particular focus in DCT on the concreteness of language (or lack thereof) as a determiner of its memorability. The quite concrete phrase “buxom blonde” is much more likely to conjure up an image than the less concrete phrase “heuristic algorithm,” and therefore, according to DCT, much more likely to undergo dual coding – with the result that it should be much more memorable.

**Baddeley’s Theory of Working Memory**

In 1974, Baddeley and Hitch proposed a model of working memory consisting of three components: a central executive, controlling attention, and two short-term storage
systems. This model is shown in Figure 3 below. One of those short-term storage systems, which they named the visuo-spatial sketchpad, was believed to store visual material; the other, termed the phonological loop, stored verbal-acoustic material (Baddeley, 2007; 2010). Baddeley and Hitch chose to use the term “working memory” to emphasize that its role extended beyond simply a storage function to influence cognition in general (Baddeley, 2010).

The model has subsequently been supplemented by the addition of another component, the episodic buffer. This updated model is shown in Figure 4. In Baddeley’s words, the episodic buffer holds “multidimensional episodes or chunks, which may combine visual and auditory information possibly also with smell and taste” (Baddeley, 2010, p. 138). In the episodic buffer, it is theorized, various components of working memory can interact with each other and with information from the senses and from long-term memory. The capacity of the episodic buffer is thought to be limited – about four chunks or episodes (Baddeley, 2007, 2010).

**Cognitive Load Theory**

Cognitive Load Theory (CLT), as developed by Sweller and colleagues, is a theory of instructional design based on a series of assumptions about human cognitive architecture (Sweller et al., 2011). One of those assumptions is that we have a very limited working memory, which can hold information for a very limited period and process just a few pieces of information at a time (Kalyuga, 2011; Mousavi, Low, & Sweller, 1995; Sweller et al., 2011). By contrast, CLT maintains, we have a long-term memory that is essentially unlimited in size, and which, true to its name, is able to store information on a long-term basis (Kalyuga, 2011; Mousavi et al., 1995; Sweller et al., 2011). According to CLT, information is stored in long-term memory in cognitive constructs called schemata (Kalyuga, 2011; Mousavi et al., 1995; Sweller et al., 2011). These schemata allow us to categorize information on the basis of the function for which it
Figure 3. Baddeley and Hitch’s original model of working memory (Baddeley, 2010, p. R137).
Figure 4. Baddeley’s multicomponent model of working memory (Baddeley, 2010, p. R138).
will be used, and reduce the load on our working memory by allowing us to treat multiple pieces of information as a single item (Kalyuga, 2011; Mousavi et al., 1995; Sweller et al., 2011). CLT sees acquisition of schemata and the automation of cognitive processes such as the automatic use of schemata as primary mechanisms of learning (Kalyuga, 2011; Mousavi et al., 1995; Sweller et al., 2011). Based on these assumptions regarding our cognitive architecture, CLT sees the limitations of our working memory as being the bottleneck that limits our learning (Kalyuga, 2011; Mousavi et al., 1995; Sweller et al., 2011). As Sweller and colleagues put it, “Once appropriate information is stored in long-term memory, the capacity and duration limits of working memory are transformed and indeed, humans are transformed. Tasks that previously were impossible or even inconceivable can become trivially simple” (Sweller et al., 2011).

In CLT’s most current incarnation, many theorists see the constraints on working memory as consisting of two separate and additive types of cognitive load – intrinsic and extraneous (Kalyuga, 2011; Sweller et al., 2011). Intrinsic cognitive load is inherent in the learning materials, and is a function of the degree of interconnectedness between information items needing to be considered in working memory simultaneously (Kalyuga, 2011; Sweller et al., 2011). This interconnectedness is referred to as element interactivity (Kalyuga, 2011). An example of low element interactivity would be a learning task that involved memorizing the location of the brake, gas pedal, and steering wheel; an example of high element interactivity would be a learning task that involved driving across town during rush hour. How much intrinsic cognitive load a learner experiences is determined by the degree of element interactivity relative to the learner’s expertise in the domain (Kalyuga, 2011). An experienced driver would, for example, experience considerably less intrinsic cognitive load during the cross-town drive just
mentioned than someone who had never been behind the wheel before. Extraneous
cognitive load is cognitive load that is not necessary for learning, and can be considered
an artifact of less-than-ideal instructional design (Kalyuga, 2011; Mousavi et al., 1995;
Sweller et al., 2011). An example might be sheet music for beginning guitar students that
puts the chord diagrams for all the chords to be used in the song at the top of the first
page (as seen on the left-hand side of Figure 5 below), rather than placing the diagrams
over the chords as they appear in the music (as seen on the right-hand side of Figure 5).

Many descriptions of CLT contain a third category of cognitive load – germane
cognitive load. This category of cognitive load is defined as cognitive load necessary for
learning by means of schema acquisition and automation (Kalyuga, 2011). This is
currently seen by many theorists as effectively indistinguishable from intrinsic load
(Sweller et al., 2011).

**Wittrock’s Generative Learning Theory**

Wittrock’s Generative Learning Theory states that learning is based on four components:
generation, motivation, attention, and memory (Wittrock, 1989). In Wittrock’s view, our
brains actively work to construct meaning and respond to perceived realities. “Learning,”
says Wittrock, “consists of the active generation of meaning, not the passive recording of
information" (Wittrock, 1992, p. 537). “The brain,” he insists, “is a model builder. It does
not transform input into output” (Wittrock, 1992, p. 532). Attention and motivation guide
a learner’s choice of cognitive strategies and selection of the sensory information to
which the learner will attend. That information is then related to memory, and meaning is
actively constructed by the learner (Wittrock, 1989).
Higher extraneous cognitive load – chord diagrams at top only

Lower extraneous cognitive load – chord diagrams at every chord change

Figure 5. Examples of higher and lower extraneous cognitive load.
Mayer’s Cognitive Theory of Multimedia Learning

The Cognitive Theory of Multimedia Learning (CTML), which forms the theoretical foundation for this proposed research, is predicated on three tenets, taken as fundamental principles, regarding how the mind works: 1) the dual channel principle, 2) the limited capacity principle, and 3) the active processing principle. These principles are summarized in Table 3 below, and discussed in more detail in the paragraphs that follow.

Table 3

Three Fundamental Principles of CTML

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual Channel Principle</td>
<td>Humans possess separate information channels for verbal and visual material</td>
</tr>
<tr>
<td>Limited Capacity Principle</td>
<td>There is only a limited amount of processing capacity available in the verbal and visual channels</td>
</tr>
<tr>
<td>Active Processing Principle</td>
<td>Learning requires substantial cognitive processing in the verbal and visual channels</td>
</tr>
</tbody>
</table>

Adapted from Mayer and Moreno, 2003

The dual channel principle, derived from both Paivio’s Dual Coding Theory and Baddeley’s Theory of Working Memory, holds that our information-processing system is made up of two separate channels: 1) an auditory/verbal channel that processes both auditory input and verbal representations; and 2) a visual/pictorial channel that processes both visual input and pictorial representations (Mayer, 2010; Mayer & Moreno, 2003).

The limited capacity principle, based on Baddeley’s Theory of Working Memory and Sweller and colleagues’ Cognitive Load Theory, says that both of the channels have limited capacity – that is, only a limited amount of cognitive processing can take place in a channel at any one time (Mayer, 2010; Mayer & Moreno, 2003).
The active processing principle, stemming from Wittrock’s Generative Learning Theory, maintains that meaningful learning – “a deep understanding of the material… reflected in the ability to apply what was taught to new situations” (Mayer & Moreno, 2003, p. 43) – requires a substantial amount of cognitive processing in the two channels (Mayer & Moreno, 2003). That processing may involve such activities as paying attention to the material presented, mentally organizing it into a coherent structure, and integrating it with existing knowledge activated from long-term memory (Mayer, 2010; Mayer & Moreno, 2003).

According to CTML, long-term memory is one of three memory stores, the other two being working memory and sensory memory (Mayer, 2010, 2017; Mayer & Moreno, 2003). Figure 6 diagrams the relationships between these three and how they are involved in processing multimedia presentations.

When attending to a multimedia presentation, our sensory memory creates an exact sensory copy of what is presented. It does so, however, for only a very brief time – less than a quarter of a second. Words may be routed to the ears when presented as sound, or to the eyes when presented in written form (Mayer, 2010, 2014a; Mayer & Moreno, 2003).

Our working memory holds a more processed version of what has been presented. It does this for a relatively short period – less than 30 seconds – and is able to process only a few items at any one time. The processing that does take place, however, is fundamental to learning, and will be examined further below (Mayer, 2010, 2014a; Mayer & Moreno, 2003).

The third memory store, our long-term memory, holds all our prior knowledge, and it does so long-term. Its storage capacity appears to be essentially unlimited (Mayer, 2010, 2014a; Mayer & Moreno, 2003).
Figure 6. The Cognitive Theory of Multimedia Learning (CTML) (Adapted from Mayer, 2010).
As just mentioned, our long-term memory seems to be able to hold an almost infinite amount of information. Sensory memory also seems to have an unlimited capacity for the stimuli with which we may bombard it. The limited processing capacity of our working memory, however, restricts what the system can effectively handle (Mayer, 2010, 2014a).

The processing that occurs in working memory is of five main types. One is the selecting of spoken words held in the sensory memory for further processing. A similar selection process occurs with the written words and images contained in sensory memory (Mayer, 2014a; Mayer & Moreno, 2003). Note, however, that printed words are converted to sounds for processing in the verbal channel, as indicated by the arrow from Images to Sounds shown in Figure 6 (Mayer, 2010). Another type of processing consists of organization: spoken words are organized into a verbal model, while images are organized into a pictorial model. The final type of processing carried out by working memory is the integration of the verbal and pictorial models created with each other and with prior knowledge retrieved from long-term memory (Mayer, 2010, 2014a; Mayer & Moreno, 2003). These five types of processing are summarized in Table 4 below.

According to CTML, meaningful learning occurs if and only if we engage in all five of these types of processing in response to a multimedia presentation (Mayer, 2010).

While the processing just mentioned is required in order to achieve meaningful learning, CTML stresses the need to ensure that the cognitive processing required during learning does not exceed the cognitive capacity of the learner (Mayer, 2010). CTML recognizes three types of cognitive processing that occur during learning from multimedia presentations: extraneous, essential, and generative (Mayer, 2010, 2014a,
### Table 4

*Types of Processing in Working Memory according to CTML*

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selecting words</td>
<td>Learner pays attention to relevant words in a multimedia message to create sounds in working memory</td>
</tr>
<tr>
<td>Selecting images</td>
<td>Learner pays attention to relevant pictures in a multimedia message to create images in working memory</td>
</tr>
<tr>
<td>Organizing words</td>
<td>Learner builds connections among selected words to create a coherent verbal model in working memory</td>
</tr>
<tr>
<td>Organizing images</td>
<td>Learner builds connections among selected images to create a coherent pictorial model in working memory</td>
</tr>
<tr>
<td>Integrating</td>
<td>Learner builds connections between verbal and pictorial models and with prior knowledge</td>
</tr>
</tbody>
</table>

From Mayer, 2014a, p. 54
These three types of cognitive processing are outlined in Table 5, and discussed in the paragraphs that follow.

Extraneous processing is cognitive processing that does not support the instructional goal (Mayer, 2010, 2014a, 2017). According to CTML, one aim in designing instruction should be to eliminate as much extraneous processing as possible, which will free up cognitive capacity for the essential and generative processing that result in meaningful learning (Mayer, 2010, 2014a, 2017).

Table 5

Demands on Cognitive Capacity During Learning in CTML

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Caused by</th>
<th>Learning processes</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraneous</td>
<td>Cognitive processing that is not related to the instructional goal</td>
<td>Poor instructional design</td>
<td>None</td>
<td>Focusing on irrelevant pictures</td>
</tr>
<tr>
<td>processing</td>
<td></td>
<td>Complexity of the material</td>
<td>Selecting</td>
<td>Memorizing the description of essential processing</td>
</tr>
<tr>
<td>Essential</td>
<td>Cognitive processing to represent the essential presented material in working memory</td>
<td>Motivation to learn</td>
<td>Organizing and integrating</td>
<td>Explaining generative processing in one's own words</td>
</tr>
<tr>
<td>processing</td>
<td>Cognitive processing aimed at making sense of the material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Mayer, 2014a, p. 60.

As shown in Table 6, CTML directs designers of instruction to follow five principles to reduce extraneous processing: the coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles (Mayer, 2010, 2014a, 2017).

The coherence principle holds that we learn better from a multimedia presentation that excludes rather than includes extraneous material. For example, a simple
<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principles for reducing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>extraneous processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coherence</td>
<td>People learn better when extraneous material is excluded.</td>
<td>0.70</td>
</tr>
<tr>
<td>Signaling</td>
<td>People learn better when essential material is highlighted.</td>
<td>0.46</td>
</tr>
<tr>
<td>Redundancy</td>
<td>People learn better from graphics and narration that from graphics, narration, and on-screen text.</td>
<td>0.87</td>
</tr>
<tr>
<td>Spatial contiguity</td>
<td>People learn better when on-screen words are placed next to the corresponding part of the graphic.</td>
<td>0.79</td>
</tr>
<tr>
<td>Temporal contiguity</td>
<td>People learn better when corresponding narration and graphics are presented simultaneously.</td>
<td>1.30</td>
</tr>
<tr>
<td>Principles for managing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>essential processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segmenting</td>
<td>People learn better when a lesson is presented in small user-paced segments.</td>
<td>0.70</td>
</tr>
<tr>
<td>Pre-training</td>
<td>People learn when they learn the key terms prior to receiving a lesson.</td>
<td>0.46</td>
</tr>
<tr>
<td>Modality</td>
<td>People learn better from a lesson when words are presented in spoken form.</td>
<td>0.72</td>
</tr>
<tr>
<td>Principles for fostering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>generative processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multimedia</td>
<td>People learn better from words and pictures than from words alone.</td>
<td>1.67</td>
</tr>
<tr>
<td>Personalization</td>
<td>People learn better when words are presented in conversational style rather than formal style.</td>
<td>0.79</td>
</tr>
<tr>
<td>Voice</td>
<td>People learn better from a human voice than a machine-like voice.</td>
<td>0.74</td>
</tr>
<tr>
<td>Embodiment</td>
<td>People learn better when an onscreen agent uses human-like gestures and movement.</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Adapted from Mayer, 2010, 2017
black-and-white map showing areas where elephantiasis is prevalent will lead to better learning than a map with full-color insets of people afflicted with elephantiasis.

The signaling principle maintains that we learn better from a multimedia presentation that signals the truly essential material by using highlighting, pointer words like “first,” “second,” “third,” etc. (Mayer, 2017). This is also referred to as visual cueing (Mayer, 2017). We will learn better, for example, from a multimedia presentation on air cabin safety if – instead of just describing what to do in the event of a loss of cabin pressure – the presentation tells us, “First put on your own air mask. Second, help put on the air mask of anyone with whom you are traveling who has been unable to do so....”

The spatial contiguity principle states that we learn better when printed words are placed near to instead of far from the corresponding part of a graphic on the screen (or page) of a multimedia presentation (Mayer, 2017). An all-too-common example of the trouble that can be caused when this principle is violated is when a passage in a textbook refers to a diagram located on the preceding page. It does not take much flipping back and forth to be convinced that this leads to an increase in extraneous processing, and that learning would be enhanced by having both the diagram and the related text on the same page.

The temporal contiguity principle asserts that we learn better if a multimedia presentation delivers narration and the corresponding graphic at same time (Mayer, 2017). Thus the temporal contiguity principle would predict that learning would be better during a multimedia presentation meant to teach young children their ABCs if, when the children hear a voice singing about the letter C, they see the letter C at the same time, rather than still being presented with B or having already moved on to D.
Essential processing is the cognitive processing needed to mentally represent the material presented, and is present to a greater or lesser degree depending on the inherent complexity of that material (Mayer, 2010, 2014a, 2017). Instructional design, says CTML, should strive to help manage essential processing for learners in those cases where the nature of the material to be learned is such that essential processing demands may overwhelm learners’ cognitive capacity (Mayer, 2010, 2014a, 2017). As Table 6 shows, essential processing can, according to CTML, be managed by following three principles: the segmenting, pre-training, and modality principles (Mayer, 2010, 2014a, 2017).

According to the segmenting principle, we learn better when a large multimedia presentation is divided into smaller segments that we can work our way through at our own pace (Mayer, 2010, 2014a, 2017). For example, in a narrated presentation on the Second World War, learning will be improved if learners are able to pause the presentation at major points – like the US entry into the war, perhaps – and then continue when they are ready for more.

The pre-training principle holds that we learn better from a multimedia presentation when we have previously been familiarized with the key concepts of the presentation (Mayer, 2010, 2014a, 2017). Before viewing a video on the nervous system, for example, learners will benefit from pre-training on the structure of a neuron, how a nervous impulse travels, the divisions of the nervous system, etc.

The modality principle maintains that we learn better when the words in a multimedia presentation are spoken instead of printed (Mayer, 2010, 2014a, 2017). According to the modality principle, we would predict that, when watching a video on
famous generals of the American Civil War, learning will be improved by having each
general named in the narration when he appears on-screen rather than having his name
appear beneath his picture.

It is worth noting that the modality principle is the most-studied of the CTML
principles of instructional design (Mayer, 2017), and researchers have to learned that the
modality principle is much more effective in some settings than others. Mayer and
Pilegard examined 61 studies of the modality principle, and found a median effect size of
0.76 (Mayer & Pilegard, 2014). In a subsequent analysis, Mayer examined 52
experimental tests and calculated an overall effect size for the modality principle of 0.72
(Mayer, 2017). A meta-analysis by Ginns looked at 43 experimental tests and also arrived
at an overall effect size of 0.72, but found that effect size could vary greatly (Ginns,
2005). Ginns found that element interactivity and pacing of the presentation can have a
dramatic impact on effect size. He calculated a mean effect size for tests with high
element interactivity materials of 0.63, while that for low element interactivity materials
was 0.10 (Ginns, 2005). Ginns found a similar contrast when looking at tests with
system-paced materials versus those with self-paced materials, with an effect size of 0.93
for system-paced materials, and -0.14 for self-paced materials (Ginns, 2005). A number
of other such boundary conditions for the modality principle have been found. Mayer and
Pilegard (2014) sum things up by saying:

According to the cognitive theory of multimedia learning, we would expect the
modality principle to apply when the material is complex rather than simple, the
presentation is system-paced rather than self-paced, the graphics are dynamic
rather than static, the learners have a low level of knowledge rather than a high
level, the verbal segments are short rather than long, and the words are familiar rather than unfamiliar. (p. 336).

The third category of cognitive processing recognized by CTML – generative processing – is cognitive processing that seeks to make sense out of what has been presented. This is analogous to the germane cognitive load category that was, until recently, part of Sweller and colleagues’ Cognitive Load Theory (CLT).

The amount of generative processing that occurs can increase or decrease depending on such factors as the learner’s motivation (Mayer, 2010, 2014a, 2017). CTML sees fostering generative processing as a fundamental goal in designing instruction, and, as shown in Table 6, advises the use of four principles to do so: the multimedia, personalization, voice, and embodiment principles (Mayer, 2010, 2014a, 2017).

The multimedia principle states that we learn better from words and pictures – that is, from a multimedia presentation – than from words alone (Mayer, 2010, 2014a, 2017). It is far easier to learn the phases of the moon, for example, if you see pictures of them while learning than it is if you simply have them described to you.

The remaining three principles aimed at fostering generative processing – the personalization, voice, and embodiment principles – are thought to function through establishing a social partnership between the learner and the narrator of the multimedia presentation (Mayer, 2010, 2014a, 2017). Once a social response has been elicited and a sense of social partnership has been created, generative processing – cognitive processing that seeks to make sense out of what has been presented – is improved. As Mayer puts it,
“People try harder to make sense of what a narrator is saying when they feel they are in a social partnership with the narrator (Mayer, 2010, p. 548).

The personalization principle holds that we learn better when words are delivered in a conversational rather than formal style, and/or in a polite rather than a direct manner (Mayer, 2010, 2014a, 2017). For example, according to the personalization principle, learning will be improved if a narrator refers to “your brain” rather than “the brain” during a multimedia presentation on the human brain.

The voice principle maintains that we learn better from a multimedia presentation delivered via computer, cell phone, etc., when the narration is in a human rather than a machine voice (Mayer, 2010, 2014a, 2017). The voice principle may perhaps be part of the reason that the teaching robots that have been developed to date have been less than completely successful.

**Moreno’s Cognitive-Affective Theory of Learning with Media**

One influential expansion of Mayer’s Cognitive Theory of Multimedia Learning (CTML) is Moreno’s Cognitive-Affective Theory of Learning with Media (CATLM). To the cognitive framework of Mayer’s theory, CATLM adds a consideration of the motivational and affective aspects of multimedia learning (Moreno, 2006, 2007; B. Park, Plass, & Brünken, 2014). This foray into the motivational and affective realms leads to three assumptions about the nature of multimedia learning in addition to Mayer’s dual channel principle, limited capacity principle, and active processing principle. The three assumptions that Moreno adds are: 1) affective mediation – the assumption that motivational factors influence learning by increasing or decreasing cognitive engagement; 2) metacognitive mediation – the assumption that metacognitive factors shape learning by regulating cognitive processing and affect; and 3) individual
differences – the assumption that differences in prior knowledge and characteristics like cognitive styles and abilities may affect how much a particular individual learns with specific methods and media (Moreno, 2006; B. Park et al., 2014).

A look at the CATLM model shown in Figure 7 shows that Moreno has expanded sources of sensory information considered in the model to include touch, taste, and smell. This is in line with the expansion of Baddeley’s model of working memory to include the same types of sensory input. It also mirrors the increased use of such inputs in multimedia, with the now-widespread use of haptic (touch) feedback in video games, computer touchpads, cell phones, etc.

The model of CATLM in Figure 7 also shows that Moreno sees self-regulation, motivation, and affect as influencing both the selection of sensory information to be transmitted to working memory and its organization and interconnection once it gets there. Self-regulation, motivation, and affect also mediate the retrieval of information from long-term memory and the integration of that retrieved information with the mental models formed in from the sensory information in working memory (Moreno, 2006; B. Park et al., 2014).

It has been pointed out that the investigation of the interplay and interactions between the cognitive and affective aspects of multimedia learning has really only just begun (B. Park et al., 2014). Mayer, for example, has said of motivation that it “is an understudied aspect of multimedia learning that needs to be better addressed in future research” (Mayer, 2017, p. 418). Nonetheless, there is considerable enthusiasm amongst researchers for the potential contributions of this area of inquiry to our understanding of
Figure 7. The Cognitive-Affective Theory of Learning with Media (CATLM) (Moreno, 2006, p. 151)
multimedia learning and effective multimedia instruction (Mayer, 2017; Mayer & Estrella, 2014; B. Park et al., 2014).

**Summary**

This review has examined some of the more influential approaches to vocabulary learning, particularly the learning of science vocabulary. In doing so, it has highlighted some of the difficulties associated with science vocabulary, and with biology vocabulary in particular. The pressing need for tools to help students learn biology vocabulary was highlighted, before moving on to examine some of the possible tools.

The use of games for vocabulary instruction – and of multimedia games in particular – was investigated, and the current dearth of such games for science vocabulary instruction, and especially for biology vocabulary instruction, was noted. Mention was also made of the variety of implementations possible for game use in vocabulary instruction.

Having looked at games, with an emphasis on multimedia games, the review then examined ideas about multimedia learning, focusing primarily on Mayer’s Cognitive Theory of Multimedia Learning, the theoretical basis of this proposed study. That examination began with a look at some of the ideas that are foundational to Mayer’s theory: Paivio’s Dual Coding Theory, Baddeley’s Theory of Working Memory, and the Cognitive Load Theory developed by Sweller and colleagues. Having examined Mayer’s antecedents, a more detailed investigation of Mayer’s Cognitive Theory of Multimedia Learning, including what was borrowed and adapted from those earlier theories, was carried out. The final portion of the review examined an extension of Mayer’s ideas, Moreno’s Cognitive-Affective Theory of Learning with Media. One of Moreno’s great
contributions to multimedia learning research was to highlight the need to consider and investigate the influence of motivation and affect on learning with multimedia – something that this study attempted to do.
CHAPTER THREE

METHODOLOGY

The purpose of this study was to examine the relationship between instructional method – either traditional instruction or digital game based instruction – and learning biology vocabulary. Also considered were the relationship between instructional method and learning of biology concepts, and motivation engendered by the learning materials used. These variables were chosen after a literature review of the use of digital games for vocabulary learning focused on their use with scientific vocabulary. The research design of the study, sample, protection of human subjects, instrumentation, procedures, proposed data analysis, and possible limitations to the study will be discussed in this section.

Research Design

This study was intended to address the following research questions:

1. Are there statistically significant differences in scores on tests of biology vocabulary knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

2. Are there statistically significant differences in scores on tests of biology concept knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?
3. Are there statistically significant differences in ratings of motivation engendered by the learning materials used by students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

A two-group, quasi-experimental study was used. There was one treatment group, which received biology vocabulary instruction using a multimedia vocabulary game; and one control group, which received traditional biology vocabulary instruction. The study employed a fixed-effects multivariate analysis of covariance (MANCOVA) for a series of three types of dependent variables. By utilizing MANCOVA it was possible to adjust participants’ results for differences in initial level on the covariate, even though random assignment to treatment and control groups was not possible. The three types of dependent variables that were examined using MANCOVA were: 1) scores on tests of biology vocabulary; 2) scores on tests of biology concepts; and 3) vocabulary feedback and instructional materials motivation survey scores. These three types of dependent variables were chosen for three reasons: 1) student scores on the tests of biology vocabulary were used because it was hoped that, as predicted by theory, the use of appropriate multimedia would result in a statistically significant increase in vocabulary scores; 2) student scores on the tests of biology concepts were used because it was hoped that any increase in vocabulary scores would not occur at the expense of concept learning; and 3) vocabulary feedback and instructional materials motivation survey scores were used because theory predicts that the use of appropriate multimedia will increase student motivation. Participant HMH Reading Inventory (formerly Scholastic Reading Inventory – SRI) Lexile reading scores were used as the covariate for all three analyses of
covariance. Lexile reading scores were chosen as the covariate because of the strong relationship between reading ability and vocabulary (Lubliner, 2005; National Institute of Child Health & Human Development, 2000; Shanahan & Shanahan, 2008), which allowed Lexile reading scores to be used as a proxy for participants’ initial level of vocabulary knowledge. A chart of the experimental design is shown in Figure 8.

Sample

Setting

The study took place a Northern California comprehensive suburban high school. The school has approximately 1,200 students enrolled in grades 9 – 12. The student population is quite diverse, as shown in Table 7 below.

Table 7

Demographic Characteristics of School Population

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>37</td>
</tr>
<tr>
<td>Asian/Pacific Islander</td>
<td>30</td>
</tr>
<tr>
<td>Latinx</td>
<td>17</td>
</tr>
<tr>
<td>Two or more races</td>
<td>10</td>
</tr>
<tr>
<td>African American</td>
<td>4</td>
</tr>
<tr>
<td>English learners</td>
<td>9</td>
</tr>
<tr>
<td>Redesignated Fluent English Proficient</td>
<td>25</td>
</tr>
<tr>
<td>Qualify for Free/Reduced Price Lunch Program</td>
<td>18</td>
</tr>
</tbody>
</table>

Adapted from “School Profile - Albany High School,” 2016
Note: The experiment took place during the course of an instructional unit on ecology that lasted 61 days. The Pretest (HMH Reading Inventory was typically given to participants 18 months prior to the start of the experiment; Time 1 was, on average, 27 days after the start of the instructional unit; Time 2 was, on average, 60 days after the start of instruction; and Time 3 was, on average, 114 days after the start of instruction and 54 days after the end of instruction.

*Figure 8. Experimental design*
Participants

The participants in this study were a convenience sample of 276 college preparatory biology students in grades 9 through 12. All students at the high school are required to take and pass biology in order to graduate high school, with the result that the composition of biology classes tends to mirror that of the school as a whole. Students will typically take biology as ninth-graders, and for that reason, although classes typically contain a mix of ninth- through twelfth-graders, ninth-graders predominate. Students are primarily assigned to particular biology classes by the school’s computerized scheduling program. While not truly random, since assignment is determined in part by the other classes in a student’s schedule, it does tend to lead to very heterogeneous classes.

The students in the sample were enrolled in ten different classes, taught by three different teachers, one of whom was the researcher. Each teacher taught half of his or her classes using a multimedia word-matching game for vocabulary instruction, and half using traditional vocabulary instruction, which used word-matching worksheets.

Sample sizes for all MANCOVAs were determined using power analysis. The power analyses were conducted using G*Power software, version 3.1.9.2, with the following inputs: an alpha of 0.05, a power of 0.80, and a medium effect size \( f^2 = 0.25 \) (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009, 2014). An analysis for a MANCOVA of two levels and three dependent variables determined a minimum total sample size of 48; and a second analysis for a MANCOVA of two levels and four dependent variables determined a minimum total sample size of 53 (Faul et al., 2007; Faul et al., 2009, 2014). Thus all minimum total sample sizes calculated were much smaller than the sample size (276) for the study.
Protection of Human Subjects

An application was submitted to the University of San Francisco’s Institutional Review Board for the Protection of Human Subjects. All research was carried out in the course of normal biology instruction, and correlates with the goals and outcomes of the high school’s college preparatory biology curriculum. To protect student confidentiality, the names of participants did not appear in stored data. Digital records, which did not include student names, were maintained on a password protected flash drive.

A request for permission to carry out the study was submitted to the school’s principal and the school district’s Director of Educational & Student Support Services. Written permission was received from both, and can be viewed in Appendix A.

Instrumentation

As outlined in Table 8 below, this study used four types of instruments: (1) the HMH Reading Inventory (formerly Scholastic Reading Inventory – SRI), (2) vocabulary tests, (3) concept tests, and (4) vocabulary feedback and instructional materials motivation surveys.

The HMH Reading Inventory, which provided the Lexile reading scores used as a covariate in data analysis, is administered to almost all district students. For most students, the score used for analysis was from the spring of 2016; for those who did not take the test in the spring of 2016, the most recent available score was used.

The curriculum-based measurements were vocabulary tests developed by the researcher; concept tests, developed by the researcher’s colleagues; and a final examination, produced by the researcher’s colleagues, from which questions were
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Source</th>
<th>Timing of Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reading Instrument</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HMH Reading Inventory</td>
<td>Houghton Mifflin Harcourt</td>
<td>Spring 2016* - i.e., 18 months prior to start of unit</td>
</tr>
<tr>
<td><strong>Vocabulary Instruments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocabulary test</td>
<td>Researcher</td>
<td>Near midpoint of unit (Time 1) and at endpoint of unit (Time 2)</td>
</tr>
<tr>
<td>Vocabulary test (in final examination)</td>
<td>Participating biology teachers</td>
<td>54 days after end of unit (Time 3)</td>
</tr>
<tr>
<td><strong>Concept Instruments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concept test</td>
<td>Participating biology teachers</td>
<td>Near midpoint of unit (Time 1) and at endpoint of unit (Time 2)</td>
</tr>
<tr>
<td>Concept test (in final examination)</td>
<td>Participating biology teachers</td>
<td>54 days after end of unit</td>
</tr>
<tr>
<td><strong>Survey Instruments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback Survey</td>
<td>Participating biology teachers</td>
<td>At end of unit section</td>
</tr>
<tr>
<td>Reduced Instructional Materials</td>
<td>Loorbach et al., 2015</td>
<td>At end of unit</td>
</tr>
<tr>
<td>Motivation Survey (RIMMS)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* For most students; for those who did not take the test in spring 2016, the most recent available test score was used.
selected for use as a posttest.

The surveys with rating scale given to participants were of two types: one was a short vocabulary feedback survey developed by the researcher; the other was a version of Keller’s Instructional Materials Motivation Survey (IMMS), which has been used extensively to measure learners’ motivation in response to instructional materials (Keller, 2010; Loorbach et al., 2015).

**HMH Reading Inventory**

The HMH Reading Inventory is a product of Houghton Mifflin Harcourt. It is a computer-adaptive reading comprehension assessment for grades K-12 that measures reading comprehension on the Lexile Framework for Reading. Lexile reading scores from the Inventory were used to provide the covariate used in MANCOVA. The reliability of the inventory is high: the reported Cronbach’s alpha for the Reading Inventory overall is .86 (Scholastic, Inc., 2014). A sample question from the HMH Reading Inventory is shown in Appendix B.

**Biology Vocabulary Tests**

The biology vocabulary tests utilized during instruction at Time 1 and Time 2 were word-and-definition matching assessment developed by the researcher. Such tests have been found to be not only good indicators of vocabulary knowledge, but of general subject matter knowledge as well (Espin et al., 2013). The vocabulary tests given at Time 1 and Time 2 will be referred to hereafter as Vocab1 and Vocab2 respectively. The tests used are shown in Appendix C. The vocabulary test given at Time 3 was composed of vocabulary questions from the semester final examination developed by the other participating teachers, and will henceforth be referred to as Vocab3.
Biology Concept Tests

The biology concept tests used were developed by the other participating teachers at the high school, and have been used for several years. The tests used are shown in Appendix D. The two concepts given at Times 1 and 2 will be referred to henceforward as Concept1 and Concept2 respectively. As with vocabulary, the concept test at Time 3 was composed of questions from the semester final examination developed by the other participating teachers, and will be referred to as Concept3.

Surveys

A short vocabulary feedback survey developed by the researcher was given at Time 1 (Vocabulary Survey 1) and Time 2 (Vocabulary Survey 2), and consisted of three short questions concerning: (1) time spent working on the vocabulary practice (henceforth referred to as Work1 for Time 1 and Work 2 for Time 2); (2) how much the practice helped them learn the vocabulary (hereafter referred to as Learn1 for Time 1 and Learn 2 for Time 2); and (3) how much it motivated them to work on learning the vocabulary (henceforward referred to as Motivate1 for Time 1 and Motivate2 for Time 2). The feedback survey is shown in Appendix E.

The Reduced Instructional Materials Motivation Survey (RIMMS) developed by Loorbach and colleagues (Loorbach et al., 2015), a shortened version of the Instructional Materials Motivation Survey (IMMS) developed by Keller (Keller, 2010), was administered at the end of the unit. The 36-question IMMS has been widely used as a measure of motivation of learners in response to instructional materials, and has shown a high level of reliability (S. Park & Lim, 2007; Keller, 2010). The same is true of the much more compact 12-question RIMMS, with values for Cronbach’s alpha for the
subscales of the RIMMS as follows: Attention, .89; Relevance, .81 Confidence, .90; and Satisfaction, .92 (Loorbach et al., 2015). The version of the RIMMS used in this study is shown in Appendix F.

With the exception of the HRM Reading Inventory, reliability statistics for all instruments were computed from raw test scores. The reliability score for the HRM Reading Inventory was reported from the Inventory’s Technical Manual (Scholastic, Inc., 2014). Reliability computations were carried out prior to missing data analysis, which accounts for the differences in sample size for the various calculations. Table 9 provides means, standard deviations, and reliability statistics for each of the instruments administered. Overall, reliability scores ranged from .47 to .87.

**Procedures**

In order to be able to carry out this study, the researcher first consulted with the biology teachers at the high school to be sure they were willing and able to help with the proposed research. Shortly after that was verified, in the spring of 2017, the researcher obtained permission from the principal of the high school. Permission was received from the school district’s director of Curriculum, Instruction, and Assessment in the fall of 2017. Having received the required letters confirming the principal and district’s permission, the researcher then applied for approval from the University’s Institutional Review Board (IRB). An “IRB Verification of Exempt Research Involving Human Subjects” was received and data collection was carried out in the fall of 2017. With the
Table 9

Means, Standard Deviations (SD), and Reliabilities for All Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>M</th>
<th>SD</th>
<th>α</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HMH Reading Inventory</td>
<td>1171.00</td>
<td>226.20</td>
<td>.86(^{a})</td>
<td></td>
</tr>
<tr>
<td>Time 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocab1</td>
<td>19.74</td>
<td>4.37</td>
<td>.87</td>
<td>278</td>
</tr>
<tr>
<td>Concept1</td>
<td>4.51</td>
<td>1.29</td>
<td>.51</td>
<td>277</td>
</tr>
<tr>
<td>Vocabulary Feedback Survey 1</td>
<td>9.29</td>
<td>2.70</td>
<td>.54(^{b})</td>
<td>260</td>
</tr>
<tr>
<td>Work1</td>
<td>3.17</td>
<td>1.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learn1</td>
<td>3.27</td>
<td>1.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motivate1</td>
<td>2.84</td>
<td>1.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocab2</td>
<td>20.50</td>
<td>3.59</td>
<td>.82</td>
<td>276</td>
</tr>
<tr>
<td>Concept2</td>
<td>5.17</td>
<td>1.04</td>
<td>.47</td>
<td>275</td>
</tr>
<tr>
<td>Vocabulary Feedback Survey 2</td>
<td>9.16</td>
<td>2.77</td>
<td>.56(^{b})</td>
<td>265</td>
</tr>
<tr>
<td>Work2</td>
<td>2.98</td>
<td>1.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learn2</td>
<td>3.29</td>
<td>1.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motivate2</td>
<td>2.89</td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIMMS</td>
<td>36.28</td>
<td>8.23</td>
<td>.87</td>
<td>257</td>
</tr>
<tr>
<td>Attention</td>
<td>8.51</td>
<td>2.64</td>
<td>.76</td>
<td></td>
</tr>
<tr>
<td>Relevance</td>
<td>9.93</td>
<td>2.33</td>
<td>.60</td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td>10.34</td>
<td>2.66</td>
<td>.75</td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td>7.50</td>
<td>2.80</td>
<td>.81</td>
<td></td>
</tr>
<tr>
<td>Time 3 (Final Exam)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocab3</td>
<td>18.67</td>
<td>3.38</td>
<td>.81</td>
<td>277</td>
</tr>
<tr>
<td>Concept3</td>
<td>13.88</td>
<td>3.23</td>
<td>.78</td>
<td>277</td>
</tr>
</tbody>
</table>

\(^{a}\) From Technical Manual (Scholastic, Inc., 2014).  
\(^{b}\) For all items together.
exception of the Lexile reading scores used as a pretest, which were collected by the
school district many months prior, and the final examination questions used as a posttest,
which were collected at the end of the semester, all data collection occurred during the
course of the participants’ ecology unit.

Each cooperating teacher was asked to give the multimedia game vocabulary
instruction treatment to half of his or her classes, and instruction via traditional
pen-and-paper matching exercises to the remaining classes. Both groups completed two
vocabulary tests during the course of instruction, and filled out vocabulary feedback
surveys after each vocabulary test. Both groups were also tested on ecology concepts
during the course of instruction, permitting the collection of data on concept learning.
After completing all tests for the ecology unit, both groups also completed the Reduced
Instructional Materials Motivation Survey (Loorbach et al., 2015). At the end of the
semester, all participants took a final examination, from which the ecology vocabulary
and concept questions used as a posttest were drawn.

As an added measure to ensure fidelity of implementation and gather qualitative
input on participant response to the treatment, classroom visits and informal teacher
interviews were done periodically by the researcher and the Science Department chair.

Treatment Description

Students in the treatment group spent 20 minutes of class time once a week playing a
multimedia biology vocabulary game. The game content consisted of vocabulary from
one of the four sections of the ecology unit of the high school’s biology curriculum.
Those students in the control group spent 20 minutes of class time once a week receiving
traditional vocabulary instruction using word-matching worksheets, which are shown in
Appendix G. Students in both the treatment and control groups took vocabulary tests on vocabulary from the unit, as well as concept tests to assess their understanding of the concepts in the unit.

**Vocabulary Game Development**

The vocabulary game used for this study was developed using the tools available on the Quizlet web site (https://quizlet.com/), and allowed players to match vocabulary items with their definitions. The game permitted players to keep track of their progress, and incorporated a leader board that gave players the opportunity to compare their performance with that of others. The vocabulary and definitions used were identical to those on the word-matching worksheets used for traditional instruction; unlike the worksheets, however, each definition in the game included a picture. While the vocabulary and definitions were taken from the textbook used for the biology course, the pictures were obtained from the Internet. Figure 9 below shows how vocabulary items, definitions and pictures were entered into the game; Figure 10 shows an example of what the game looked like as it was being played.

**Preliminary Data Analyses**

This section describes the process used to prepare the data gathered for data analysis. It first outlines the procedures used to score the instruments, and then discusses the steps taken to compensate for missing data.

**Scoring**

All tests used Scantron machine-readable answer forms, and were scored using a Scantron optical mark-reading scanner. All survey instruments were scored manually.
Figure 9. Example of vocabulary matching game content being entered.
Figure 10. Example of vocabulary matching game being played.
None of the survey items had negatively worded questions, and therefore none required reflection.

One of the three teachers followed a somewhat different data-gathering schedule: while other teachers administered two concept tests and four feedback surveys during the course of the ecology unit, the remaining teacher administered four concept tests (with additional questions beyond those used by the remaining teachers) and two feedback surveys. For this reason, only the data from the two feedback surveys administered at the same time to all participants and the concept questions administered by all teachers were analyzed. Data for feedback survey question 1 (“How many minutes did you spend actually working on the vocabulary practice?”) also had to be transformed. All values for that question for that teacher were halved, which still left some extreme values (in excess of the time allotted for practice), so all times for all teachers 15 minutes or greater were assigned a value of 5; those 12 minutes or more but less than 15 minutes were assigned a value of 4; those 8 minutes or more but less than 12 minutes were assigned a value of 3; those 5 minutes or more but less than 8 minutes were assigned a value of 2; and those less than 5 minutes were assigned a value of 1.

Once raw scores were obtained, they were entered into SPSS, Version 22, Release 22.0.0.0, for analysis. All data were kept in a single SPSS database.

**Missing Data**

A total of 19 variables had some missing data. The decision was made to drop those individuals missing data for more than half the variables, bringing the final data set total to 276. The remaining missing scores were estimated with the EM algorithm using LISREL 9.3. Table 10 shows missing data per variable as a percentage of total scores.
Table 10

*Missing Data Per Variable as a Percentage of Total Scores*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number of scores</th>
<th>Number of scores missing and estimated</th>
<th>Percentage of total scores estimated for variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>242</td>
<td>34</td>
<td>0.72%</td>
</tr>
<tr>
<td>Vocab1</td>
<td>272</td>
<td>4</td>
<td>0.09%</td>
</tr>
<tr>
<td>Vocab2</td>
<td>274</td>
<td>2</td>
<td>0.04%</td>
</tr>
<tr>
<td>Concept1</td>
<td>271</td>
<td>5</td>
<td>0.11%</td>
</tr>
<tr>
<td>Concept2</td>
<td>273</td>
<td>3</td>
<td>0.06%</td>
</tr>
<tr>
<td>Work1</td>
<td>262</td>
<td>14</td>
<td>0.30%</td>
</tr>
<tr>
<td>Learn1</td>
<td>259</td>
<td>17</td>
<td>0.36%</td>
</tr>
<tr>
<td>Motivate1</td>
<td>259</td>
<td>17</td>
<td>0.36%</td>
</tr>
<tr>
<td>Work2</td>
<td>267</td>
<td>9</td>
<td>0.19%</td>
</tr>
<tr>
<td>Learn2</td>
<td>266</td>
<td>10</td>
<td>0.21%</td>
</tr>
<tr>
<td>Motivate2</td>
<td>265</td>
<td>11</td>
<td>0.23%</td>
</tr>
<tr>
<td>Attention</td>
<td>257</td>
<td>19</td>
<td>0.40%</td>
</tr>
<tr>
<td>Relevance</td>
<td>259</td>
<td>17</td>
<td>0.36%</td>
</tr>
<tr>
<td>Confidence</td>
<td>258</td>
<td>18</td>
<td>0.38%</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>258</td>
<td>18</td>
<td>0.38%</td>
</tr>
<tr>
<td>Vocab3</td>
<td>272</td>
<td>4</td>
<td>0.09%</td>
</tr>
<tr>
<td>Concept3</td>
<td>272</td>
<td>4</td>
<td>0.09%</td>
</tr>
</tbody>
</table>
Data Analyses

To determine if difference in instructional method (multimedia digital game or traditional) had an affect on learning of biology vocabulary, a series of one-way MANCOVAs were performed using the instructional group (multimedia digital game or traditional) as the independent variable, the participant’s Lexile reading score as the covariate, and scores on the test of biology vocabulary, tests of biology concepts, and survey responses as the dependent variables.

SPSS was used for statistical analysis of the data. Means and standard deviations for treatment and control groups are shown in Table 11. As the three-question Vocabulary Feedback Survey was only given during the course of instruction (at Times 1 and 2), no data were collected for analysis for the three Vocabulary Feedback Survey questions (‘‘Work, “Learn,” and “Motivate”) at Time 3, which fell well after the end of instruction. Similarly, The Reduced Instructional Materials Motivation Survey (RIMMS) was given only after instruction was completed (Time 3) no data were collected for analysis for the RIMMS or its subscales (Attention, Relevance, Confidence or Satisfaction) at Times 1 or 2.

Research Question One

The study’s first research question asked if there are statistically significant differences in biology vocabulary learning for students using a multimedia game to learn biology vocabulary compared to students receiving traditional vocabulary instruction. To address this question, fixed-effects multivariate analysis of covariance (MANCOVA) was carried out using biology vocabulary test scores as the dependent variables and Lexile reading scores as the covariate.
### Table 11

**Means and Standard Deviations for Treatment and Control Groups**

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment Group</td>
<td>Control Group</td>
<td>Treatment Group</td>
</tr>
<tr>
<td></td>
<td>$\bar{x}$</td>
<td>SD</td>
<td>$\bar{x}$</td>
</tr>
<tr>
<td>Vocab</td>
<td>19.41</td>
<td>4.69</td>
<td>20.07</td>
</tr>
<tr>
<td>Concept</td>
<td>4.59</td>
<td>1.24</td>
<td>4.44</td>
</tr>
<tr>
<td>Work</td>
<td>3.60</td>
<td>1.24</td>
<td>2.73</td>
</tr>
<tr>
<td>Learn</td>
<td>3.33</td>
<td>1.20</td>
<td>3.21</td>
</tr>
<tr>
<td>Motivate</td>
<td>2.96</td>
<td>1.26</td>
<td>2.72</td>
</tr>
<tr>
<td>Attention</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* n for treatment = 139; n for control = 137
Research Question Two

The second research question examined whether or not there are statistically significant differences in biology concept knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. To address this second question, a fixed-effects MANCOVA was carried out utilizing biology concept test scores as the dependent variables and Lexile reading scores as the covariate.

Research Question Three

The third and final research question asked if there are statistically significant differences in ratings of motivation engendered by the learning materials used by students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. To answer this last question, fixed-effects MANCOVAs were once again carried out, making use of student responses to motivation-related survey questions as the dependent variable. As with all the previous analyses, Lexile reading scores were used as the covariate.

Summary

The study was conducted using a convenience sample of ten classes (N = 276 students) from college preparatory biology classes at a medium-sized suburban California high school. Half of the classes received vocabulary instruction via a multimedia vocabulary game, and half received traditional vocabulary instruction. The classes were taught by three teachers, each of whom taught half of his or her classes using the multimedia game, and half using traditional vocabulary instruction. Students received
scores on the HMH Reading Inventory prior to beginning instruction, and vocabulary tests, concept tests, and surveys during and after instruction.
CHAPTER FOUR

RESULTS

This study used analysis of covariance procedures to determine if using a multimedia game for instruction resulted in a statistically significant difference in biology vocabulary learning, biology concept learning, or motivation when compared to traditional instruction. Vocabulary has been shown to be a crucial component of all learning, and has long been recognized as particularly crucial in science, and in biology in particular. Both multimedia and games have been explored as tools for vocabulary learning – but despite the recognized need for tools to aid in the learning of biology vocabulary, there have been few if any studies of the use of multimedia games in biology vocabulary learning to date.

The 276 study participants in this study were students in grades 9 through 12 at a comprehensive high school in a medium-size suburban school district. All participants were enrolled in the high school’s college preparatory biology classes.

The results of the study are described in three sections to answer the three research questions. The first section examines the vocabulary learning of students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. The second section describes differences in scores on tests of biology concept knowledge for students using a multimedia game to learn biology
vocabulary compared to students using traditional vocabulary learning methods. The third section analyzes differences in motivation-related rating engendered by the learning materials used by students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. The chapter concludes with a summary of the overall results. All analyses were conducted with a sample of N = 276.

For all statistical tests, \( p \) was set at .05. Multivariate \( \eta^2 \) is reported for all multivariate analyses of covariance (MANCOVAs); partial \( \eta^2 \) is reported for all analyses of covariance (ANCOVAs). For multivariate \( \eta^2 \), small, medium, and large effects are considered to be 0.01, 0.06, and 0.13, respectively (Gall, Gall, & Borg, 2011). For partial \( \eta^2 \), small, medium, and large effects are considered to be 0.0099, 0.0588 and 0.1379 respectively (Cohen, 1988).

**Analysis Related to Research Question One**

The first research question asked if there were statistically significant differences in scores on tests of biology vocabulary knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. To answer this question, fixed-effects multivariate analysis of covariance (MANCOVA) was conducted to determine the effect of instructional method on vocabulary learning as measured by scores on vocabulary tests while controlling for previous vocabulary knowledge as reflected by Lexile reading scores.

Prior to running MANCOVA, the assumption of homogeneity of variance was tested and found to be untenable (Box’s M = 31.06, \( F(6,543636.48) = 5.12, p < .001 \)).
The assumption of homogeneity of regression coefficients was tested, and found to be tenable (Wilks’ $\Lambda = .974$, $F(3,270) = 2.40, p = .068$).

The results of MANCOVA indicated a statistically significant effect of instructional method on vocabulary test scores (Wilks’ $\Lambda = .971$, $F(3,271) = 2.67, p = .048$, multivariate $\eta^2 = .029$). Since the assumption of homogeneity of variance was violated, the value obtained for Pillai’s trace, which is more robust to violations of homogeneity of variance, was examined as well (Pillai’s trace = .029, $F(3,271) = 2.67, p = .048$, multivariate $\eta^2 = .029$). Both values obtained for the multivariate $\eta^2$ indicated that the effect size was relatively small. Analysis of covariance (ANCOVA) was conducted on each dependent variable as a follow-up test to MANCOVA. Instructional method was not significant for vocabulary test scores at Time 1 ($F(1,273) = 1.987, p = .160$, partial $\eta^2 = .007$), Time 2 ($F(1,273) = 3.640, p = .057$, partial $\eta^2 = .013$) – although the partial $\eta^2$ for Time 2 does qualify as a small effect – or Time 3 ($F(1,273) = .441, p = .507$, partial $\eta^2 = .002$).

A comparison of adjusted means revealed that at no time did the mean scores for the multimedia and traditional instruction groups differ by more than 0.65 points. The comparison also showed that neither group consistently scored higher than the other. The traditional group scored higher at Times 1 and 2, but the multimedia group scored higher at Time 3. Table 12 presents adjusted and unadjusted means for vocabulary scores by instructional method.

**Analysis Related to Research Question Two**

The second research question asked if there were statistically significant differences in scores on tests of biology concept knowledge for students using a
Table 12

*Adjusted and Unadjusted Means for Vocabulary Test Scores by Time and Instructional Method*

<table>
<thead>
<tr>
<th>Time</th>
<th>Instructional Method</th>
<th>Vocabulary Test Scores</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Adjusted Mean</td>
<td>Unadjusted Mean</td>
</tr>
<tr>
<td>Time 1</td>
<td>Multimedia</td>
<td>19.48</td>
<td>19.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>20.01</td>
<td>20.07</td>
<td></td>
</tr>
<tr>
<td>Time 2</td>
<td>Multimedia</td>
<td>20.18</td>
<td>20.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>20.83</td>
<td>20.88</td>
<td></td>
</tr>
<tr>
<td>Time 3</td>
<td>Multimedia</td>
<td>18.78</td>
<td>18.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traditional</td>
<td>18.57</td>
<td>18.62</td>
<td></td>
</tr>
</tbody>
</table>

Just as was done prior to running the previous MANCOVA, the assumption of homogeneity of variance was tested, and found to be tenable (Box’s $M = 4.886$, $F(6,543636.427) = .805, p = .566$). Similarly, the assumption of homogeneity of regression coefficients was tested, and also found to be tenable (Wilks’ $\Lambda = .983$, $F(3,270) = 1.532, p = .206$).

The results of MANCOVA indicated no statistically significant effect of instructional method on concept test scores (Wilks’ $\Lambda = .991$, $F(3,271) = .864, p = .468$, multivariate $\eta^2 = .009$).
Analysis Related to Research Question Three

The third research question asked if there were statistically significant differences in ratings of motivation engendered by the learning materials used by students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. To answer this third question, fixed-effects MANCOVAs were conducted to determine the effect of instructional method on motivation as measured by scores on the survey questions that were given at Times 1, 2 and 3 while controlling for previous vocabulary knowledge as reflected by Lexile reading scores.

As was done previously, prior to running MANCOVA on survey results from Time 1, the assumption of homogeneity of variance was tested and found to be tenable (Box’s M = 31.06, $F(6,543636.43) = 5.115, p < .001$). Similarly, the assumption of homogeneity of regression coefficients was tested, and also found to be tenable (Wilks’ $\Lambda = .988, F(3,270) = 1.095, p = .352$).

The results of MANCOVA indicated a statistically significant effect of instructional method on motivation scores at Time 1 (Wilks’ $\Lambda = .891, F(3,271) = 11.098, p < .001$, multivariate $\eta^2 = .109$). ANCOVA was conducted on each dependent variable as a follow-up test to MANCOVA. Instructional method was not significant for Learn1 ($F(1,273) = .733, p = .393$, partial $\eta^2 = .003$), or Motivate1 ($F(1,273) = 2.581, p = .109$, partial $\eta^2 = .009$), but was significant for Work1 ($F(1,273) = 30.380, p < .001$, partial $\eta^2 = .100$). This value for partial $\eta^2$ indicates a medium effect size. A comparison of adjusted means revealed that scores for Work1 were almost a full point higher for the multimedia instruction group than for the traditional instruction group. Table 13 presents
adjusted and unadjusted means for feedback survey question 1 at Time 1 (Work1) by instructional method.

Table 13

*Adjusted and Unadjusted Means for Feedback Survey Question 1 at Time 1 (Work1) by Instructional Method*

<table>
<thead>
<tr>
<th>Instructional Method</th>
<th>Adjusted Mean</th>
<th>Unadjusted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multimedia</td>
<td>3.61</td>
<td>3.60</td>
</tr>
<tr>
<td>Traditional</td>
<td>2.73</td>
<td>2.73</td>
</tr>
</tbody>
</table>

Prior to running MANCOVA on survey results from Time 2, the assumption of homogeneity of variance was tested and found to be tenable (Box’s M = 5.129, $F(6,543636.43) = .845, p = .535$). The assumption of homogeneity of regression coefficients was likewise tested and found to be tenable (Wilks’ $\Lambda = .974, F(3,270) = 2.40, p = .068$).

As at Time 1, MANCOVA indicated a statistically significant effect of instructional method on motivation scores at Time 2 (Wilks’ $\Lambda = .792, F(3,271) = 23.79, p < .001$, multivariate $\eta^2 = .208$). ANCOVA was conducted on each dependent variable as a follow-up test to MANCOVA. Instructional method was not significant for Learn2 ($F(1,273) = 2.614, p = .107$, partial $\eta^2 = .009$), but was significant for Work2 ($F(1,273) = 58.755, p < .001$, partial $\eta^2 = .177$). This value for partial $\eta^2$ indicates a large effect. Instructional method was also significant for Motivate2 ($F(1,273) = 13.268, p < .001$, partial $\eta^2 = .046$). This value for partial $\eta^2$ indicates a small effect. A comparison of adjusted means revealed that scores for Work2 were almost 1.2 points higher for the multimedia instruction group than for the traditional instruction group. Scores for Motivate2 were just over one-half point higher for the multimedia instruction group than
for the traditional instruction group. Table 14 presents adjusted and unadjusted means for feedback survey questions 1 (Work2) and 3 (Motivate2) at Time 2 by instructional method.

Before running MANCOVA on results of the Reduced Instructional Materials Motivation Survey (RIMMS) from Time 3, the assumption of homogeneity of variance was tested and found to be tenable (Box’s M = 7.902, $F(10,358756.25) = .778, p = .650$).

Table 14

*Adjusted and Unadjusted Means for Feedback Survey Questions 1 (Work2) and 3 (Motivate2) at Time 2 by Instructional Method*

<table>
<thead>
<tr>
<th>Instructional Method</th>
<th>Survey Question</th>
<th>Work2</th>
<th>Motivate2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adjusted Means</td>
<td>Unadjusted Means</td>
<td>Adjusted Means</td>
</tr>
<tr>
<td>Multimedia</td>
<td>3.57</td>
<td>3.57</td>
<td>3.16</td>
</tr>
<tr>
<td>Traditional</td>
<td>2.38</td>
<td>2.38</td>
<td>2.62</td>
</tr>
</tbody>
</table>

Similarly, the assumption of homogeneity of regression coefficients was tested, and also found to be tenable (Wilks’ $\Lambda = .986, F(43,269) = .961, p = .429$).

As with the surveys given at Times 1 and 2, MANCOVA also indicated a statistically significant effect of instructional method on scores on the RIMMS from Time 3 as well (Wilks’ $\Lambda = .954, F(4,4270) = 3.291, p = .012, \eta^2 = .046$). This value for multivariate $\eta^2$ indicates a small effect size. ANCOVA was conducted on each dependent variable as a follow-up test to MANCOVA. Instructional method was not significant for Attention ($F(1,273) = 2.221, p = .137, \eta^2 = .008$), Relevance ($F(1,273) = .277, p = .599, \eta^2 = .001$), or Confidence ($F(1,273) = .053, p = .818$),
partial $\eta^2 < .001$). Instructional method was significant, however, for Satisfaction $(F(1,273) = 7.378, p = .007, \text{partial } \eta^2 = .026)$. This value for partial $\eta^2$ indicates a small effect size.

A comparison of adjusted means revealed that scores for Satisfaction were almost a point higher for the multimedia instruction group than for the traditional instruction group. Table 15 presents adjusted and unadjusted means for RIMMS Satisfaction by instructional method.

<table>
<thead>
<tr>
<th>Instructional Method</th>
<th>Adjusted Means</th>
<th>Unadjusted Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multimedia</td>
<td>7.94</td>
<td>7.95</td>
</tr>
<tr>
<td>Traditional</td>
<td>7.04</td>
<td>7.04</td>
</tr>
</tbody>
</table>

This quantitative evidence of a higher level of motivation in the participants using the digital multimedia vocabulary game was corroborated by the qualitative evidence obtained by the classroom visits and informal teacher interviews done by the researcher and the Science Department chair. Adjectives such as “engaged” and “positive” came up repeatedly in observers’ notes taken during classroom visits, and it was reported by all participating teachers that it was hard to get students to stop the digital vocabulary activity and move on – something that was definitely not an issue with the traditional vocabulary learning activity.

**Summary**

In this study comparing the effectiveness of multimedia games and traditional instruction for teaching high school biology vocabulary, multivariate analysis of
covariance (MANCOVA) was conducted on student scores on biology vocabulary tests, using Lexile reading scores as a covariate. Additionally, this study examined the influence of the two types of instruction on biology concept learning and motivation.

The quantitative results of the multivariate analyses of covariance (MANCOVAs) and analyses of covariance (ANCOVAs) carried out as part of this study are summarized in Table 16 below.

<table>
<thead>
<tr>
<th>Variable</th>
<th>MANCOVA</th>
<th>ANCOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' Λ</td>
<td>F</td>
</tr>
<tr>
<td>Vocabulary a</td>
<td>.971</td>
<td>2.67</td>
</tr>
<tr>
<td>Time 1</td>
<td>3.64</td>
<td>1,273</td>
</tr>
<tr>
<td>Time 2</td>
<td>0.44</td>
<td>1,273</td>
</tr>
<tr>
<td>Concepts b</td>
<td>.991</td>
<td>0.86</td>
</tr>
<tr>
<td>Motivation</td>
<td>.891</td>
<td>11.10</td>
</tr>
<tr>
<td>Time 1</td>
<td>0.73</td>
<td>1,273</td>
</tr>
<tr>
<td>Work1</td>
<td>2.58</td>
<td>1,273</td>
</tr>
<tr>
<td>Learn1</td>
<td>58.76</td>
<td>1,273</td>
</tr>
<tr>
<td>Motivate1</td>
<td>2.61</td>
<td>1,273</td>
</tr>
<tr>
<td>Time 2</td>
<td>13.27</td>
<td>1,273</td>
</tr>
<tr>
<td>Work2</td>
<td>3.29</td>
<td>4,270</td>
</tr>
<tr>
<td>Learn2</td>
<td>2.22</td>
<td>1,273</td>
</tr>
<tr>
<td>Motivate2</td>
<td>0.28</td>
<td>1,273</td>
</tr>
<tr>
<td>Time 3</td>
<td>0.05</td>
<td>1,273</td>
</tr>
<tr>
<td>Attention</td>
<td>7.37</td>
<td>1,273</td>
</tr>
<tr>
<td>Relevance</td>
<td>8.49</td>
<td>1,273</td>
</tr>
<tr>
<td>Confidence</td>
<td>0.05</td>
<td>1,273</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>0.28</td>
<td>1,273</td>
</tr>
</tbody>
</table>

Notes:  

a Assumption of homogeneity of variance was violated; Pillai’s trace = .029,  
F(3,271) = 2.67, p = .048, multivariate η² = .029.  

b Since MANCOVA indicated no statistically significant effect of instructional method on concept test scores, ANCOVA was not performed.
First, MANCOVA was performed on vocabulary test scores obtained at three times: once near the midpoint of an instructional unit on ecology (Time 1); once near the end of the unit (Time 2); and once six weeks after the end of the unit (Time 3). A statistically significant effect of instructional method on vocabulary test scores was found, although with a small effect size. Analyses of variance (ANOVAs) performed subsequent to the MANCOVA indicated that the students in the traditional-instruction control group slightly outperformed those who had received the multimedia game treatment at Times 1 and 2, and the students in the multimedia game treatment group outperformed the traditional-instruction control group at Time 3, in none of those cases was the difference statistically significant.

In the next analysis, a MANCOVA was performed on concept test scores obtained at Time 1, Time 2, and Time 3. The MANCOVA indicated no statistically significant effect of instructional method on concept test scores.

For the final analysis, MANCOVAs were performed on responses to two surveys. The first survey was a three-question feedback survey given to participants at Times 1 and 2. The first question (Work) asked students about how much work they put into the vocabulary practice; the second question (Learn) asked how much the practice helped them learn the vocabulary; and the third question (Motivate) asked how much they felt the practice motivated them to study the vocabulary.

The second survey, the Reduced Instructional Materials Motivational Survey, or RIMMS, was given at the end of the ecology unit. It consists of a series of questions designed to measure four aspects of motivation related to instructional materials: Attention, Relevance, Confidence and Satisfaction.
MANCOVA performed on the feedback survey found a statistically significant effect of instructional method on motivation scores at Time 1. ANOVAs carried out after the MANCOVA indicated that the multimedia group said they put more work into the vocabulary practice at Time 1 than did the traditional-instruction group, to a degree that was statistically significant.

MANCOVA performed on the feedback survey found a statistically significant effect of instructional method on motivation scores at Time 2 as well. ANOVAs performed indicated that the multimedia group once again said they put more work into the vocabulary practice at Time 2 than did the traditional-instruction group, as well as having an increased feeling that the practice was helping them learn the vocabulary. Both of these were to a degree that was statistically significant.

MANCOVA also showed a statistically significant effect of instructional method on scores on the Reduced Instructional Materials Motivation Survey, or RIMMS. ANCOVAs conducted as a follow-up test to MANCOVA showed that instructional method had a statistically significant impact on Satisfaction, with the digital multimedia instruction group scoring higher than the traditional-instruction control group.

The quantitative evidence of higher levels of motivation among participants receiving the digital multimedia vocabulary game treatment was further substantiated by qualitative evidence in the form of classroom visits and informal teacher interviews done by the researcher and the Science Department chair. These seemed to indicate a clear pattern of greater engagement and motivation in the classes using the digital multimedia treatment compared to the classes using traditional instruction.
CHAPTER FIVE
DISCUSSION OF RESULTS

The purpose of this study was to compare the effectiveness of multimedia games and traditional instruction for teaching biology vocabulary to a heterogeneous group of students in high school college preparatory biology classes. Additionally, this study examined the influence of multimedia instruction on biology concept learning and motivation relative to traditional instruction. This chapter presents a summary of the study and its findings, as well as a discussion of its limitations and implications for both research and practice.

Summary of Study

It has been widely recognized that difficulties with vocabulary can cause difficulties in learning (Gall, Gall, & Borg, 2011). In no area of learning is that truer than in science (Hakuta et al., 2013) – and in no area of science is that truer than in biology (Grillo & Dieker, 2013). While a typical high school foreign language textbook introduced over 1700 new words, a researcher found, a high school physical science textbook might introduce over 2000 – and a high school biology textbook over 17,000 (Groves, 1995).

Given the need for and interest in effective vocabulary instruction, it is no surprise that a number of different approaches to vocabulary learning have arisen. Many of those
approaches fall into one of two main camps: those that stress the importance of learning vocabulary in context (e.g., Stahl & Nagy, 2006), and those that feel that it can be beneficial to learn words in isolation (e.g., Nation, 2006, 2008).

Although Nation, Stahl and Nagy and others may have different levels of tolerance for decontextualized vocabulary instruction, most researchers are in agreement about one facet of vocabulary learning – the value of games (Andrade, 2009; Lubliner & Scott, 2008; Manyak, 2012; Stahl & Nagy, 2006). Games are widely used as instructional tools, and appear to aid vocabulary learning in a variety of ways (Andrade, 2009; Hitosugi, Schmidt, & Hayashi, 2014). Surprisingly, despite the pressing need for effective tools for learning scientific vocabulary, there has been little investigation into the use of games for learning science vocabulary – and even less into their use in learning of biology vocabulary.

Another tool that is recognized as aiding learning in many areas, including vocabulary (Castek et al., 2012; Kennedy, Deshler, & Lloyd, 2013), is multimedia, i.e., a combination of words and pictures (Mayer, 2014a). Mayer has termed this increased learning from words and pictures as opposed to words alone the multimedia principle, and made it the foundation of his cognitive theory of multimedia learning (CTML). A number of researchers believe that the use of multimedia may aid in learning by increasing learner motivation (Mayer, 2010; Mayer, 2014b; Moreno, 2006; Plass et al., 2015; Pedra, Mayer, & Albertin, 2015).

With the successful instructional track records of both games and multimedia, it is not surprising that the combination of the two – multimedia games – has been intensively studied as an aid to learning (Tobias et al., 2014). The use of multimedia games for
teaching vocabulary has been relatively little-studied, their use in teaching science vocabulary even less so – and when we turn to their use in teaching biology vocabulary, there is essentially no research being done. This study attempted to step into that gap, and examine the effectiveness of using digital multimedia games to help high school students learn biology vocabulary.

A two-group, quasi-experimental study with one treatment and one control group was carried out in order to answer the following questions:

1. Are there statistically significant differences in scores on tests of biology vocabulary knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

2. Are there statistically significant differences in scores on tests of biology concept knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

3. Are there statistically significant differences in ratings of motivation engendered by the learning materials used by students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods?

The study used a convenience sample of 10 college preparatory high school biology classes (N = 276) at a comprehensive high school in a medium-size suburban school district. The three participating teachers taught half of their classes using a multimedia game for vocabulary instruction and the other half using traditional
vocabulary instruction. Fixed-effects multivariate analysis of covariance (MANCOVA) was employed for a series of three types of dependent variables: 1) scores on tests of biology vocabulary; 2) scores on tests of biology concepts; and 3) vocabulary feedback and instructional materials motivation survey scores. These three types of dependent variables were used for three reasons: 1) student scores on the tests of biology vocabulary were used to ascertain if the use of appropriate multimedia resulted in a statistically significant increase in vocabulary scores; 2) student scores on the tests of biology concepts were used to check that any increase in vocabulary scores did not occur at the expense of concept learning; and 3) vocabulary feedback and instructional materials motivation survey scores were used to determine if the use of appropriate multimedia increased learner motivation. Students’ Lexile reading scores were used as the covariate for all three analyses of covariance. Lexile reading scores were employed as the covariate because the strongly-established link between reading ability and vocabulary (Lubliner, 2005; National Institute of Child Health & Human Development, 2000; Shanahan & Shanahan, 2008), allowed Lexile reading scores to be used as a reliable indicator of participants’ initial level of vocabulary knowledge.

**Summary of Findings**

The first research question was if there are statistically significant differences in scores on tests of biology vocabulary knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. Vocabulary scores were gathered at three different times: once near the midpoint of the instructional unit (Time 1); once near the end of the unit (Time 2); and once approximately six weeks after the end of the unit (Time 3). Analysis of the
experimental results indicated higher vocabulary test scores for the multimedia group to a degree that was statistically significant (at the .05 level of significance) overall. A closer examination of scores for the multimedia and traditional instruction groups indicated that the traditional instruction group had slightly outscored the multimedia group Time 1 and Time 2, but the multimedia group had outscored the traditional instruction group at Time 3, the posttest given several weeks after the end of the instructional unit.

The second research question was if there are statistically significant differences in scores on tests of biology concept knowledge for students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. Analysis of the experimental results indicated no statistically significant effect (at the .05 level of significance) of instructional method on concept test scores.

The third research question was if there are statistically significant differences in ratings of motivation engendered by the learning materials used by students using a multimedia game to learn biology vocabulary compared to students using traditional vocabulary learning methods. Analysis of the experimental results at Time 1 indicated higher motivation scores for the multimedia group to a degree that was statistically significant (at the .05 level of significance) overall. A closer look at the scores indicated that the higher overall scores were due to higher scores on the question asking how much of the available class time students spent actually working on the instructional materials.

Analysis of the experimental results at Time 2 also showed higher motivation scores for the multimedia group to a degree that was statistically significant (at the .05 level of significance) overall. Further examination of the scores indicated that, once again, the multimedia group had scored higher on the question asking how much of the
available class time students spent actually working on the instructional materials. In addition, they had scored higher on a question asking if the instructional materials had motivated them to learn the vocabulary.

Participants were also given the Reduced Instructional Materials Motivation Survey, or RIMMS, after the end of the instructional unit. Students in the multimedia group scored higher on the RIMMS to a degree that was statistically significant (at the .05 level of significance) overall, indicating a higher level of motivation than the students using traditional vocabulary learning methods. Additional analysis indicated that the multimedia students’ higher score for motivation was due to a higher score on the Satisfaction subscale of the RIMMS.

Limitations

Taking place in a medium-sized public high school, this study was fortunate enough to involve access to a large sample in the real-world setting of the high school’s college preparatory biology classes. The real-world setting, however, was a bit of a double-edged sword, as the most obvious limitations of the study involve that same high school classroom venue: random selection was impossible, and the sample was a convenience sample; furthermore, that sample was drawn from a single school. Both of these factors may limit the extent to which generalizing the study’s findings to other settings can be justified. While the aforementioned factors are the most glaring limitations of this study, there are at least eight others, which are discussed below.

1) The game that was used as treatment for this study lacked some of the features the participants may have been used to seeing in digital multimedia games. For example, there was little ability to increase or decrease the challenge of the game; essentially, the
only way to change the challenge of the game was to try to complete it faster or slower. In the parlance of commercial multimedia game developers, participants could control pacing “(i.e., the time pressure to make decisions and the development of it),” (Baumann, Lürig, & Engeser, 2016, p. 509) but not ramping “(i.e., the decision complexity and the development of it)” (Baumann, Lürig, & Engeser, 2016, p. 509). Given that the ability to modulate the level of difficulty to personalize a game to suit the needs of individual players has long been recognized as an extremely valuable aspect of game design (Baumann, et al., 2016; Malone, 1981; Plass, et al., 2015), the lack of any capacity for ramping in the games used for this study may have reduced participants’ engagement from what it might have been had the games had such features.

2) It is also the case that the control treatment used, a pencil-and-paper matching exercise, could be considered to have game-like features, in that it had a goal, rules, and an element of competition, since it may have been possible for participants to have some sense of when other participants finished the exercise. One possible area for fruitful investigation in the future might be to examine the combination of a multimedia biology vocabulary game with in-game or in-game and pregame worksheets, as recent research indicates that such combination can improve learning when compared to use of a multimedia game without the incorporation of such worksheets (Pilegard & Mayer, 2016).

3) Although teachers were trained to implement the instruction (digital multimedia game or traditional instruction) in the same way, it is possible that it was not always implemented exactly as intended. While the investigator was not able to observe all classrooms at all times to ensure fidelity of implementation, the cooperating teachers
were all very cooperative, and both feedback from those teachers and periodic
observation by the department chair indicated that instruction was implemented as
planned. Moreover, the participating teachers were all veterans, whose combined
teaching experience comes frighteningly close to a century. Also aiding fidelity in
implementation of instruction was the fact that both the treatment and control were
relatively simple to carry out.

4) As with implementation of instruction, it is impossible to guarantee that all
tests and surveys were administered exactly as intended. However, as with
implementation of instruction, indications are, based on observation and feedback, that
this also went as planned. Also as was the case with implementation of instruction,
administration of the required tests and surveys was quite simple and straightforward.

5) The vocabulary and concept tests administered to the participants in the study
had student scores clustered at the higher end of the score range, with a number of
students obtaining perfect scores. The study would have benefited from assessments that
did not exhibit this. This slight negative skew may have been a result of a number of
factors. One possibility is that not enough vocabulary or concept items were included in
the assessments. Another possibility is that controlling the time allowed for the
assessments would have helped reduce the slight negative skew that was observed.
Typically, teachers will give students essentially unlimited time to take most assessments,
since it obviates the need to make special arrangements for – or call special attention to –
those students who are legally entitled to extended time on assessments. This has the
effect, however, of eliminating any need for speedy recall on the part of learners. Had
that been part of the assessments, it might have led to fewer participants’ scores clustered at the top, and perhaps a more normal distribution of scores.

6) It is possible that students did not put forth their best efforts on all assessments, and this may have affected the results obtained. This was made somewhat less likely by the fact that all students received grades for the assessments, but it remains a possibility nonetheless.

7) It is also possible that students may have not have been completely forthright when responding to the questions on the surveys. They may, for instance, have given answers that they believed their teachers would like to see, rather than what they might truly have wanted to give for an answer. While participants were urged to give truthful answers – and there is no indication they gave anything else – they may still have hesitated to be completely candid in their responses, knowing that a teacher would see them.

8) Some students were added to or dropped from classes during the course of the study, while others were absent for extended periods due to factors such as poor health. All of these things led to missing data – and while the amount of missing data in this study was relatively small, it cannot help but have influenced the results to some degree.

Discussion of Findings

This study examined the effectiveness of using digital multimedia games to help high school students learn biology vocabulary, as well as the impact of instruction via digital multimedia games on participants’ concept learning and motivation. Given that few if any studies seem to have been done investigating the use of multimedia games for biology vocabulary instruction, this study is apparently unique. Given the widespread
recognition of the problems learners face with biology vocabulary, however (e.g., Grillo & Dieker, 2013; Groves, 1995, 2016), it is possible that the findings in this study may prove of interest to researchers and practitioners. That may be particularly true given the paucity of studies that permit have tested Mayer’s Cognitive Theory of Multimedia Learning – and specifically his Multimedia Principle (Mayer, 2014, 2017) – in a real-world classroom setting (Clark & Mayer, 2016; Mayer & Pilegard, 2014; Sweller, et al., 2011).

Vocabulary Learning

The findings in this study indicate that instruction using a digital multimedia game may result in biology vocabulary learning that is at least equal to that of traditional instruction. Comparisons of biology vocabulary test scores did not show any statistically significant differences in scores at Time 1, Time 2 or Time 3 between participants using a digital multimedia game for instruction and those traditional instruction methods. It is intriguing to note, though, that students in the multimedia game group had higher scores than the traditional instruction group on the delayed vocabulary posttest that occurred at Time 3, indicating the possibility that multimedia game instruction may lead to somewhat better long-term retention. While the vocabulary scores of multimedia game users in this study were not sufficiently higher on the Time 3 posttest to achieve statistical significance, it does indicate that this might possibly be a fruitful subject for future research. A number of studies of have shown that input-based tasks, of which the digital multimedia matching game used for this study is one, can positively influence language learning, including the learning of vocabulary (Franciosi, 2017; Prabhu, 1994; Shintani,
Particularly noteworthy is the evidence that such tasks may increase long-term retention of learned language as measured in repeated post-tests (Shintani, 2012).

**Concept Learning**

The study findings appear to show no statistically significant difference in concept learning between instruction using a digital multimedia game and traditional instruction. This indicates that students do not learn biology concepts better when exposed to multimedia-game-based vocabulary instruction when compared to those exposed to traditional vocabulary instruction. The other side of the coin, though, is that students using multimedia games for vocabulary instruction seem to learn biology concepts no more poorly than those using traditional vocabulary instruction – which should help allay fears that any advantage gained through use of multimedia games for vocabulary instruction might come at the expense of concept learning.

**Motivation**

The results of this study seem to indicate that motivation was greater, to a degree that is statistically significant, for those learning using a multimedia game than for those learning via traditional instruction. In particular, reported time on task seems to be greater, to a degree that is statistically significant, for those learning using a multimedia game versus those learning via traditional instruction. Satisfaction also seems to be higher to a degree that is statistically significant in the multimedia game group compared to the traditional instruction group.

Taken together, these results indicate the possibility that, when compared to traditional instruction, use of a digital multimedia game for biology vocabulary instruction may lead to at least equal vocabulary learning, with no negative effect on
biology concept learning, and foster a higher level of motivation, with learners spending more time on task and experiencing greater satisfaction.

If it were shown that biology vocabulary learning benefited by the use of multimedia games, that would be an excellent result; but even if learning of biology vocabulary (and, it appears, biology concepts) is simply equal for learners using multimedia-game and traditional methods, if motivation increases, the learner (and the teacher) would still come out ahead using a multimedia game. In this study, time available to use the instructional materials (i.e., multimedia game or traditional paper-and-pencil worksheet) was held constant; in most situations, research and theory indicate that a more motivated student would be able to – and being motivated, willing to – spend more time engaged in learning with the instructional materials (Fletcher, 2011; Tobias et al., 2014; Tobias & Fletcher, 2012). That being the case, multimedia game instruction would be expected to lead to greater learning than traditional instruction. As Tobias and colleagues (Tobias et al., 2014) have put it regarding such games:

“Even if research reveals that games are only as effective per unit of time as other instructional methods, the motivation they engender and the time spent playing them can make games a cost-effective alternative for delivering instruction… or for supplementing other instructional methods (p. 763).

It is also possible that if the multimedia game was sufficiently engaging, it might be possible to successfully shift a significant portion of vocabulary instruction outside of class time. Fletcher makes the point that “if... young people aged 8-18 are averaging 13.2 hours per week playing computer games, not because they have to, but because they want to, then they might persevere equally persistently in playing games with learning material
embedded in them” (Fletcher, 2011, p. 1283). That would be good news indeed, since as Kamil and Taitague have emphasized, “it is very difficult through classroom instruction alone to make a significant dent in the thousands of words students need to learn. (Kamil & Taitague, 2011, p. 1007). “There is a clear need,” they state, “for increasing instructional time for vocabulary learning,” and if a vocabulary game is engaging enough to encourage its use outside of regular class time, “the amount of time for vocabulary learning is increased and students will be exposed to learning beyond the typical school day” (Kamil & Taitague, 2011, p. 1008).

If use of a digital multimedia game for vocabulary instruction yields at least equal vocabulary gains with no cost to concept learning, and has a positive effect on learner motivation, that gain in learner motivation would then be an extremely strong motivation for a teacher to use the game. Often, a teacher will see that many of the students who struggle most with vocabulary are those who are most unmotivated and disengaged (Grillo & Dieker, 2013; Reed, Medina, Martinez, & Veleta, 2013). Small wonder, then, that researchers point to use with learners who may often face special challenges – such as English Learners, those of lower socioeconomic status, and those in special education – as one very promising context for the implementation of multimedia games in instruction (Dai & Wind, 2011; Fletcher, 2011).

**Conclusions**

At least two conclusions can be drawn from this study. One is that, contrary to what one would expect based on Mayer’s Cognitive Theory of Multimedia Learning and Multimedia Principle (Mayer, 2014, 2017), this study did not conclusively demonstrate that use of multimedia instruction (in this case, a digital multimedia game) led to greater
learning than traditional instruction. While overall vocabulary test scores were higher in the treatment group of study participants using the digital multimedia game for biology vocabulary instruction compared to those in the control group using traditional instruction methods, to a degree that was statistically significant, the effect size was quite small. Furthermore, examination of the scores for the test administrations at the three different administration times showed no clear pattern of higher scores for the digital multimedia game treatment group – nor did it show any statistically significant difference in scores between the treatment and control groups. It did, however, show a difference in scores at Time 2 (the 59th day of instruction, on average) that approached statistical significance, and exhibited a small effect size. This leaves the results of this study in the ambiguous position of neither confirming nor denying Mayer’s cognitive theory of multimedia learning and multimedia principle.

Other researchers have also found that the results predicted by the cognitive theory of multimedia learning and supported by laboratory research do not always transfer to the classroom. Tabbers and colleagues, for example, investigated the modality and cuing effects in a classroom setting. The modality effect suggests learning will be enhanced when verbal information is presented as narration rather than on screen text, and the cueing effect states that it will be enhanced when visual cues in an animation aid in linking images to the associated narration. Tabbers and his team found that neither of these produced the effect that cognitive load theory and the cognitive theory of multimedia would have led them to expect (Tabbers, Martens, & Van Merriënboer, 2004). They attributed this in part to the fact that the instruction given to participants to test the modality and cuing effects was user-paced, whereas that used in previous
laboratory experiments was system-paced. Since Tabbers’ group’s learners could control the pace of instruction, this allowed them to reduce the cognitive load by reducing the pace.

This may also have been a factor in the present study of the multimedia principle, given that learners had the ability to set their own pace during instruction. There was far more time provided than was needed to complete the instructional activities. As in Tabbers and colleagues’ investigation, this would have allowed participants to reduce cognitive load by reducing the pace – and thus reducing the advantage one would expect from the use of multimedia instruction.

Like Tabbers and his co-investigators, Muller and colleagues, in a study of the application of the coherence principle in a real-world classroom setting, also found that their results were contrary to what the cognitive theory of multimedia learning would predict (Muller, Lee, & Sharma, 2008). According to the coherence principle, eliminating all non-essential information in multimedia messages can minimize demands on cognitive resources. Following the principle, however, did not lead to the expected learning gains, and both treatment and control groups had similar scores on assessments of learning. Muller and his team attributed this in part to possible greater-than-expected prior knowledge on the part of some participants, as well as the possibility that the assessments used were not sensitive enough to discriminate differences in learning that might have existed.

Both these factors – greater-than-expected participant prior knowledge and slightly negatively-skewed assessments – could have played a part in the ambiguous results obtained by this study of the multimedia principle. No test of ecology vocabulary
knowledge was given to participants prior to the beginning of instruction; instead, Lexile reading scores were used as an indicator of general vocabulary knowledge. In part, that was because the test used to obtain Lexile reading scores is an extremely sophisticated, well-tested way to get precise information about participants’ vocabulary level. It may also have been, in part, due to a subconscious assumption that, given that students have for many years in the past come to the high school biology classroom with little prior knowledge of ecology vocabulary, the students participating in this study also had little prior knowledge of ecology vocabulary. That may have been a false assumption; in any case, it remained an untested assumption. If it was a false assumption, that might explain why the digital multimedia game did not have the expected impact on biology vocabulary learning. It is also the case that, at the high school level, there is probably more overlap between ecology vocabulary and “regular” academic vocabulary than might be the case for some other areas of biology – for example, genetics – studied in a college preparatory biology class.

The assessments used in this study may also have been unable to accurately discriminate among students based on biology vocabulary learning. The fact that most scores were clustered at the high end of the range is an indication that more sensitive instruments might be in order. In any case, this study is yet another that shows, as Muller, Lee, and Sharma have stated, that “empirical support for multimedia principles in laboratory settings… does not guarantee applicability to real learning environments” (Muller, Lee, & Sharma, 2008 p. 212).

A second conclusion that can be drawn from this study is that, as predicted by prior research (e.g., Moreno, 2006; Tobias & Fletcher, 2011a, 2012), use of multimedia
and games – combined in this study in the form of a multimedia game – for instruction led to higher learner motivation. In the current study, this higher motivation seems to have been expressed most notably in a greater level of satisfaction with the instructional materials and a greater willingness to spend more time on task on the part of learners using the multimedia game when compared to learners receiving traditional instruction.

**Implications for Research**

Results from this study appear to indicate that use of a digital multimedia game for biology vocabulary instruction results in at least equal biology vocabulary learning, increased motivation, and no decrease in biology concept learning when compared to traditional vocabulary instruction using pencil-and-paper vocabulary matching exercises. Given that some of the instruments used were slightly negatively skewed, one possible area for future research might be to repeat the study using improved instruments. Another instrument-related possibility for future research might be to repeat the investigation using the 12-question Reduced Instructional Materials Motivation Survey (RIMMS) throughout, rather than the 3-question feedback survey at Times 1 and 2 and the RIMMS administered later. While the fact that the 3-question survey could be completed relatively quickly was helpful, given the time constraints involved in administering the survey in a classroom setting, the time needed to complete the RIMMS turned out to be not that much greater.

Still another instrument-related extension might be to administer a biology vocabulary pretest to be used as a covariate in data analysis in place of or in addition to the Lexile reading scores that were used in this study. This might allow the researcher to
control for prior knowledge of the relevant vocabulary, which was not done in this investigation.

Another potential extension might be to replicate the study, but use different biology vocabulary – vocabulary for cell biology, say – in place of the ecology used in the present investigation. As has been pointed out (Burton, 2011; Burton, 2014; Montgomery, 2004), each area of biology has its own vocabulary, with its own somewhat different challenges. The only way to be certain that what holds for ecology vocabulary holds for genetics vocabulary, for example, is to carry out a similar study or studies using vocabulary from genetics. Also, as was mentioned earlier, using vocabulary from another domain of biology might reduce the potential for a high level of prior knowledge due to “overlap” between the biology vocabulary used for the study and the vocabulary students are learning in other academic settings.

Yet another extension might be to conduct instruction with a particular set of vocabulary prior to the vocabulary’s being used to acquire concepts – that is, frontloading the vocabulary. For example, vocabulary introduced in a textbook chapter would be explicitly taught before starting the chapter. Although that was not done in the current study for logistical reasons, it is standard instructional practice (Greenleaf et al., 2011; Larson, 2014).

It might a useful extension also to explore the relative effectiveness of a digital multimedia game for contextual learning of biology vocabulary. Once again, partly for logistical reasons, this study looked only at explicit vocabulary instruction – but an examination of the implementation of a digital multimedia game for contextual vocabulary learning would be well worth carrying out.
Given that the participants in this study were not randomly selected, were in intact classrooms, and were also drawn from a single school, another obvious area for future research might be replicate the study using randomly selected participants. Of course, random selection might be difficult to implement – but repeating the study with participants from different regions, demographic makeup, socioeconomic status, learning needs, etc. would certainly be possible, and might yield even more worthwhile results. As mentioned previously, one use of instructional multimedia games that appears to show a great deal of potential is in working with learners encountering special challenges, such as those in special education, of lower socioeconomic status, and English Learners (Dai & Wind, 2011; Fletcher, 2011).

**Implications for Practice**

One implication of this study for practice is that a practitioner should not be surprised to find that the improvement in vocabulary learning that one sees when implementing the multimedia principle in the classroom is considerably less dramatic than what one might expect based on theory and laboratory experiments.

Another implication of this study for practice is that, all other things being equal, it makes sense to consider using multimedia games for biology vocabulary instruction. As pointed out previously, the use of a multimedia game can increase learner motivation and provide equal vocabulary learning with no negative impact on concept learning when compared to more traditional instructional methods. All other things are seldom equal, however – and so it becomes important to understand that one’s mileage may vary when implementing a multimedia game for vocabulary instruction.
It certainly requires more time and training to make a multimedia game than a matching worksheet, for example; but assuming (and this is a large assumption) that it will be possible to use the multimedia game more or less indefinitely, one receives a very worthwhile return on investment. It has been pointed out that this is often the case with multimedia games used for instruction (Fletcher, 2011; Tobias & Fletcher, 2012) – but it is worth bearing in mind that this is predicated on certain factors remaining constant. For example, during this study, the Quizlet game interface was changed several months prior to data collection, but thankfully remained unchanged throughout this study. It is certainly possible, though, that a teacher – or investigator – might spend considerable time and energy developing a game, only to have the platform change so as to make the game unworkable. It is also possible – inevitable, in fact – that course textbooks will change, and when they do the game will have to be updated or scrapped. The vocabulary used in the present study was taken from a textbook over 15 years old; when a new textbook is adopted, it is certain that a great deal of the vocabulary will have changed. Terms like “CRISPR” (clustered regularly interspaced short palindromic repeat) and “induced pluripotent stem cell” did not exist 15 years ago, but are essential for today’s high school biology classes; 15 years from now, these will probably have been shouldered aside by an entirely new crop of essential vocabulary items.

Another concern for any practitioner considering the use of multimedia games for biology vocabulary instruction is technology. Technology is obviously necessary to implement a digital multimedia game – and technology, like vocabulary, is constantly changing. In some cases, that change could render a game unusable within a fairly short time after development. This has certainly happened in the past with many other games
and activities. Sometimes a game or activity will still be usable – but not on the platform the practitioner may have available. One relevant example familiar to many high school science teachers is the inability to use probeware (digital devices that sense and record data like temperature and pH). Students had used probeware routinely in the past with Macs or PCs; but are now unable to use it with the new Chromebooks to which many school districts have shifted for student use.

Nonetheless, while the devil is obviously in the details, the basic concept of using digital multimedia games for biology vocabulary instruction and learning seems to be a promising one, heralding a future where such technology aids student learning and saves teachers time and energy. It is to be hoped that this study contributes, in some small measure, to that future.
References


Seifert, K., & Espin, C. (2012). Improving reading of science text for secondary students with learning disabilities: Effects of text reading, vocabulary learning, and


Appendix A

District Approval Letters
June 1, 2017

Institutional Review Board for the Protection of Human Subjects
University of San Francisco
2130 Fulton Street
San Francisco, CA 94117

Dear Members of the Committee:

On behalf of Albany High School, I am writing to formally confirm our consent to the research proposed by Mr. Ian Murray, a doctoral student at University of San Francisco. We are aware that Mr. Murray intends to conduct research into the application of digital multimedia to biology vocabulary instruction for high school students. The instruction, assessment, and data collection required as part of this research will be carried out with students in our college preparatory biology classes during the 2017-2018 school year.

If you have any questions or concerns, please feel free to contact me at (510) 558-2510.

Sincerely,

Ron Rosenbaum
Principal
Institutional Review Board for the Protection of Human Subjects
University of San Francisco
2130 Fulton Street
San Francisco, CA 94117

September 8, 2017

Dear Members of the Committee:

On behalf of Albany Unified School District, I am writing to formally confirm our consent to the research proposed by Mr. Ian Murray, a doctoral student at University of San Francisco. We are aware that Mr. Murray intends to conduct research into the application of digital multimedia to biology vocabulary instruction for high school students. The instruction, assessment, and data collection required as part of this research will be carried out with students in our college preparatory biology classes during the 2017-2018 school year.

If you have any questions or concerns, please feel free to contact me at (510) 558-3771.

Sincerely,

[Signature]

Marie Williams
Director of Curriculum, Instruction & Assessment
Albany Unified School District
mwilliams@ausdk12.org
(510) 558-3771
Appendix B

HMH Reading Inventory Sample Test Item
“I leaned back for a moment and let my eyes wander down below. We were way out over the ocean. I looked at my watch—a little more than thirty minutes from Orlando so far. The sea looked choppy, even with the bright, sunny weather. An occasional cloud cast its shadow down on the stony-looking water surface. The wavering outline of the plane appeared and disappeared.”

I had a good ________.
- nap
- view
- idea
- lunch

From Knutson, 2006
Appendix C

Vocabulary Tests
Ecology Vocabulary Test 1

Write the letter of the choice that best completes the statement.

1. ___ The scientific study of interactions among organisms and between organisms and their environment, or surroundings is
   a. biology.
   b. organology.
   c. ecology.
   d. teleology.

2. ___ The combined portions of the planet in which all of life exists, including land, water, and air, or atmosphere is the
   a. ecosystem.
   b. biozone.
   c. biome.
   d. biosphere.

3. ___ A group of organisms so similar to one another that they can breed and produce fertile offspring is a
   a. population.
   b. species.
   c. community.
   d. genus.

4. ___ A network of complex interactions formed by the feeding relationships among the various organisms in an ecosystem is a
   a. food chain.
   b. trophic level.
   c. food web.
   d. food network.

5. ___ A group of ecosystems that have the same climate and similar dominant communities is
   a. biozone.
   b. biome.
   c. biosphere.
   d. ecosphere.

6. ___ An organism that relies on other organisms for its energy and food supply is a
   a. producer.
   b. saprophyte.
   c. detritivore.
   d. heterotroph.
Ecology Vocabulary Test 1

7. ___ A collection of all the organisms that live in a particular place, together with their nonliving, or physical, environment is a/an
   a. ecosystem.
   b. assemblage.
   c. biome.
   d. trophic network.

8. ___ A step in a food chain or web is a
   a. trophic level.
   b. feeding level.
   c. feeding step.
   d. consumption step.

9. ___ An assemblage of different populations that live together in a defined area is a/an
   a. ecosystem.
   b. community.
   c. trophic web.
   d. biome.

10. ___ A series of steps in which organisms transfer energy by eating and being eaten is a
   a. trophic step.
   b. trophic chain.
   c. food chain.
   d. food step.

11. ___ An organism that can capture energy from sunlight or chemicals and use that energy to produce food is a/an
    a. autotroph.
    b. saprophyte.
    c. consumer.
    d. developer.

12. ___ A group of individuals that belong to the same species and live in the same area is a
    a. community.
    b. genus.
    c. trophic clan.
    d. population.

13. ___ The day-to-day condition of Earth’s atmosphere at a particular time and place is
    a. temperature.
    b. climate.
    c. locale.
    d. weather.
Ecology Vocabulary Test 1

14. ___ A biological influence on organisms within an ecosystem is a/an
   a. biogenic factor.
   b. ecological factor.
   c. biotic factor.
   d. bene factor.

15. ___ A relationship in which both species benefit from the relationship is
   a. commensalism.
   b. mutualism.
   c. parasitism.
   d. equalism.

16. ___ A relationship in which one member of the association benefits and the other is neither
   helped nor harmed is
   a. mutualism.
   b. commensalism.
   c. parasitism.
   d. inequalism.

17. ___ An ecosystem in which water either covers the soil or is present at or near the surface of
   the soil for at least part of the year is a/an
   a. artesian.
   b. moor.
   c. wetland.
   d. taiga.

18. ___ A climate within a small area that differs significantly from the climate around it is a/an
   a. microclimate.
   b. biome.
   c. niche.
   d. artesian.

19. ___ The average, year-after-year conditions of temperature and precipitation in a particular
   region are
   a. weather.
   b. biome.
   c. niche.
   d. climate.

20. ___ A physical, or nonliving, factor that shapes an ecosystem is a/an
   a. biotic factor.
   b. community.
   c. malefactor.
   d. abiotic factor.
Ecology Vocabulary Test 1

21. ___ The full range of physical and biological condition in which an organism lives and the way in which the organism uses those conditions is a
   a. niche.
   b. trophic network.
   c. symbiosis.
   d. biome.

22. ___ A relationship in which two species live closely together is
   a. cisbiosis.
   b. symbiosis.
   c. niche.
   d. benthos.

23. ___ A relationship in which one organism lives on or inside another organism and harms it is
   a. allopatry.
   b. mutualism.
   c. parasitism.
   d. commensalism.

24. ___ The organisms that live attached to or near the ocean floor are
   a. benthos
   b. bashibazouks.
   c. bassos.
   d. limnos.
   e. estuaries.
Ecology Vocabulary Test 2

Write the letter of the choice that best completes the statement.

1. The number of individuals per unit area is
   a. population crowding.
   b. static.
   c. population density.
   d. subjective.

2. The movement of individuals into an area is
   a. immigration.
   b. emigration.
   c. eximigration.
   d. immigration.

3. The movement of individuals out of a population is
   a. immigration.
   b. emigration.
   c. eximigration.
   d. immigration.

4. A growth pattern in which individuals in a population reproduce at a constant rate is
   a. flatline growth.
   b. logistic growth.
   c. exponential growth.
   d. balloon growth.

5. A growth pattern in which a population’s growth slows or stops following a period of exponential growth is
   a. flatline growth.
   b. logistic growth.
   c. experiential growth.
   d. balloon growth.

6. A factor that causes population growth to decrease is a
   a. limiting capacity.
   b. restricting factor.
   c. restricting capacity.
   d. limiting factor.

7. A limiting factor that depends on population size is a/an
   a. density-dependent limiting factor.
   b. density-independent limiting factor.
   c. population-limiting factor.
   d. size-limiting factor.

8. A limiting factor that affects all populations in similar ways, regardless of population size is a
   a. density-independent limiting factor.
   b. density-dependent limiting factor.
   c. size-limiting factor.
   d. population-limiting factor.
Ecology Vocabulary Test 2

9. A mechanism of population control in which a population is regulated by predation is a/an
   a. unhealthy relationship.
   b. predator-prey relationship.
   c. mechanical relationship.
   d. controlling relationship.

10. The scientific study of human populations is
   a. democracy.
   b. population dynamics.
   c. demography.
   d. dendrology.

11. A change in a population from high birth and death rates to low birth and death rate is the
    a. demographic transition.
    b. democratic transition.
    c. population dynamics transition.
    d. dendrological transition.

12. The largest number of individuals that a given environment can support is the
    a. environmental capacity.
    b. Individual capacity.
    c. trophic capacity.
    d. carrying capacity.

13. A resource that can regenerate and is therefore replaceable is a
    a. regenerating resource.
    b. viable resource.
    c. reliable resource.
    d. renewable resource.

14. A resource that cannot be replaced by natural processes is a/an
    a. unprocessed resource.
    b. nonviable resource.
    c. nonrenewable resource.
    d. nonregenerating resource.
Ecology Vocabulary Test 2

15. The farming of aquatic organisms is
   a. moriculture.
   b. aquaculture.
   c. agriculture.
   d. silviculture.

16. A mixture of chemicals that occurs as a gray-brown haze in the atmosphere is
   a. fog.
   b. smog.
   c. grog.
   d. blog.

17. A harmful material that can enter the biosphere through the land, air, or water is a/an
   a. adjuvant.
   b. adjutant.
   c. pollutant.
   d. pollinator.

18. Biological diversity is also termed
   a. biodiversity.
   b. ecodiversity.
   c. biovariety.
   d. the ecospectrum.

19. The sum total of all the different forms of genetic information carried by all organisms living on Earth today is also termed
   a. genodiversity.
   b. genovariety.
   c. the genospectrum.
   d. genetic diversity.

20. When a species disappears from all or part of its range it is termed
   a. extirpation.
   b. extempore.
   c. extenuation.
   d. extinction.

21. A species whose population size is declining in a way that places it in danger of extinction is called a/an
   a. an endangered species.
   b. an extirping species.
   c. a relict.
   d. the living dead.
Ecology Vocabulary Test 2

22. The process by which concentrations of a harmful substance increase in organisms at higher trophic levels in a food chain or food web is termed
   a. bioaccumulation.
   b. biological magnification.
   c. trophic concentration.
   d. toxiccoalescence.

23. Plants and animals that have migrated to places where they are not native are called
   a. non-native guests.
   b. exotic visitors.
   c. invasive species.
   d. exogenous organisms.

24. An increase in the average temperature of the biosphere is termed
   a. global warming.
   b. climatic inflation.
   c. hyperthermia.
   d. temperature averaging.
Appendix D

Biology Concept Tests
Multiple Choice

Mark the letter of the choice that best completes the statement or answers the question in the space at the left.

1. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. economy.
   b. modeling.
   c. recycling.
   d. ecology.

2. The combined portions of Earth in which all living things exist is called the
   a. biome.
   b. community.
   c. ecosystem.
   d. biosphere.

3. Which of the following descriptions about the organization of an ecosystem is correct?
   a. Communities make up species, which make up populations.
   b. Populations make up species, which make up communities.
   c. Species make up communities, which make up populations.
   d. Species make up populations, which make up communities.

4. Plants are
   a. producers.
   b. consumers.
   c. herbivores.
   d. omnivores.

5. What is the original source of almost all the energy in most ecosystems?
   a. carbohydrates
   b. sunlight
   c. water
   d. carbon

6. Which of the following organisms does NOT require sunlight to live?
   a. chemosynthetic bacteria
   b. algae
   c. autotroph.
   d. producer.

7. An organism that cannot make its own food is called a(an)
   a. heterotroph.
   b. chemotroph.
   c. autotroph.
   d. producer.

8. What is an organism that feeds only on plants called?
   a. carnivore
   b. herbivore
   c. omnivore
   d. detritivore

9. All the interconnected feeding relationships in an ecosystem make up a food
   a. interaction.
   b. chain.
   c. network.
   d. web.

10. The total amount of living tissue within a given trophic level is called the
    a. organic mass.
    b. trophic mass.
    c. energy mass.
    d. biomass.

11. A bird stalks, kills, and then eats an insect. Based on its behavior, which ecological terms describe the bird?
    a. herbivore, decomposer
    b. producer, heterotroph
    c. carnivore, consumer
    d. autotroph, herbivore

12. A snake that eats a frog that has eaten an insect that fed on a plant is a
    a. first-level producer.
    b. first-level consumer.
    c. second-level producer.
    d. third-level consumer.

13. Only 10 percent of the energy stored in an organism can be passed on to the next trophic level. Of the remaining energy, some is used for the organism’s life processes, and the rest is
    a. used in reproduction.
    b. stored as body tissue.
    c. stored as fat.
    d. eliminated as heat.

14. Which of the following is NOT recycled in the biosphere?
    a. water
    b. nitrogen
    c. carbon
    d. energy
15. What is the process by which bacteria convert nitrogen gas in the air to ammonia?  
   a. nitrogen fixation  
   b. excretion  
   c. decomposition  
   d. denitrification

16. Carbon cycles through the biosphere in all of the following processes EXCEPT  
   a. photosynthesis  
   b. transpiration  
   c. burning of fossil fuels  
   d. decomposition of plants and animals

17. How is carbon stored in the biosphere?  
   a. in the atmosphere as carbon dioxide and oceans as dissolved carbon dioxide  
   b. underground as fossil fuels and calcium carbonate rock  
   c. in living and dead tissues of plants and animals  
   d. all of the above

18. Nitrogen fixation is carried out primarily by  
   a. humans  
   b. plants  
   c. bacteria  
   d. consumers

19. The movements of energy and nutrients through living systems are different because  
   a. energy flows in one direction and nutrients recycle.  
   b. energy is limited in the biosphere and nutrients are always available.  
   c. nutrients flow in one direction and energy recycles.  
   d. energy forms chemical compounds and nutrients are lost as heat.

20. Biogeochemical cycling ensures that  
   a. human activity will have no effect on elements, chemical compounds, and other forms of matter.  
   b. living organisms will not become limited in any one nutrient.  
   c. nutrients will be circulated throughout the biosphere.  
   d. many nutrients will not reach toxic concentrations in the biosphere.

21. If a nutrient is in such short supply in an ecosystem that it affects an animal’s growth, the  
   a. animal becomes a decomposer  
   b. substance is a limiting nutrient  
   c. nutrient leaves the food chain  
   d. ecosystem will not survive

Completion  
Complete each sentence or statement.

22. Of the organisms represented in Figure 3–1, the organisms in the oceans with the smallest total biomass are most likely the _______.

23. In a four-level energy pyramid, if the first level contains 500 calories of energy, the third level will contain approximately _______ calories.

Short Answer

24. Describe the role of algae illustrated in Figure 3–1.

25. Describe the flow of energy among the following members of an ecosystem: decomposers, autotrophs, heterotrophs, and the sun.
chapter 3 Test B

Name _________________________

Multiple Choice
Mark the letter of the choice that best completes the statement or answers the question in the space at the left.

____ 1. Which of the following is NOT recycled in the biosphere?
   a. water
   b. nitrogen
   c. carbon
   d. energy

____ 2. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. economy
   b. modeling
   c. recycling
   d. ecology

____ 3. Biogeochemical cycling ensures that
   a. human activity will have no effect on elements, chemical compounds, and other forms of matter.
   b. living organisms will not become limited in any one nutrient.
   c. nutrients will be circulated throughout the biosphere.
   d. many nutrients will not reach toxic concentrations in the biosphere.

____ 4. The movements of energy and nutrients through living systems are different because
   a. energy flows in one direction and nutrients recycle.
   b. energy is limited in the biosphere and nutrients are always available.
   c. nutrients flow in one direction and energy recycles.
   d. energy forms chemical compounds and nutrients are lost as heat.

____ 5. How is carbon stored in the biosphere?
   a. in the atmosphere as carbon dioxide and oceans as dissolved carbon dioxide
   b. underground as fossil fuels and calcium carbonate rock
   c. in living and dead tissues of plants and animals
   d. all of the above

____ 6. The combined portions of Earth in which all living things exist is called the
   a. biome
   b. community
   c. ecosystem
   d. biosphere

____ 7. The total amount of living tissue within a given trophic level is called the
   a. organic mass
   b. trophic mass
   c. energy mass
   d. biomass

____ 8. Nitrogen fixation is carried out primarily by
   a. humans
   b. plants
   c. bacteria
   d. consumers

____ 9. Which of the following descriptions about the organization of an ecosystem is correct?
   a. Communities make up species, which make up populations.
   b. Populations make up species, which make up communities.
   c. Species make up communities, which make up populations.
   d. Species make up populations, which make up communities.

____ 10. Plants are
    a. producers
    b. consumers
    c. herbivores
    d. omnivores

____ 11. What is an organism that feeds only on plants called?
    a. carnivore
    b. herbivore
    c. omnivore
    d. detritivore

____ 12. A bird stalks, kills, and then eats an insect. Based on its behavior, which ecological terms describe the bird?
    a. herbivore, decomposer
    b. producer, heterotroph
    c. carnivore, consumer
    d. autotroph, herbivore
13. What is the process by which bacteria convert nitrogen gas in the air to ammonia?
   a. nitrogen fixation  c. decomposition
   b. excretion  d. denitrification

14. All the interconnected feeding relationships in an ecosystem make up a food
   a. interaction  c. network
   b. chain  d. web

15. What is the original source of almost all the energy in most ecosystems?
   a. carbohydrates  c. water
   b. sunlight  d. carbon

16. Carbon cycles through the biosphere in all of the following processes EXCEPT
   a. photosynthesis  c. burning of fossil fuels
   b. transpiration  d. decomposition of plants and animals

17. A snake that eats a frog that has eaten an insect that fed on a plant is a
   a. first-level producer  c. second-level producer
   b. first-level consumer  d. third-level consumer

18. Which of the following organisms does NOT require sunlight to live?
   a. chemosynthetic bacteria  c. trees
   b. algae  d. photosynthetic bacteria

19. If a nutrient is in such short supply in an ecosystem that it affects an animal’s growth, the
   a. animal becomes a decomposer  c. nutrient leaves the food chain
   b. substance is a limiting nutrient  d. ecosystem will not survive

20. An organism that cannot make its own food is called a(an)
   a. heterotroph  c. autotroph
   b. chemotroph  d. producer

21. Only 10 percent of the energy stored in an organism can be passed on to the next trophic level. Of the
   remaining energy, some is used for the organism’s life processes, and the rest is
   a. used in reproduction  c. stored as fat
   b. stored as body tissue  d. eliminated as heat

Completion
Complete each sentence or statement.

Figure 3–1

22. Of the organisms represented in Figure 3–1, the organisms in the oceans with the smallest total biomass
    are most likely the _____________________

23. In a four-level energy pyramid, if the first level contains 500 calories of energy, the third level will
    contain approximately ______________ calories.

Short Answer

24. Describe the flow of energy among the following members of an ecosystem: decomposers, autotrophs,
    heterotrophs, and the sun.

25. Describe the role of algae illustrated in Figure 3–1.
chapter 4 test A

Name __________________________

Multiple Choice
Mark the letter of the choice that best completes the statement or answers the question in the space at the left.

___ 1. The average year-after-year conditions of temperature and precipitation in a particular region are referred to as the region's
   a. weather.  c. ecosystem.
   b. latitude.  d. climate.

___ 2. All of the following factors contribute to Earth's climate EXCEPT
   a. latitude.  c. transport of heat.
   b. longitude. d. shape and elevation of landmasses.

___ 3. Each of the following is an abiotic factor in the environment EXCEPT
   a. plant life.  c. rainfall.
   b. soil type.  d. temperature.

___ 4. Which is a biotic factor that affects the size of a population in a specific ecosystem?
   a. average temperature of the ecosystem
   b. type of soil in the ecosystem
   c. number and kinds of predators in the ecosystem
   d. concentration of oxygen in the ecosystem

___ 5. An organism's niche is
   a. the range of physical and biological conditions in which an organism lives and the way in which it uses those conditions.
   b. all the physical and biological factors in the organism's environment.
   c. the range of temperatures that the organism needs to survive.
   d. a full description of the place an organism lives.

___ 6. An interaction in which one organism captures and feeds on another organism is called
   a. competition.  c. mutualism.
   b. sybiosis.  d. predation.

___ 7. A symbiotic relationship in which one organism lives on or inside another organism and harms it is
   a. commensalism.  c. predation.
   b. mutualism.  d. parasitism.

___ 8. The symbiotic relationship between a flower and the insect that feeds on its nectar is an example of
   a. mutualism because the flower provides the insect with food and the insect pollinates the flower.
   b. parasitism because the insect lives off the nectar from the flower.
   c. commensalism because the insect does not harm the flower and the flower does not benefit from the relationship.
   d. predation because the insect feeds on the flower.

___ 9. The series of predictable changes that occurs in a community over time is called
   a. population growth.  c. climax community.
   b. ecological succession.  d. climate change.

___ 10. Primary succession can begin after
    a. a forest fire.  c. farm land is abandoned.
    b. a lava flow.  d. a severe storm.

___ 11. What is one difference between primary and secondary succession?
    a. Primary succession is slow and secondary succession is rapid.
    b. Secondary succession begins on soil and primary succession begins on newly exposed surfaces.
    c. Primary succession modifies the environment and secondary succession does not.
    d. Secondary succession begins with lichens and primary succession begins with trees.
12. Which biome is characterized by very low temperatures, little precipitation, and permafrost? Test A
   a. desert
   b. temperate forest
   c. tundra
   d. tropical dry forest

13. Which two biomes have the least amount of precipitation?
   a. tropical rain forest and temperate grassland
   b. tropical savanna and tropical dry forest
   c. tundra and desert
   d. boreal forest and temperate woodland and shrubland

14. Aquatic ecosystems are classified by all of the following EXCEPT
   a. depth and flow of the water.
   b. temperature of the water.
   c. organisms that live there.
   d. chemistry of the water.

15. The photic zone
   a. extends to the bottom of the open ocean.
   b. extends to a depth of about 200 meters.
   c. is deep, cold, and permanently dark.
   d. is where chemosynthetic bacteria are the producers.

16. Earth has three main climate zones because of the differences in latitude and, thus,
   a. amount of precipitation received.
   b. angle of heating.
   c. ocean currents.
   d. prevailing winds.

Short Answer

17. Describe the greenhouse effect and explain how it maintains Earth’s temperature range.

18. List three biotic and three abiotic factors that determine the survival of a rabbit in a temperate forest.

Language of Science

Matching

19. photo
   a. origin, beginning

20. genesis
   b. foot

21. troph
   c. to make

22. pod
   d. different, other

23. synthesis
   e. middle

24. meso
   f. eat, consume

25. hetero
   g. light
chapter 4 test B

Name ______________________

Multiple Choice
Mark the letter of the choice that best completes the statement or answers the question in the space at the left.

1. All of the following factors contribute to Earth’s climate EXCEPT
   a. shape and elevation of landmasses.
   b. transport of heat.
   c. latitude.
   d. longitude.

2. What is one difference between primary and secondary succession?
   a. Primary succession modifies the environment and secondary succession does not.
   b. Secondary succession begins with lichens and primary succession begins with trees.
   c. Secondary succession begins on soil and primary succession begins on newly exposed surfaces.
   d. Primary succession is slow and secondary succession is rapid.

3. Aquatic ecosystems are classified by all of the following EXCEPT
   a. organisms that live there.
   b. depth and flow of the water.
   c. temperature of the water.
   d. chemistry of the water.

4. The symbiotic relationship between a flower and the insect that feeds on its nectar is an example of
   a. commensalism because the insect does not harm the flower and the flower does not benefit from the relationship.
   b. mutualism because the flower provides the insect with food and the insect pollinates the flower.
   c. predation because the insect feeds on the flower.
   d. parasitism because the insect lives off the nectar from the flower.

5. Each of the following is an abiotic factor in the environment EXCEPT
   a. soil type.
   b. temperature.
   c. rainfall.
   d. plant life.

6. A symbiotic relationship in which one organism lives on or inside another organism and harms it is
   a. predation.
   b. parasitism.
   c. mutualism.
   d. commensalism.

7. Which biome is characterized by very low temperatures, little precipitation, and permafrost?
   a. desert.
   b. tundra.
   c. temperate forest.
   d. tropical dry forest.

8. The series of predictable changes that occurs in a community over time is called
   a. climax community.
   b. ecological succession.
   c. climate change.
   d. population growth.

9. Primary succession can begin after
   a. a forest fire.
   b. a lava flow.
   c. a severe storm.
   d. farm land is abandoned.

10. An organism’s niche is
    a. the range of physical and biological conditions in which an organism lives and the way in which it uses those conditions.
    b. the range of temperatures that the organism needs to survive.
    c. a full description of the place an organism lives.
    d. all the physical and biological factors in the organism’s environment.

11. Which is a biotic factor that affects the size of a population in a specific ecosystem?
    a. concentration of oxygen in the ecosystem
    b. type of soil in the ecosystem
    c. average temperature of the ecosystem
    d. number and kinds of predators in the ecosystem
12. Which two biomes have the least amount of precipitation?
   a. tropical rain forest and temperate grassland
   b. tundra and desert
   c. tropical savanna and tropical dry forest
   d. boreal forest and temperate woodland and shrubland

13. The photic zone
   a. extends to a depth of about 200 meters.
   b. is deep, cold, and permanently dark.
   c. extends to the bottom of the open ocean.
   d. is where chemosynthetic bacteria are the producers.

14. The average year-after-year conditions of temperature and precipitation in a particular region are referred to as the region’s
   a. weather.
   b. latitude.
   c. climate.
   d. ecosystem.

15. An interaction in which one organism captures and feeds on another organism is called
   a. sybiosis.
   b. competition.
   c. mutualism.
   d. predation.

16. Earth has three main climate zones because of the differences in latitude and, thus,
   a. angle of heating.
   b. amount of precipitation received.
   c. prevailing winds.
   d. ocean currents.

**Short Answer**

17. List three biotic and three abiotic factors that determine the survival of a rabbit in a temperate forest.

18. Describe the greenhouse effect and explain how it maintains Earth’s temperature range.

**Language of Science**

Matching

19. mono a. both, doubly
   20. aero b. break down
   21. lys c. small
   22. arthro d. needing oxygen or air
   23. lateral e. one, single
   24. amphi f. joint
   25. micro g. side
Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. economy.
   b. modeling.
   c. recycling.
   d. ecology.

2. Plants are
   a. producers.
   b. consumers.
   c. herbivores.
   d. omnivores.

3. What is the original source of almost all the energy in most ecosystems?
   a. carbohydrates
   b. sunlight
   c. water
   d. carbon

4. Which of the following organisms does NOT require sunlight to live?
   a. chemosynthetic bacteria
   b. algae
   c. trees
   d. photosynthetic bacteria

5. An organism that cannot make its own food is called a(An)
   a. heterotroph.
   b. chemotroph.
   c. autotroph.
   d. producer.

6. Organisms that obtain nutrients by breaking down dead and decaying plants and animals are called
   a. decomposers.
   b. producers.
   c. autotrophs.
   d. omnivores.

7. All the interconnected feeding relationships in an ecosystem make up a food
   a. interaction.
   b. chain.
   c. network.
   d. web.

8. The total amount of living tissue within a given trophic level is called the
   a. organic mass.
   b. trophic mass.
   c. energy mass.
   d. biomass.

9. A snake that eats a frog that has eaten an insect that fed on a plant is a
   a. first-level producer.
   b. first-level consumer.
   c. second-level producer.
   d. third-level consumer.

10. Only 10 percent of the energy stored in an organism can be passed on to the next trophic level. Of the remaining energy, some is used for the organism’s life processes, and the rest is stored as fat.
    a. used in reproduction.
    b. stored as body tissue.
    c. stored as fat.
    d. eliminated as heat.

11. Which of the following is NOT recycled in the biosphere?
    a. water
    b. nitrogen
    c. carbon
    d. energy

12. What is the process by which bacteria convert nitrogen gas in the air to ammonia?
    a. nitrogen fixation
    b. excretion
    c. decomposition
    d. denitrification

13. Carbon cycles through the biosphere in all of the following processes EXCEPT
    a. photosynthesis.
    b. transpiration.
    c. burning of fossil fuels.
    d. decomposition of plants and animals.

14. How is carbon stored in the biosphere?
    a. in the atmosphere as carbon dioxide
    b. underground as fossil fuels and calcium carbonate rock
    c. in the oceans as dissolved carbon dioxide
    d. all of the above
15. If a nutrient is in such short supply in an ecosystem that it affects an animal’s growth, the
   a. animal becomes a decomposer.
   b. substance is a limiting nutrient.
   c. nutrient leaves the food chain.
   d. ecosystem will not survive.

16. All of the following factors contribute to Earth’s climate EXCEPT
   a. latitude.
   b. longitude.
   c. transport of heat.
   d. shape and elevation of landmasses.

17. Earth has three main climate zones because of the differences in latitude and, thus,
   a. amount of precipitation received.
   b. angle of sunlight received and heating.
   c. ocean currents.
   d. prevailing winds.

18. Each of the following is an abiotic factor in the environment EXCEPT
   a. plant life.
   b. soil type.
   c. rainfall.
   d. temperature.

19. An organism’s niche is
   a. the range of physical and biological conditions in which an organism lives and the way in
   which it uses those conditions.
   b. all the physical and biological factors in the organism’s environment.
   c. the range of temperatures that the organism needs to survive.
   d. a full description of the place an organism lives.

20. The symbiotic relationship between a flower and the insect that feeds on its nectar is an example of
   a. mutualism because the flower provides the insect with food and the insect pollinates the
   flower.
   b. parasitism because the insect lives off the nectar from the flower.
   c. commensalism because the insect does not harm the flower and the flower does not benefit
   from the relationship.
   d. predation because the insect feeds on the flower.

21. The series of predictable changes that occurs in a community over time is called
   a. population growth.
   b. ecological succession.
   c. climax community.
   d. climate change.

Completion
Complete each sentence or statement.

22. In a four-level energy pyramid, if the first level contains 500 calories of energy, the third level will contain
    approximately ________ calories.

23. Of the organisms represented in Figure 3–1, the organisms in the oceans with the smallest total biomass are most likely the

Figure 3–1

Algae

Zooplankton

Small fishes

Squid

Shark

Short Answer
24. Describe the role of algae illustrated in Figure 3–1.

25. Describe the flow of energy among the following members of an ecosystem: decomposers, autotrophs,
    heterotrophs, and the sun.
Unit 2 Test chapter 3 and 4 Biosphere and Ecosystems – B

Name ____________________________

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. Only 10 percent of the energy stored in an organism can be passed on to the next trophic level. Of the remaining energy, some is used for the organism’s life processes, and the rest is
   a. stored as fat.          c. used in reproduction.
   b. stored as body tissue. d. eliminated as heat.

2. Earth has three main climate zones because of the differences in latitude and, thus,
   a. ocean currents.          c. angle of sunlight received and heating.
   b. amount of precipitation received. d. prevailing winds.

3. The total amount of living tissue within a given trophic level is called the
   a. biomass.          c. trophic mass.
   b. energy mass. d. organic mass.

4. What is the original source of almost all the energy in most ecosystems?
   a. carbohydrates c. sunlight
   b. carbon d. water

5. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. recycling. c. economy.
   b. ecology. d. modeling.

6. Each of the following is an abiotic factor in the environment EXCEPT
   a. rainfall. c. plant life.
   b. temperature. d. soil type.

7. If a nutrient is in such short supply in an ecosystem that it affects an animal’s growth, the
   a. animal becomes a decomposer. c. substance is a limiting nutrient.
   b. nutrient leaves the food chain. d. ecosystem will not survive.

8. How is carbon stored in the biosphere?
   a. underground as fossil fuels and calcium carbonate rock
   b. in the atmosphere as carbon dioxide
   c. in the oceans as dissolved carbon dioxide
   d. all of the above

9. The symbiotic relationship between a flower and the insect that feeds on its nectar is an example of
   a. commensalism because the insect does not harm the flower and the flower does not benefit from the relationship.
   b. parasitism because the insect lives off the nectar from the flower.
   c. predation because the insect feeds on the flower.
   d. mutualism because the flower provides the insect with food and the insect pollinates the flower.

10. All of the following factors contribute to Earth’s climate EXCEPT
    a. longitude. c. latitude.
    b. transport of heat. d. shape and elevation of landmasses.

11. A snake that eats a frog that has eaten an insect that fed on a plant is a
    a. first-level consumer. c. second-level producer.
    b. first-level producer. d. third-level consumer.

12. What is the process by which bacteria convert nitrogen gas in the air to ammonia?
    a. denitrification c. excretion
    b. decomposition d. nitrogen fixation

13. An organism that cannot make its own food is called a(an)
    a. autotroph. c. producer.
    b. chemotroph. d. heterotroph.
14. All the interconnected feeding relationships in an ecosystem make up a food  
a. web  
b. chain  
c. network  
d. interaction.

15. The series of predictable changes that occurs in a community over time is called  
a. climate change  
b. population growth  
c. ecological succession  
d. climax community.

16. An organism’s niche is  
a. the range of physical and biological conditions in which an organism lives and the way in which it uses those conditions  
b. the range of temperatures that the organism needs to survive  
c. a full description of the place an organism lives  
d. all the physical and biological factors in the organism’s environment.

17. Plants are  
a. consumers  
b. producers  
c. omnivores  
d. herbivores.

18. Which of the following organisms does NOT require sunlight to live?  
a. trees  
b. chemosynthetic bacteria  
c. algae  
d. photosynthetic bacteria

19. Carbon cycles through the biosphere in all of the following processes EXCEPT  
a. burning of fossil fuels  
b. transpiration  
c. photosynthesis  
d. decomposition of plants and animals.

20. Organisms that obtain nutrients by breaking down dead and decaying plants and animals are called  
a. decomposers  
b. omnivores  
c. producers  
d. autotrophs.

21. Which of the following is NOT recycled in the biosphere?  
a. carbon  
b. nitrogen  
c. water  
d. energy

Completion

Complete each sentence or statement.

22. In a four-level energy pyramid, if the first level contains 500 calories of energy, the third level will contain approximately __________ calories.

23. Of the organisms represented in Figure 3–1, the organisms in the oceans with the smallest total biomass are most likely the __________.

![Figure 3–1](image)

Short Answer

24. Describe the role of algae illustrated in Figure 3–1.

25. Describe the flow of energy among the following members of an ecosystem: decomposers, autotrophs, heterotrophs, and the sun.
Biology Chapter 5 test A

Name ________________________________

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. One of the main characteristics of a population is its
   a. independent factors.                c. dynamics.
   b. geographic distribution.          d. habitat.

2. What does the range of a population tell you that density does not?
   a. the number that live in an area    c. the births per unit area
   b. the areas inhabited by a population d. the deaths per unit area

3. Which of the following tells you population density?
   a. the number of births per year      c. population shift.
   b. the number of frogs in a pond      d. carrying capacity.
   c. the number of deaths per year
   d. the number of bacteria per square millimeter

4. The movement of organisms into a given area from another area is called
   a. immigration.                       c. population shift.
   b. emigration.                        d. carrying capacity.

5. What is happening in a population as it decreases?
   a. The birthrate and the death rate remain the same.
   b. The death rate becomes lower than the birthrate.
   c. The death rate stays the same and the birthrate increases.
   d. The death rate becomes higher than the birthrate.

6. Which are two ways a population can decrease in size?
   a. immigration and emigration         c. decreased birthrate and emigration
   b. increased death rate and immigration d. emigration and increased birthrate

7. When individuals in a population reproduce at a constant high rate, it is called
   a. logistic growth.                   c. exponential growth.
   b. growth density.                   d. multiple growth.

8. The various growth phases through which most populations go are represented on a(an)
   a. logistic growth curve.             c. carrying capacity graph.
   b. bell curve.                       d. population curve.

9. As resources in a population become less available, the population
   a. declines rapidly.                  c. reaches carrying capacity.
   b. increases rapidly.                 d. enters a phase of exponential growth.

10. In a logistic growth curve, exponential growth is the phase in which the population
    a. reaches carrying capacity.         c. growth begins to slow down.
    b. grows quickly.                    d. growth stops.

11. When the exponential phase of a logistic growth curve of a population ceases,
    a. the size of the population drops.
    b. the size of the population stays the same.
    c. population growth begins to slow down.
    d. population growth begins to speed up.

12. A biotic or an abiotic resource in the environment that causes population size to decrease is a
    a. carrying capacity.                c. limiting factor.
    b. recycling nutrient.              d. growth factor.

13. Each of the following is a density-dependent limiting factor EXCEPT
    a. competition.                     c. crowding.
    b. seasonal cycles.                d. disease.

14. Which of the following is a density-independent limiting factor?
    a. earthquake                       c. emigration
    b. disease                          d. parasitism
15. Demographic transition is change from high birthrates and high death rates to
   a. exponential growth.       c. a low birthrate and a high death rate.
   b. a low birthrate and a low death rate.   d. indefinite growth.

16. About 500 years ago, the world’s population started
   a. decreasing.       c. growing more rapidly.
   b. to reach carrying capacity.   d. to level off.

17. Demographic transition begins with changes in society that
   a. lower the birthrate.       c. lower the death rate.
   b. increase the birthrate.     d. increase the death rate.

18. In Rwanda, there are more young children than teenagers, and more teenagers than adults. This age structure
    indicates a population that
   a. has stopped growing.       c. has a slow growth rate.
   b. has a fast growth rate.     d. will decrease in 30 years.

Short Answer

USING SCIENCE SKILLS

Graph I shows the growth curve for a culture of *Paramecium aurelia*. Graph II shows the growth curve for a
 culture of *Paramecium caudatum*, a larger species. Graph III shows the growth curves of both species when they
 are grown together.

![Graphs I, II, and III showing growth curves.](image)

Figure 5–2

19. **Observing** What type of population growth curve can be observed in Graphs I and II of Figure 5–2?

20. **Drawing Conclusions** What is the most likely explanation for the decline of the *P. caudatum* shown in Graph III
    of Figure 5–2?
Biology Chapter 5 test B

Name

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. Which are two ways a population can decrease in size?
   a. increased death rate and immigration  c. decreased birthrate and emigration
   b. immigration and emigration          d. emigration and increased birthrate

2. One of the main characteristics of a population is its
   a. independent factors.  c. dynamics.
   b. geographic distribution.  d. habitat.

3. About 500 years ago, the world’s population started
   a. growing more rapidly.  c. to level off.
   b. to reach carrying capacity.  d. decreasing.

4. In a logistic growth curve, exponential growth is the phase in which the population
   a. reaches carrying capacity.  c. growth stops.
   b. grows quickly.  d. growth begins to slow down.

5. When individuals in a population reproduce at a constant high rate, it is called
   a. logistic growth.  c. multiple growth.
   b. growth density.  d. exponential growth.

6. What is happening in a population as it decreases?
   a. The death rate becomes higher than the birthrate.
   b. The birthrate and the death rate remain the same.
   c. The death rate becomes lower than the birthrate.
   d. The death rate stays the same and the birthrate increases.

7. In Rwanda, there are more young children than teenagers, and more teenagers than adults. This age structure
   indicates a population that
   a. has stopped growing.  c. has a fast growth rate.
   b. has a slow growth rate.  d. will decrease in 30 years.

8. The movement of organisms into a given area from another area is called
   a. population shift.  c. emigration.
   b. carrying capacity.  d. immigration.

9. Which of the following tells you population density?
   a. the number of births per year  c. the number of deaths per year
   b. the number of frogs in a pond  d. the number of bacteria per square millimeter

10. The various growth phases through which most populations go are represented on a(an)
    a. carrying capacity graph.  c. logistic growth curve.
    b. bell curve.  d. population curve.

11. Which of the following is a density-independent limiting factor?
    a. emigration                      c. disease
    b. parasitism                     d. earthquake

12. Demographic transition begins with changes in society that
    a. lower the birthrate.  c. increase the death rate.
    b. increase the birthrate.  d. lower the death rate.

13. When the exponential phase of a logistic growth curve of a population ceases,
    a. population growth begins to speed up.
    b. the size of the population stays the same.
    c. the size of the population drops.
    d. population growth begins to slow down.

14. As resources in a population become less available, the population
    a. enters a phase of exponential growth.  c. declines rapidly.
    b. increases rapidly.  d. reaches carrying capacity.
15. Demographic transition is change from high birthrates and high death rates to
   a. a low birthrate and a low death rate.
   b. exponential growth.
   c. indefinite growth.
   d. a low birthrate and a high death rate.
   test B

16. What does the range of a population tell you that density does not?
   a. the number that live in an area
   b. the births per unit area
   c. the areas inhabited by a population
   d. the deaths per unit area
   __

17. Each of the following is a density-dependent limiting factor EXCEPT
   a. disease.
   b. competition.
   c. crowding.
   d. seasonal cycles.
   __

18. A biotic or an abiotic resource in the environment that causes population size to decrease is a
   a. recycling nutrient.
   b. growth factor.
   c. carrying capacity.
   d. limiting factor.

Short Answer USING SCIENCE SKILLS
Graph I shows the growth curve for a culture of Paramecium aurelia. Graph II shows the growth curve for a
culture of Paramecium caudatum, a larger species. Graph III shows the growth curves of both species when they
are grown together.

![Growth curves](image)

Figure 5-2

19. Observing What type of population growth curve can be observed in Graphs I and II of Figure 5–2?

20. Drawing Conclusions What is the most likely explanation for the decline of the P. caudatum shown in Graph III
    of Figure 5–2?
Biology Chapter 6 Test A

Name ______________________

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. The Americans, Europeans, and Asians who settled in the islands of Hawaii changed the islands by
   a. clearing vast areas for the growth of sugar cane.
   b. using large amounts of water.
   c. introducing nonnative crop plants.
   d. all of the above

2. Early hunters and gatherers in North America may have been responsible for
   a. natural plant and animal populations.
   b. a major extinction event of large animals.
   c. producing new varieties of crops.
   d. inventing technology such as manufactured tools.

3. Which has become an important source of environmental changes such as desertification, species extinction, and deforestation on Earth?
   a. aquaculture
   b. sustainable use
   c. human activity
   d. conservation biology

4. Land is a resource that provides
   a. space for cities and suburbs.
   b. raw materials for industry.
   c. soil for growing crops.
   d. all of the above

5. A resource, such as air or parts of the oceans, that is open to anyone is called a
   a. international resource
   b. magnified resource
   c. sustainable resource
   d. commons

6. Why are fossil fuels nonrenewable?
   a. They require hundreds of millions of years to form.
   b. Their ecosystems change forever when they are burned.
   c. They are converted to carbon dioxide when they are burned.
   d. They exist in a very small supply.

7. Using renewable resources while ensuring that they are not depleted is a practice called
   a. sustainable development.
   b. monoculture.
   c. biological magnification.
   d. industrial development.

8. The sulfur and nitrogen compounds in smog combine with water to form
   a. ozone.
   b. ammonia.
   c. acid rain.
   d. chlorofluorocarbons.

9. When toxic chemicals are discarded into a stream, they may
   a. pose a threat to human health.
   b. enter the food chain.
   c. harm aquatic plants and animals
   d. all of the above.

10. When erosion and other factors cause soil to lose its ability to hold water and other nutrients and to support plant life, it is called
    a. desertification.
    b. sustainable farming.
    c. ozone depletion.
    d. monoculture.

11. What is the “Tragedy of the Commons”?
    a. The idea that the English had to leave their ancestral villages.
    b. The sad fact that the average person, “a commoner,” can never get ahead.
    c. The secret shame of the Canadian Federal Legislature.
    d. The idea that a resource everyone can use but for which no one is responsible will eventually be destroyed.

12. Biodiversity is important to human society because it
    a. is a natural resource.
    b. provides food and goods.
    c. provides medicines.
    d. all of the above
13. The sum total of the genetically based variety of living organisms in the biosphere is called
   a. species diversity.  
b. sustainable development.  
c. biodiversity.  
d. conservation biology.

14. Human well-being is tied to biodiversity because
   a. keeping extra species around gets in the way of development.  
b. humans are part of the food webs and energy cycles that a great variety of organisms share.  
c. less biodiversity makes humans more able to get through difficult times.  
d. natural things are of no use to us.

15. An endangered species is
   a. a diseased animal.  
b. a dangerous predator.  
c. a group of organisms in danger of extinction.  
d. all organisms at the top of a food chain.

16. DDT was used to
   a. fertilize soil.  
b. kill insects.  
c. form ozone.  
d. feed animals.

17. All of the following are threats to biodiversity EXCEPT
   a. biological magnification of toxic compounds.  
b. habitat fragmentation.  
c. invasive species.  
d. species preservation.

18. One of the greatest threats today to biological diversity is
   a. old-growth forests.  
b. sustainable development.  
c. habitat destruction.  
d. protecting entire ecosystems.

19. As DDT moves up the trophic levels in food chains, or food webs, its concentration
   a. stays the same.  
b. increases.  
c. decreases.  
d. is eliminated.

20. One of the goals of conservation biology is to
   a. enforce environmental laws.  
b. protect habitats.  
c. manage natural resources.  
d. all of the above

21. An ecological “hot spot” is an area where
   a. habitats and species are healthy.  
b. hunting is encouraged.  
c. habitats and species are in the most danger of extinction.  
d. species diversity is too high.

22. The goals of conservation biology include all of the following EXCEPT
   a. wise management of natural resources.  
b. introducing foreign species into new environments.  
c. preservation of habitats and wildlife.  
d. protection of biodiversity.

23. Overexposure to UV radiation can
   a. cause cancer.  
b. decrease organisms’ resistance to disease.  
c. damage eyes.  
d. all of the above

24. An increase in Earth’s average temperature from the buildup of carbon dioxide and other gases in the atmosphere is called
   a. biological magnification.  
b. ozone depletion.  
c. global warming.  
d. particulate dispersal.

25. The major cause of ozone depletion is
   a. nitric acid.  
b. sulfuric acid.  
c. chlorofluorocarbons (CFC’s).  
d. ultraviolet light.
Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

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9. The sum total of the genetically based variety of living organisms in the biosphere is called
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   d. conservation biology.

10. Using renewable resources while ensuring that they are not depleted is a practice called
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    b. monoculture.
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    d. industrial development.

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   b. conservation biology
   c. human activity
   d. aquaculture

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Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. What does the range of a population tell you that density does not?
   a. the number that live in an area  
   b. the areas inhabited by a population  
   c. the births per unit area  
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2. What is happening in a population as it decreases?
   a. The birthrate and the death rate remain the same.  
   b. The death rate becomes lower than the birthrate.  
   c. The death rate stays the same and the birthrate increases.  
   d. The death rate becomes higher than the birthrate.

3. Which are two ways a population can decrease in size?
   a. immigration and emigration  
   b. increased death rate and immigration  
   c. decreased birthrate and emigration  
   d. emigration and increased birthrate

4. In a logistic growth curve, exponential growth is the phase in which the population
   a. reaches carrying capacity.  
   b. grows quickly.  
   c. growth begins to slow down.  
   d. growth stops.

5. A biotic or an abiotic resource in the environment that causes population size to decrease is a
   a. carrying capacity.  
   b. recycling nutrient.  
   c. limiting factor.  
   d. growth factor.

6. Each of the following is a density-dependent limiting factor EXCEPT
   a. competition.  
   b. seasonal cycles.  
   c. crowding.  
   d. disease.

7. Which of the following is a density-independent limiting factor?
   a. earthquake  
   b. disease  
   c. emigration  
   d. parasitism

8. Demographic transition is change from high birthrates and high death rates to
   a. exponential growth.  
   b. a low birthrate and a low death rate.  
   c. a low birthrate and a high death rate.  
   d. indefinite growth.

9. About 500 years ago, the world’s population started
   a. decreasing.  
   b. to reach carrying capacity.  
   c. growing more rapidly.  
   d. to level off.

10. Demographic transition begins with changes in society that
    a. lower the birthrate.  
    b. increase the birthrate.  
    c. lower the death rate.  
    d. increase the death rate.

11. In Rwanda, there are more young children than teenagers, and more teenagers than adults. This age structure
    a. has stopped growing.  
    b. has a fast growth rate.  
    c. has a slow growth rate.  
    d. will decrease in 30 years.

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Short Answer USING SCIENCE SKILLS

Graph I shows the growth curve for a culture of *Paramaecium aurelia*. Graph II shows the growth curve for a culture of *Paramaecium caudatum*, a larger species. Graph III shows the growth curves of both species when they are grown together.

---

25. **Observing** What type of population growth curve can be observed in Graphs I and II of Figure 5–2?

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Graph I shows the growth curve for a culture of Paramecium aurelia. Graph II shows the growth curve for a culture of Paramecium caudatum, a larger species. Graph III shows the growth curves of both species when they are grown together.
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Identify the letter of the choice that best completes the statement or answers the question.

1. The sulfur and nitrogen compounds in smog combine with water to form
   a. chlorofluorocarbons.    c. acid rain.
   b. ammonia.               d. ozone.

2. Which of the following is NOT a principle of the cell theory?
   a. Very few cells reproduce.  c. Cells are the basic units of life.
   b. All cells are produced by existing cells. d. All living things are made of cells.

3. An organism’s niche is
   a. a full description of the place an organism lives.
   b. all the physical and biological factors in the organism’s environment.
   c. the range of temperatures that the organism needs to survive.
   d. the range of physical and biological conditions in which an organism lives and the way in which it uses those conditions.

4. Organisms that cannot make their own food and must obtain energy from the foods they eat are called
   a. autotrophs.             c. plants.
   b. heterotrophs.           d. thylakoids.

5. All the interconnected feeding relationships in an ecosystem make up a food
   a. biome.                 c. network.
   b. interaction.           d. web.

6. Which of the following organisms does NOT require sunlight to live?
   a. trees                   c. chemosynthetic bacteria
   b. photosynthetic bacteria d. algae

7. The human population experienced exponential growth after
   a. improvements in medicine, sanitation,    c. plowing and irrigation began.
      agriculture, energy use, and technology  d. agriculture began.
   b. the bubonic plague began.

8. An increase in Earth’s average temperature from the buildup of carbon dioxide and other gases in the atmosphere is called
   a. tropicalization.        c. ozone depletion.
   b. particulate dispersal.  d. global warming.

9. Carbon cycles through the biosphere in all of the following processes EXCEPT
   a. transpiration.          c. photosynthesis.
   b. decomposition of plants and animals. d. burning of fossil fuels.

10. Which of the following is a density-independent limiting factor?
    a. parasitism              c. disease.
    b. earthquake             d. emigration.

11. Which of the following is NOT one of the factors that play a role in population growth rate?
    a. immigration            c. death rate.
    b. demography             d. emigration.

12. Which of the following makes up a molecule of water?
    a. one atom of hydrogen and two atoms of oxygen
    b. one atom of hydrogen and one atom of oxygen
    c. one atom of sodium and one atom of chlorine
    d. two atoms of hydrogen and one atom of oxygen

13. What is an organism that feeds only on plants called?
    a. omnivore               c. herbivore
    b. carnivore              d. detritivore
14. Which has become the most important source of environmental change on Earth?
   a. conservation biology  
   b. human activity  
   c. ecological succession  
   d. biomass pyramids

15. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. economy.  
   b. recycling.  
   c. modeling.  
   d. ecology.

16. The greenhouse effect is
   a. a natural phenomenon caused by gases in the atmosphere that maintains Earth’s temperature range.  
   b. the result of an excess of carbon dioxide dissolved in the oceans.  
   c. an unnatural phenomenon that causes heat energy to be radiated back into the Earth’s core.  
   d. the result of the differences in the angle of the sun’s rays.

17. Demographic transition is change from high birthrates and high death rates to
   a. a low birthrate and a low death rate.  
   b. a low birthrate and a high death rate.  
   c. exponential growth.  
   d. indefinite growth.

18. What is the correct equation for cellular respiration?
   a. $6\text{O}_2 + C_6\text{H}_12\text{O}_6 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy (ATP)}$  
   b. $6\text{O}_2 + C_6\text{H}_12\text{O}_6 + \text{Energy (ATP)} \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$  
   c. $6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy (ATP)} \rightarrow 6\text{O}_2 + C_6\text{H}_12\text{O}_6$  
   d. $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow 6\text{O}_2 + C_6\text{H}_12\text{O}_6 + \text{Energy (ATP)}$

19. The wearing away of surface soil by water and wind is known as
   a. overgrazing.  
   b. the green revolution.  
   c. deforestation.  
   d. soil erosion.

20. Which biome is characterized by very low temperatures, little precipitation, and permafrost?
   a. tundra  
   b. desert  
   c. temperate forest  
   d. tropical dry forest

21. The diffusion of water across a selectively permeable membrane is called
   a. active transport.  
   b. facilitated diffusion.  
   c. osmosis.  
   d. osmotic pressure.

22. Diffusion is the movement of molecules from
   a. an area of high concentration to an area of low concentration.  
   b. an area of low concentration to an area of high concentration.  
   c. an area of equilibrium to an area of high concentration.  
   d. all of the above

23. A controlled experiment allows the scientist to isolate and test
   a. a conclusion.  
   b. a mass of information.  
   c. a single variable.  
   d. multiple variables in the same set up.

24. Aquatic ecosystems are determined primarily by abiotic factors including all of the following EXCEPT
   a. depth and flow of the water.  
   b. chemistry of the water.  
   c. temperature of the water.  
   d. organisms that live there.

25. Which will reduce competition within a species’ population?
   a. fewer resources  
   b. higher birthrate  
   c. fewer individuals  
   d. higher population density

26. Cancer is a disorder in which some cells have lost the ability to control their
   a. spindle fibers.  
   b. surface area.  
   c. size.  
   d. growth rate.

27. Which country has not yet completed the demographic transition?
   a. Japan  
   b. Great Britain  
   c. India  
   d. United States

28. Biodiversity is important to human society because it
   a. provides food and goods.  
   b. provides medicines.  
   c. is a natural resource.  
   d. all of the above
29. A biotic or an abiotic resource in the environment that causes population to stop growing or decrease in size is a
   a. responding nutrient.
   b. limiting factor.
   c. carrying capacity.
   d. growth factor.

30. Which of the following organic compounds is the main source of energy for living things?
   a. carbohydrates
   b. proteins
   c. ethyl alcohol
   d. nucleic acids

31. The structures labeled B in Figure 10–2 are called
   a. spindles.
   b. sister chromatids.
   c. centrioles.
   d. centromeres.

32. Which of the following is a function of the nucleus?
   a. controls most of the cell’s processes
   b. stores DNA
   c. contains the information needed to make proteins
   d. all of the above

33. The goals of conservation biology include all of the following EXCEPT
   a. protection of biodiversity.
   b. wise management of natural resources.
   c. introducing foreign species into new environments.
   d. preservation of habitats and wildlife.

34. What is the term for a group of organisms of one type living in the same place?
   a. biosphere
   b. ecosystem
   c. environment
   d. population

35. What does the range of a population tell you that density does not?
   a. the number that live in an area
   b. the deaths per unit area
   c. the births per unit area
   d. the areas inhabited by a population

36. When a population reaches a size where it is using all the available resources it
   a. declines rapidly.
   b. enters a phase of exponential growth.
   c. reaches carrying capacity.
   d. undergoes ecological succession

37. A theory
   a. is an explanation based on observations and experiments that may be revised or replaced.
   b. is always true.
   c. is the opening statement of an experiment.
   d. is a problem to be solved.

38. A student is collecting the gas bubbles given off from an aquatic plant in bright sunlight at a temperature of 27°C. The gas being collected is probably
   a. ATP.
   b. oxygen.
   c. carbon dioxide.
   d. vaporized water.

39. What is a final product of the Calvin cycle during photosynthesis?
   a. high-energy sugars
   b. ATP
   c. light
   d. carbon dioxide gas

40. All of the following are threats to biodiversity EXCEPT
   a. species preservation.
   b. biological magnification of toxic compounds.
   c. habitat fragmentation.
   d. invasive species.
41. A covalent bond is formed as the result of
   a. transferring electrons.
   b. transferring protons.
   c. sharing a proton pair.
   d. sharing an electron pair.

42. Which process is used to produce beer and wine?
   a. alcoholic fermentation
   b. glycolysis
   c. the Krebs cycle
   d. lactic acid fermentation

43. An interaction in which one organism captures and feeds on another organism is called
   a. predation.
   b. mutualism.
   c. competition.
   d. symbiosis.

44. If a nutrient is in such short supply in an ecosystem that it affects an organism’s growth, the
   a. ecosystem will not survive.
   b. animal becomes a decomposer.
   c. nutrient leaves the food chain.
   d. substance is a limiting nutrient.

45. Which event occurs during interphase?
   a. The cell grows.
   c. Spindle fibers begin to form.
   d. Centromeres divide.

46. All of the following are problems that growth causes for cells EXCEPT
   a. expelling wastes.
   b. DNA overload.
   c. excess oxygen.
   d. obtaining enough food.

47. There are 150 Saguaro cactus plants per square kilometer in a certain area of Arizona desert. To which population
   characteristic does this information refer?
   a. population density
   b. age structure
   c. growth rate
   d. geographic distribution

48. The unequal heating of Earth’s surface
   a. has important effects on Earth’s climate regions.
   b. causes winds that transport heat throughout the biosphere.
   c. drives wind and ocean currents.
   d. all of the above

49. Human population growth has slowed down to about the replacement rate in
   a. Rwanda.
   b. India.
   c. many parts of South America.
   d. the United States.

50. The process by which organisms keep their internal conditions fairly constant is called
   a. photosynthesis.
   b. evolution.
   c. reproduction.
   d. homeostasis.

51. An endangered species is
   a. a group of organisms in danger of extinction.
   b. a dangerous predator.
   c. a diseased animal.
   d. all organisms at the top of a food chain.

52. Which organelle would you expect to find in plant cells but not animal cells?
   a. chloroplast
   b. mitochondrion
   c. ribosome
   d. smooth endoplasmic reticulum

53. Only about 10 percent of the energy stored in an organism can be passed on to the next trophic level. Of the
   remaining energy, some is used for the organism’s life processes, and the rest is
   a. eliminated as heat.
   b. stored as fat.
   c. used in reproduction.
   d. stored as body tissue.

54. An organism that uses energy to produce its own food supply from inorganic compounds is called a(an)
   a. detritivore.
   b. consumer.
   c. heterotroph.
   d. autotroph.

55. Which of the following is NOT recycled in the biosphere?
   a. energy
   b. carbon
   c. nitrogen
   d. water

56. The major cause of ozone depletion which is allowing increased UV light penetration through the atmosphere is
   a. sulfuric acid.
   b. solar flares.
   c. nitric acid.
   d. chlorofluorocarbons (CFC’s).
57. Demography is the scientific study of
   a. human populations. 
   b. parasitism and disease. 
   c. modernized countries. 
   d. none of the above
58. Safety procedures are important when working
   a. with animals. 
   b. in the field. 
   c. in a laboratory. 
   d. all of the above
59. Where do the light-dependent reactions take place?
   a. in the stroma 
   b. in the ribosome 
   c. in the chlorophyll within the thylakoid membranes 
   d. in the mitochondria

![Figure 8-1]

60. In Figure 8-1, between which parts of the molecule must the bonds be broken to form an ADP molecule and release energy?
   a. A and B 
   b. B and C 
   c. C and D 
   d. all of the above
61. In Rwanda, there are more young children than teenagers, and more teenagers than adults. This age structure indicates a population that
   a. has stopped growing. 
   b. will increase rapidly. 
   c. will decrease over the next 30 years. 
   d. will decrease immediately.
62. The various growth phases through which most populations eventually go are represented on a(n)
   a. normal curve. 
   b. emigration curve. 
   c. exponential growth curve. 
   d. logistic growth curve.
63. During which phase of mitosis do the chromosomes line up along the middle of the dividing cell?
   a. anaphase 
   b. prophase 
   c. telophase 
   d. metaphase
64. The total amount of living tissue within a given trophic level is called the
   a. trophic mass. 
   b. energy mass. 
   c. biomass. 
   d. organic mass.
65. Biology is the study of
   a. the environment. 
   b. the living world. 
   c. animals and plants only. 
   d. the land, water, and air on Earth.
66. Which organelles help provide cells with energy?
   a. mitochondria and chloroplasts 
   b. smooth endoplasmic reticulum 
   c. Golgi apparatus and ribosomes 
   d. rough endoplasmic reticulum
67. How are cellular respiration and photosynthesis almost opposite processes?
   a. Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back. 
   b. Photosynthesis removes oxygen from the atmosphere, and cellular respiration puts it back. 
   c. Photosynthesis releases energy, and cellular respiration stores energy. 
   d. all of the above
68. Which of the following is the correct sequence of events in cellular respiration?
   a. Krebs cycle $\rightarrow$ glycolysis $\rightarrow$ electron transport
   b. Krebs cycle $\rightarrow$ electron transport $\rightarrow$ glycolysis
   c. glycolysis $\rightarrow$ fermentation $\rightarrow$ Krebs cycle
   d. glycolysis $\rightarrow$ Krebs cycle $\rightarrow$ electron transport

69. Which of the following is NOT a function of proteins?
   a. control the rate of reactions and regulate cell processes
   b. build tissues such as bone and muscle
   c. help to fight disease as antibodies
   d. store and transmit heredity

70. During normal mitotic cell division, a parent cell having four chromosomes will produce two daughter cells, each containing
   a. eight chromosomes.
   b. sixteen chromosomes.
   c. two chromosomes.
   d. four chromosomes.

71. Which structure makes proteins using coded instructions that come from the nucleus?
   a. mitochondrion
   b. vacuole
   c. ribosome
   d. Golgi apparatus

72. What is the original source of almost all the energy in most ecosystems?
   a. carbohydrates
   b. water
   c. carbon
   d. sunlight

73. A substance with a pH of 3 is called
   a. neither an acid nor a base.
   b. a base.
   c. an acid.
   d. both an acid and a base.

74. What type of ion forms when an atom gains electrons?
   a. neutral
   b. possibly positive or negative
   c. positive
   d. negative

75. Prokaryotes lack
   a. a nucleus.
   b. a cell membrane.
   c. cytoplasm.
   d. genetic material.

76. Why are fossil fuels nonrenewable?
   a. They are remade in large quantities quickly.
   b. Their ecosystems change forever when they are burned.
   c. They require hundreds of millions of years to form.
   d. They are converted to carbon dioxide when they are burned.

77. Amino acid is to protein as
   a. cellulose is to lipid.
   b. simple sugar is to fat.
   c. simple sugar is to starch.
   d. DNA is to RNA.

78. Which of the following statements is true about catalysts?
   a. Catalysts slow down the rate of chemical reactions.
   b. Catalysts are used up during a chemical reaction.
   c. Catalysts speed up reactions by lowering the activation energy of a chemical reaction.
   d. All catalysts are enzymes.

79. Which of the following is NOT a characteristic of all living things?
   a. response to the environment
   b. ability to walk
   c. ability to reproduce
   d. growth and development

80. As DDT moves up the trophic levels in food chains, or food webs, its concentration
   a. increases.
   b. decreases.
   c. stays the same.
   d. is eliminated.

81. The movement of organisms into a given area from another area is called
   a. population shift.
   b. immigration.
   c. emigration.
   d. carrying capacity.

82. Cellular respiration is called an aerobic process because it requires
   a. oxygen.
   b. exercise.
   c. light.
   d. glucose.
83. Using renewable resources while ensuring that they are not depleted is a practice called  
   a. monoculture.  
   b. subsistence hunting.  
   c. sustainable development.  
   d. biological magnification.  

84. You suggest that cold weather could slow down the growth of bread mold. This is a(an)  
   a. experiment.  
   b. analysis.  
   c. conclusion.  
   d. hypothesis.  

85. Which of the following terms describes a substance formed by the combination of two or more elements in 
   definite proportions?  
   a. compound  
   b. isotope  
   c. nucleus  
   d. enzyme  

86. Cellular respiration releases energy by breaking down  
   a. water.  
   b. ATP.  
   c. carbon dioxide.  
   d. food molecules (sugars).  

87. Plants are  
   a. producers.  
   b. herbivores.  
   c. omnivores.  
   d. consumers.  

88. The starting molecule for glycolysis is  
   a. citric acid.  
   b. glucose.  
   c. ADP.  
   d. pyruvic acid.  

89. The combined portions of Earth in which all living things exist is called the  
   a. community.  
   b. biome.  
   c. biosphere.  
   d. ecosystem.  

90. The average year-after-year conditions of temperature and precipitation in a particular region are referred to as the 
   region’s  
   a. weather.  
   b. climate.  
   c. ecosystem.  
   d. latitude.  

91. Carbon dioxide is released into the atmosphere by all of the following EXCEPT the  
   a. depletion of the ozone layer.  
   b. burning of trees and forests.  
   c. burning of fossil fuels.  
   d. burning of gasoline  

![Figure 3-1](image)

92. The algae at the beginning of the food chain in Figure 3–1 are  
   a. heterotrophs.  
   b. producers.  
   c. consumers.  
   d. decomposers.  

93. Photosynthesis uses sunlight to convert water and carbon dioxide into  
   a. oxygen and high-energy sugars and starches.  
   b. oxygen only.  
   c. high-energy sugars and starches only.  
   d. ADP and oxygen.  

94. The process by which a cell divides into two daughter cells is called  
   a. metaphase.  
   b. cell division.  
   c. S phase.  
   d. interphase.  

95. What is the process by which bacteria convert nitrogen gas in the air to ammonia?  
   a. denitrification  
   b. nitrogen fixation  
   c. excretion  
   d. decomposition
96. Which of the following affects the rate of photosynthesis?
   a. water  
   b. temperature  
   c. light intensity  
   d. all of the above

97. If carbon dioxide is completely removed from a plant’s environment, what would you expect to happen to the plant’s production of high-energy sugars?
   a. More sugars will be produced.
   b. The same number of sugars will be produced but without carbon dioxide.
   c. Carbon dioxide does not affect the production of high-energy sugars in plants.
   d. No sugars will be produced.

98. Most plants appear green because chlorophyll
   a. does not absorb green light.
   b. absorbs green light.
   c. reflects violet light.
   d. none of the above

99. The main function of the cell wall is to
   a. support and protect the cell.
   b. help the cell move.
   c. direct the activities of the cell.
   d. store DNA.

100. What is the term used to describe the energy needed to get a reaction started?
    a. chemical energy
    b. activation energy
    c. adhesion energy
    d. cohesion energy
Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

1. The unequal heating of Earth’s surface
   a. drives wind and ocean currents.
   b. has important effects on Earth’s climate regions.
   c. causes winds that transport heat throughout the biosphere.
   d. all of the above

2. Photosynthesis uses sunlight to convert water and carbon dioxide into
   a. oxygen only.
   b. oxygen and high-energy sugars and starches.
   c. high-energy sugars and starches only.
   d. ADP and oxygen.

3. Biology is the study of
   a. the living world.
   b. the land, water, and air on Earth.
   c. animals and plants only.
   d. the environment

4. The goals of conservation biology include all of the following EXCEPT
   a. protection of biodiversity.
   b. introducing foreign species into new environments.
   c. wise management of natural resources.
   d. preservation of habitats and wildlife.

5. Which of the following terms describes a substance formed by the combination of two or more elements in definite proportions?
   a. isotope
   b. enzyme
   c. compound
   d. nucleus

6. Which will reduce competition within a species’ population?
   a. higher population density
   b. fewer individuals
   c. fewer resources
   d. higher birthrate

7. An interaction in which one organism captures and feeds on another organism is called
   a. mutualism
   b. symbiosis
   c. predation
   d. competition

8. An increase in Earth’s average temperature from the buildup of carbon dioxide and other gases in the atmosphere is called
   a. tropicalization
   b. partculate dispersal
   c. global warming
   d. ozone depletion

9. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. economy
   b. ecology
   c. modeling
   d. recycling

10. What type of ion forms when an atom gains electrons?
    a. neutral
    b. positive
    c. negative
    d. possibly positive or negative

11. Only about 10 percent of the energy stored in an organism can be passed on to the next trophic level. Of the remaining energy, some is used for the organism’s life processes, and the rest is
    a. stored as fat
    b. eliminated as heat
    c. used in reproduction
    d. stored as body tissue

12. Which process is used to produce beer and wine?
    a. the Krebs cycle
    b. glycolysis
    c. alcoholic fermentation
    d. lactic acid fermentation

13. What is a final product of the Calvin cycle during photosynthesis?
    a. ATP
    b. carbon dioxide gas
    c. light
    d. high-energy sugars
14. If a nutrient is in such short supply in an ecosystem that it affects an organism’s growth, the
   a. nutrient leaves the food chain.        c. ecosystem will not survive.
   b. substance is a limiting nutrient.    d. animal becomes a decomposer.
15. The process by which a cell divides into two daughter cells is called
   a. interphase.                         c. metaphase.
   b. cell division.                    d. S phase.
16. Safety procedures are important when working
   a. in the field.                      c. with animals.
   b. in a laboratory.                   d. all of the above
17. When a population reaches a size where it is using all the available resources it
   a. declines rapidly.                  c. undergoes ecological succession
   b. reaches carrying capacity.         d. enters a phase of exponential growth.
18. The average year-after-year conditions of temperature and precipitation in a particular region are referred to as the region’s
   a. ecosystem.                         c. weather.
   b. latitude.                          d. climate.
19. What is the process by which bacteria convert nitrogen gas in the air to ammonia?
   a. nitrogen fixation                   c. excretion
   b. decomposition                       d. denitrification
20. What is the original source of almost all the energy in most ecosystems?
   a. sunlight                           c. carbon
   b. carbohydrates                     d. water
21. Which biome is characterized by very low temperatures, little precipitation, and permafrost?
   a. tropical dry forest                c. tundra
   b. temperate forest                   d. desert
22. A theory
   a. is always true.
   b. is an explanation based on observations and experiments that may be revised or replaced.
   c. is the opening statement of an experiment.
   d. is a problem to be solved.
23. A substance with a pH of 3 is called
   a. both an acid and a base.            c. a base.
   b. neither an acid nor a base.        d. an acid.
24. If carbon dioxide is completely removed from a plant’s environment, what would you expect to happen to the plant’s production of high-energy sugars?
   a. No sugars will be produced.
   b. The same number of sugars will be produced but without carbon dioxide.
   c. Carbon dioxide does not affect the production of high-energy sugars in plants.
   d. More sugars will be produced.
25. All of the following are problems that growth causes for cells EXCEPT
   a. DNA overload.                      c. obtaining enough food.
   b. expelling wastes.                  d. excess oxygen.
26. Which of the following makes up a molecule of water?
   a. one atom of hydrogen and two atoms of oxygen
   b. one atom of sodium and one atom of chlorine
   c. two atoms of hydrogen and one atom of oxygen
   d. one atom of hydrogen and one atom of oxygen
27. Carbon cycles through the biosphere in all of the following processes EXCEPT
   a. photosynthesis.                    c. burning of fossil fuels.
   b. transpiration.                    d. decomposition of plants and animals.
28. The major cause of ozone depletion which is allowing increased UV light penetration through the atmosphere is
   a. nitric acid.                       c. chlorofluorocarbons (CFC’s).
   b. sulfuric acid.                    d. the number that live in an area
   c. the deaths per unit area
   d. the births per unit area
30. Which of the following is a density-independent limiting factor?
   a. parasitism
   b. disease
   c. earthquake
   d. emigration

31. Which of the following organisms does NOT require sunlight to live?
   a. trees
   b. photosynthetic bacteria
   c. chemosynthetic bacteria
   d. algae

32. Diffusion is the movement of molecules from
   a. an area of equilibrium to an area of high concentration.
   b. an area of low concentration to an area of high concentration.
   c. an area of high concentration to an area of low concentration.
   d. all of the above

33. The movement of organisms into a given area from another area is called
   a. emigration.
   b. immigration.
   c. population shift.
   d. carrying capacity.

![Figure 3-1](image)

34. The algae at the beginning of the food chain in Figure 3–1 are
   a. decomposers.
   b. heterotrophs.
   c. consumers.
   d. producers.

35. Which has become the most important source of environmental change on Earth?
   a. biomass pyramids
   b. conservation biology
   c. ecological succession
   d. human activity

36. Demographic transition is change from high birthrates and high death rates to
   a. a low birthrate and a high death rate.
   b. exponential growth.
   c. indefinite growth.
   d. a low birthrate and a low death rate.

37. The total amount of living tissue within a given trophic level is called the
   a. trophic mass.
   b. organic mass.
   c. energy mass.
   d. biomass.

38. Which of the following is NOT one of the factors that play a role in population growth rate?
   a. death rate
   b. demography
   c. emigration
   d. immigration

39. Cellular respiration releases energy by breaking down
   a. food molecules (sugars).
   b. water.
   c. ATP.
   d. carbon dioxide.

40. The main function of the cell wall is to
   a. store DNA.
   b. help the cell move.
   c. support and protect the cell.
   d. direct the activities of the cell.

41. In Rwanda, there are more young children than teenagers, and more teenagers than adults. This age structure indicates a population that
   a. will decrease immediately.
   b. will decrease over the next 30 years.
   c. has stopped growing.
   d. will increase rapidly.

42. What is the term for a group of organisms of one type living in the same place?
   a. biosphere
   b. environment
   c. ecosystem
   d. population
43. An endangered species is
   a. a diseased animal.
   b. a group of organisms in danger of extinction.
   c. a dangerous predator.
   d. all organisms at the top of a food chain.

44. Which organelles help provide cells with energy?
   a. smooth endoplasmic reticulum
   b. Golgi apparatus and ribosomes
   c. mitochondria and chloroplasts
   d. rough endoplasmic reticulum

45. Plants are
   a. herbivores.
   b. omnivores.
   c. producers.
   d. consumers.

46. Demography is the scientific study of
   a. modernized countries.
   b. human populations.
   c. parasitism and disease.
   d. none of the above

47. Cancer is a disorder in which some cells have lost the ability to control their
   a. size.
   b. surface area.
   c. growth rate.
   d. spindle fibers.

48. Which of the following is NOT a function of proteins?
   a. control the rate of reactions and regulate cell processes
   b. help to fight disease as antibodies
   c. store and transmit heredity
   d. build tissues such as bone and muscle

49. A controlled experiment allows the scientist to isolate and test
   a. a conclusion.
   b. a single variable.
   c. a mass of information.
   d. multiple variables in the same set up.

50. Organisms that cannot make their own food and must obtain energy from the foods they eat are called
   a. heterotrophs.
   b. thylakoids.
   c. autotrophs.
   d. plants.

51. Using renewable resources while ensuring that they are not depleted is a practice called
   a. sustainable development.
   b. monoculture.
   c. biological magnification.
   d. subsistence hunting.

52. The various growth phases through which most populations eventually go are represented on a(an)
   a. emigration curve.
   b. normal curve.
   c. exponential growth curve.
   d. logistic growth curve.

53. Carbon dioxide is released into the atmosphere by all of the following EXCEPT the
   a. burning of trees and forests.
   b. depletion of the ozone layer.
   c. burning of fossil fuels.
   d. burning of gasoline

54. What is the correct equation for cellular respiration?
   a. $6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + Energy (ATP)$
   b. $6CO_2 + 6H_2O + Energy (ATP) \rightarrow 6O_2 + C_6H_{12}O_6$
   c. $6CO_2 + 6H_2O \rightarrow 6O_2 + C_6H_{12}O_6 + Energy (ATP)$
   d. $6O_2 + C_6H_{12}O_6 + Energy (ATP) \rightarrow 6CO_2 + 6H_2O$

55. The combined portions of Earth in which all living things exist is called the
   a. community.
   b. ecosystem.
   c. biosphere.
   d. biome.

56. Which of the following statements is true about catalysts?
   a. All catalysts are enzymes.
   b. Catalysts speed up reactions by lowering the activation energy of a chemical reaction.
   c. Catalysts are used up during a chemical reaction.
   d. Catalysts slow down the rate of chemical reactions.

57. All the interconnected feeding relationships in an ecosystem make up a food
   a. web.
   b. network.
   c. interaction.
   d. biome.
58. Which of the following affects the rate of photosynthesis?
   a. temperature  c. water
   b. light intensity  d. all of the above
59. Which country has not yet completed the demographic transition?
   a. Japan  c. Great Britain
   b. United States  d. India
60. An organism that uses energy to produce its own food supply from inorganic compounds is called a(an)
   a. detritivore.  c. heterotroph.
   b. autotroph.  d. consumer.
61. How are cellular respiration and photosynthesis almost opposite processes?
   a. Photosynthesis releases energy, and cellular respiration stores energy.
   b. Photosynthesis removes oxygen from the atmosphere, and cellular respiration puts it back.
   c. Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back.
   d. all of the above
62. The sulfur and nitrogen compounds in smog combine with water to form
   a. ammonia.  c. ozone.
   b. chlorofluorocarbons.  d. acid rain.
63. Most plants appear green because chlorophyll
   a. absorbs green light.  c. reflects violet light.
   b. does not absorb green light.  d. none of the above
64. Amino acid is to protein as
   a. cellulose is to lipid.  c. simple sugar is to starch.
   b. simple sugar is to fat.  d. DNA is to RNA.
65. Which organelle would you expect to find in plant cells but not animal cells?
   a. chloroplast  c. ribosome
   b. smooth endoplasmic reticulum  d. mitochondrion
66. The starting molecule for glycolysis is
   a. glucose.  c. citric acid.
   b. pyruvic acid.  d. ADP.
67. A covalent bond is formed as the result of
   a. transferring protons.  c. sharing an electron pair.
   b. transferring electrons.  d. sharing a proton pair.
68. Which of the following organic compounds is the main source of energy for living things?
   a. proteins  c. nucleic acids
   b. ethyl alcohol  d. carbohydrates

![Diagram]

Figure 8–1

69. In Figure 8–1, between which parts of the molecule must the bonds be broken to form an ADP molecule and release energy?
   a. B and C  c. A and B
   b. C and D  d. all of the above
70. The greenhouse effect is
   a. an unnatural phenomenon that causes heat energy to be radiated back into the Earth’s core.
   b. a natural phenomenon caused by gases in the atmosphere that maintains Earth’s temperature range.
   c. the result of an excess of carbon dioxide dissolved in the oceans.
   d. the result of the differences in the angle of the sun’s rays.

71. Where do the light-dependent reactions take place?
   a. in the stroma
   b. in the chlorophyll within the thylakoid membranes
   c. in the mitochondria
   d. in the ribosome

72. What is an organism that feeds only on plants called?
   a. omnivore
   b. detritivore
   c. carnivore
   d. herbivore

73. Which of the following is NOT a characteristic of all living things?
   a. response to the environment
   b. ability to reproduce
   c. ability to walk
   d. growth and development

74. Human population growth has slowed down to about the replacement rate in
   a. Rwanda.
   b. the United States.
   c. India.
   d. many parts of South America.

75. All of the following are threats to biodiversity EXCEPT
   a. biological magnification of toxic compounds.
   b. species preservation.
   c. invasive species.
   d. habitat fragmentation.

76. The process by which organisms keep their internal conditions fairly constant is called
   a. photosynthesis.
   b. homeostasis.
   c. evolution.
   d. reproduction.

77. Which of the following is a function of the nucleus?
   a. stores DNA
   b. controls most of the cell’s processes
   c. contains the information needed to make proteins
   d. all of the above

78. Cellular respiration is called an aerobic process because it requires
   a. light.
   b. glucose.
   c. exercise.
   d. oxygen.

79. A biotic or an abiotic resource in the environment that causes population to stop growing or decrease in size is a
   a. carrying capacity.
   b. limiting factor.
   c. responding nutrient.
   d. growth factor.

80. Which structure makes proteins using coded instructions that come from the nucleus?
   a. ribosome
   b. vacuole
   c. mitochondrion
   d. Golgi apparatus

81. Which of the following is NOT a principle of the cell theory?
   a. Cells are the basic units of life.
   b. All cells are produced by existing cells.
   c. Very few cells reproduce.
   d. All living things are made of cells.
82. The structures labeled B in Figure 10–2 are called
   a. centrioles.
   b. centromeres.
   c. sister chromatids.
   d. spindles.

83. Biodiversity is important to human society because it
   a. is a natural resource.
   b. provides food and goods.
   c. provides medicines.
   d. all of the above

84. During which phase of mitosis do the chromosomes line up along the middle of the dividing cell?
   a. prophase
   b. anaphase
   c. telophase
   d. metaphase

85. A student is collecting the gas bubbles given off from an aquatic plant in bright sunlight at a temperature of 27°C. The gas being collected is probably
   a. ATP.
   b. carbon dioxide.
   c. vaporized water.
   d. oxygen.

86. There are 150 Saguaro cactus plants per square kilometer in a certain area of Arizona desert. To which population characteristic does this information refer?
   a. population density
   b. growth rate
   c. age structure
   d. geographic distribution

87. You suggest that cold weather could slow down the growth of bread mold. This is a(an)
   a. hypothesis.
   b. experiment.
   c. analysis.
   d. conclusion.

88. Aquatic ecosystems are determined primarily by abiotic factors including all of the following EXCEPT
   a. temperature of the water.
   b. organisms that live there.
   c. chemistry of the water.
   d. depth and flow of the water.

89. Which event occurs during interphase?
   a. Centromeres divide.
   b. Spindle fibers begin to form.
   d. The cell grows.

90. During normal mitotic cell division, a parent cell having four chromosomes will produce two daughter cells, each containing
   a. two chromosomes.
   b. four chromosomes.
   c. sixteen chromosomes.
   d. eight chromosomes.

91. As DDT moves up the trophic levels in food chains, or food webs, its concentration
   a. increases.
   b. stays the same.
   c. decreases.
   d. is eliminated.

92. Why are fossil fuels nonrenewable?
   a. They require hundreds of millions of years to form.
   b. Their ecosystems change forever when they are burned.
   c. They are remade in large quantities quickly.
   d. They are converted to carbon dioxide when they are burned.

93. An organism’s niche is
   a. the range of physical and biological conditions in which an organism lives and the way in which it uses those conditions.
   b. a full description of the place an organism lives.
   c. the range of temperatures that the organism needs to survive.
   d. all the physical and biological factors in the organism’s environment.
94. The human population experienced exponential growth after
   a. improvements in medicine, sanitation, agriculture, energy use, and technology during the Industrial Revolution began.
   b. the bubonic plague began.
   c. plowing and irrigation began.
   d. agriculture began.

95. Which of the following is NOT recycled in the biosphere?
   a. nitrogen
   b. water
   c. carbon
   d. energy

96. What is the term used to describe the energy needed to get a reaction started?
   a. cohesion energy
   b. activation energy
   c. adhesion energy
   d. chemical energy

97. Prokaryotes lack
   a. a cell membrane.
   b. a nucleus.
   c. cytoplasm.
   d. genetic material.

98. The wearing away of surface soil by water and wind is known as
   a. soil erosion.
   b. overgrazing.
   c. deforestation.
   d. the green revolution.

99. Which of the following is the correct sequence of events in cellular respiration?
   a. glycolysis → Krebs cycle → electron transport
   b. glycolysis → fermentation → Krebs cycle
   c. Krebs cycle → electron transport → glycolysis
   d. Krebs cycle → glycolysis → electron transport

100. The diffusion of water across a selectively permeable membrane is called
    a. osmotic pressure.
    b. active transport.
    c. facilitated diffusion.
    d. osmosis.
Semester Exam - Biology - Bubble in the Scantron (100 pts)

Do not write on this test!

Multiple Choice

Identify the letter of the choice that best completes the statement or answers the question. Completely erase any answers that you change.

___ 1. Where do the light-dependent reactions take place?
   a. in the chlorophyll in the thylakoid membranes
   b. in the stroma
d. in the ribosome

___ 2. Which of the following is NOT one of the factors that play a role in population growth rate?
   a. immigration
   b. death rate
d. emigration

___ 3. During which phase of mitosis do the chromosomes line up along the middle of the dividing cell?
   a. prophase
d. anaphase
   b. telophase
   c. metaphase

___ 4. Which event occurs during interphase?
   b. Centromeres divide.
d. Spindle fibers begin to form.
   c. The cell grows.

___ 5. Which of the following is NOT a function of proteins?
   a. store and transmit heredity
d. help to fight disease
   b. build tissues such as bone and muscle
   c. control the rate of chemical reactions and regulate cell processes

___ 6. A gummy bear in water overnight swells in size because
   a. solutes moved out of the gummy bear
d. water moved out of the gummy bear
   b. water moved into the gummy bear
   c. solutes moved into the gummy bear

___ 7. Which of the following is NOT recycled in the biosphere?
   a. carbon
d. energy
   b. nitrogen
   c. water

___ 8. An increase in Earth’s average temperature from the buildup of carbon dioxide and other gases in the atmosphere is called
   a. ozone depletion.
d. the greenhouse effect.
b. global warming.
   c. particulate dispersal.

___ 9. The chemistry of aquatic ecosystems is determined by the
   a. amount of salts, nutrients, and oxygen dissolved in the water.
   b. amount of rainfall the water receives.
d. biotic and abiotic factors in the water.
   c. the number of other organisms present in the water.
10. The algae at the beginning of the food chain in Figure 3–1 are
   a. heterotrophs.
   b. consumers.
   c. decomposers.
   d. producers.

11. Which of the following statements is true about catalysts?
   a. Catalysts are used up during a chemical reaction.
   b. Catalysts slow down the rate of chemical reactions.
   c. Catalysts lower the activation energy of a chemical reaction.
   d. All catalysts are enzymes.

12. Which two biomes have the least amount of precipitation?
   a. tropical rain forest and temperate grassland
   b. tropical savanna and tropical dry forest
   c. tundra and desert
   d. boreal forest and temperate woodland and shrubland

13. A controlled experiment allows the scientist to isolate and test
   a. a single variable.
   b. a conclusion.
   c. a mass of information.
   d. several variables.

14. The various growth phases through which most populations go are represented on a(an)
   a. population curve.
   b. logistic growth curve.
   c. exponential growth curve.
   d. normal curve.

15. What are the products of the Calvin cycle?
   a. high-energy sugars
   b. oxygen gas
   c. ATP
   d. light

16. During normal mitosis, a parent cell having 46 chromosomes will produce two daughter cells, each
   containing
   a. 23 chromosomes.
   b. 46 chromosomes.
   c. 79 chromosomes.
   d. 92 chromosomes.

17. The main function of the cell wall is to
   a. support and protect the cell.
   b. help the cell move.
   c. store DNA.
   d. direct the activities of the cell.

18. Cellular respiration releases energy by breaking down
   a. water.
   b. carbon dioxide.
   c. ATP.
   d. food molecules.

19. The total amount of living tissue within a given trophic level is called the
   a. trophic mass.
   b. organic mass.
   c. energy mass.
   d. biomass.
20. What is the term used to describe the energy needed to get a reaction started?
   a. activation energy  b. cohesion energy  c. adhesion energy  d. chemical energy

21. Demography is the scientific study of
   a. modernized countries.  c. parasitism and disease.
   b. human populations.  d. none of the above

22. Which type of transport requires energy from the cell?
   a. active transport  c. osmosis
   b. diffusion  d. facilitated diffusion

23. What is the correct equation for cellular respiration?
   a. \(6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow 6\text{O}_2 + 6\text{CH}_2\text{O}_6 + \text{Energy (ATP)}\)
   b. \(6\text{O}_2 + 6\text{CH}_2\text{O}_6 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy (ATP)}\)
   c. \(6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy (ATP)} \rightarrow 6\text{O}_2 + 6\text{CH}_2\text{O}_6\)
   d. \(6\text{O}_2 + 6\text{CH}_2\text{O}_6 + \text{Energy (ATP)} \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}\)

24. An interaction in which one organism captures and feeds on another organism is called
   a. predation.  c. symbiosis.
   b. competition.  d. mutualism.

25. What is the original source of almost all the energy in most ecosystems?
   a. carbon  c. sunlight
   b. carbohydrates  d. water

26. Which will reduce competition within a species' population?
   a. higher population density  c. fewer individuals
   b. higher birthrate  d. fewer resources

27. Which of the following is a density-independent limiting factor?
   a. disease  c. emigration
   b. parasitism  d. earthquake

28. Which of the following organic compounds is the main source of energy for living things?
   a. nucleic acids  b. lipids  c. proteins  d. carbohydrates

29. The movement of organisms into a given area from another area is called
   a. immigration.  b. emigration.  c. population shift.
   d. carrying capacity.

30. Plants are
   a. herbivores.  b. omnivores.  c. producers.
   d. consumers.

31. Prokaryotes do not have
   a. a cell membrane.  b. genetic material.  c. a nucleus  d. cytoplasm.

32. Which has become the most important source of environmental change on Earth?
   a. energy  b. climate  c. conservation biology  d. human activity

33. The process by which a cell divides into two daughter cells is called
   a. cytokinesis.  b. anaphase.  c. interphase.  d. metaphase.
34. The structure labeled B in Figure 10-2 are called
   a. centrioles.  b. sister c. spindles. d. centromeres.
   chromatids.

35. The structure labeled A in Figure 10-2 is called the
   a. sister chromatid. b. centriole. c. spindle. d. centromere.

36. The Calvin cycle is another name for
   a. photosynthesis. b. light-dependent reactions.
   c. light-independent reactions. d. all of these

37. An organism’s niche is
   a. the range of temperatures that the organism needs to survive.
   b. all the physical and biological factors in the organism’s environment.
   c. the range of physical and biological conditions in which an organism lives and the
      way in which it uses those conditions.
   d. a full description of the place an organism lives.

38. What type of ion forms when an atom loses electrons?
   a. a neutral ion b. possibly a positive or a negative ion
   c. a negative ion d. a positive ion

39. If a nutrient is in such short supply in an ecosystem that it affects an animal’s growth, the
   a. animal becomes a decomposer. b. ecosystem will not survive.
   c. nutrient leaves the food chain. d. substance is a limiting nutrient.

40. The greenhouse effect is
   a. the result of an excess of carbon dioxide in the atmosphere.
   b. an unnatural phenomenon that causes heat energy to be radiated back into the
      atmosphere.
   c. a natural phenomenon that maintains Earth’s temperature range.
   d. the result of the differences in the angle of the sun’s rays.

41. The human population experienced exponential growth after
   a. the bubonic plague began. b. agriculture began.
   c. the Industrial Revolution began. d. plowing and irrigation began.

42. Which of the following terms describes a substance formed by the combination of two or more
    elements in definite proportions?
   a. compound b. nucleus c. enzyme d. isotope

43. Which organelle would you expect to find only in plant cells?
   a. smooth endoplasmic reticulum c. chloroplast
   b. mitochondrion d. ribosome
44. The wearing away of surface soil by water and wind is known as
a. soil erosion. b. deforestation. c. overgrazing. d. desertification.

45. An organism that uses energy to produce its own food supply from inorganic compounds is
    called a(an)
    a. consumer. b. heterotroph. c. detritivore. d. autotroph.

46. Which of the following undergo cellular respiration?
    a. mushrooms  b. dogs  c. pine trees  d. all of the above

47. A biotic or an abiotic resource in the environment that causes population size to decrease is a
    a. limiting nutrient. b. limiting factor. c. carrying capacity. d. growth factor.

48. Several species of warblers can live in the same spruce tree ONLY because they
    a. have different habitats within the tree. b. occupy different niches within the tree. c. eat different foods within the tree. d. can find different temperatures within the tree.

49. Organisms keep their internal conditions relatively stable through
    a. evolution. b. homeostasis. c. metabolism. d. photosynthesis.

50. Demographic transition is change from high birthrates and high death rates to
    a. exponential growth. b. indefinite growth. c. a low birthrate and a high death rate. d. a low birthrate and a low death rate.

51. The combined portions of Earth in which all living things exist is called the
    a. biosphere.  b. biome.  c. community.  d. ecosystem.

52. What is the term for each step in the transfer of energy and matter within a food web?
    a. food pyramid  b. energy path  c. trophic level  d. food chain

53. A covalent bond is formed as the result of
    a. transferring electrons. b. transferring protons. c. sharing an electron pair. d. sharing a proton pair.

54. Photosynthesis uses sunlight to convert water and carbon dioxide into
    a. oxygen and high-energy sugars. b. ATP and oxygen. c. oxygen. d. high-energy sugars.

55. What does the range of a population tell you that density does not?
    a. the areas inhabited by a population  b. the births per unit area  c. the deaths per unit area  d. the number that live in an area

56. Which biome is characterized by very low temperatures, little precipitation, and permafrost?
    a. tundra  b. desert  c. tropical dry forest  d. temperate forest

57. Diffusion is the movement of molecules from
    a. an area of equilibrium to an area of high concentration.
    b. an area of low concentration to an area of high concentration.
    c. an area of high concentration to an area of low concentration.
    d. all of the above
58. What is the process by which bacteria convert nitrogen gas in the air to ammonia?
   a. nitrogen fixation  
   b. decomposition  
   c. denitrification  
   d. excretion  

59. The process by which a cell divides into two daughter cells is called
   a. mitosis.  
   b. interphase.  
   c. metaphase.  
   d. cell division.  

60. Which of the following is a function of the nucleus?
   a. contains the information needed to make proteins  
   b. stores DNA  
   c. controls most of the cell's processes  
   d. all of the above  

61. An endangered species is
   a. a group of organisms in danger of extinction.  
   b. a diseased animal.  
   c. a dangerous predator.  
   d. all organisms at the top of a food chain.  

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62. In Figure 8-1, between which parts of the ATP molecule must the bonds be broken to form an ADP molecule?
   a. A and B  
   b. B and C  
   c. C and D  
   d. all of these  

63. Biodiversity is important to human society because it
   a. provides medicines.  
   b. provides food and goods.  
   c. is a natural resource.  
   d. all of the above  

64. The sulfur and nitrogen compounds in smog combine with water to form
   a. acid rain.  
   b. ozone.  
   c. ammonia.  
   d. chlorofluorocarbons.  

65. The diffusion of water across a selectively permeable membrane is called
   a. osmotic pressure  
   b. facilitated diffusion  
   c. active transport  
   d. osmosis.
66. How are cellular respiration and photosynthesis almost opposite processes?
   a. Photosynthesis removes oxygen from the atmosphere and cellular respiration puts it back.
   b. Photosynthesis releases energy and cellular respiration stores energy.
   c. Photosynthesis removes carbon dioxide from the atmosphere and cellular respiration puts it back.
   d. all of the above

67. Which organelles help provide cells with energy?
   a. rough endoplasmic reticulum  
   b. Golgi apparatus and ribosomes  
   c. mitochondria and chloroplasts  
   d. smooth endoplasmic reticulum

68. Which country has not yet completed the demographic transition?
   a. Great Britain  
   b. United States  
   c. Japan  
   d. India

69. Which organelle makes proteins using coded instructions that come from the nucleus?
   a. vacuole  
   b. Golgi apparatus  
   c. mitochondrion  
   d. ribosome

70. Human population growth has slowed down in
   a. China  
   b. India  
   c. Africa  
   d. the United States

71. Aquatic ecosystems are classified by all of the following EXCEPT
   a. temperature of the water  
   b. depth and flow of the water  
   c. chemistry of the water  
   d. organisms that live there

72. Which of the following makes up a molecule of water?
   a. one atom of hydrogen and one atom of oxygen  
   b. two atoms of hydrogen and one atom of oxygen  
   c. one atom of sodium and one atom of chlorine  
   d. one atom of hydrogen and two atoms of oxygen

73. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. ecology  
   b. economy  
   c. recycling  
   d. modeling

74. Using renewable resources while ensuring that they are not depleted is a practice called
   a. sustainable development  
   b. biological magnification  
   c. monoculture  
   d. subsistence hunting

75. When organisms move out of the population, this is known as
   a. immigration  
   b. abandonment  
   c. succession  
   d. emigration

76. One cause of muscle soreness is
   a. the Krebs cycle  
   b. glycolysis  
   c. lactic acid fermentation  
   d. alcoholic fermentation

77. Cool air over the poles will
   a. sink  
   b. flow parallel to Earth’s surface  
   c. absorb heat from the equator  
   d. rise

78. What is an organism that feeds only on plants called?
   a. carnivore  
   b. herbivore  
   c. detritivore  
   d. omnivore
79. Which process is used to produce beer and wine?
   a. lactic acid fermentation  c. the Krebs cycle
   b. glycolysis                    d. alcoholic fermentation

80. As DDT moves up the trophic levels in food chains, or food webs, its concentration
   a. increases.                     c. decreases.
   b. stays the same.                d. is eliminated.

81. If carbon dioxide is removed from a plant's environment, what would you expect to happen to its
   production of high-energy sugars?
   a. The same number of sugars will be produced but without carbon dioxide.
   b. Fewer sugars will be produced.
   c. More sugars will be produced.
   d. Carbon dioxide does not affect the production of high-energy sugars in plants.

82. A student is collecting the gas given off from a plant in bright sunlight at a temperature of 27°C. The
   gas being collected is probably
   a. vaporized water.  b. carbon dioxide.  c. oxygen.  d. ATP.

83. You write that cold weather could slow down the growth of bread mold. This is a(an)
   a. hypothesis.   b. analysis.  c. experiment.  d. conclusion.

84. The rate at which wastes are produced by a cell depends on the cell’s
   a. ratio of surface area to volume.  c. volume.
   b. surface area.                    d. environment.

85. What are the reactants in the equation for cellular respiration?
   a. oxygen and lactic acid  c. water and glucose
   b. carbon dioxide and water    d. glucose and oxygen

86. Which of the following affects the rate of photosynthesis?
   a. water  b. light intensity  c. temperature  d. all of these

87. Which of the following organisms does NOT require sunlight to live?
   a. trees  b. chemosynthetic bacteria  c. photosynthetic bacteria
   b. algae

88. Organisms that cannot make their own food and must obtain energy from the foods they eat are called
   a. autotrophs.  b. heterotrophs.  c. thylakoids.  d. plants.

89. Most plants appear green because chlorophyll
   a. reflects violet light.  c. does not absorb green light.
   b. absorbs green light.  d. none of these

90. All the interconnected feeding relationships in an ecosystem make up a food
   a. web.  b. interaction.  c. chain.  d. network.

91. Climate conditions in a small area that differ significantly from the climate of the surrounding area
   are called
   a. microclimates.  b. ecosystems.  c. natural features.  d. biomes.

92. Why are fossil fuels nonrenewable?
   a. They are converted to carbon dioxide when they are burned.
   b. They require hundreds of millions of years to form.
   c. Their ecosystems change forever when they are burned.
   d. They exist in a very small supply.
93. The starting molecule for glycolysis is
   a. ADP.    b. glucose.    c. pyruvic acid.    d. citric acid.

94. Biology is the study of
   a. the living world.    c. the land, water, and air on Earth.
   b. the environment.    d. animals and plants only.

95. If a population grows larger than the carrying capacity of the environment, the
   a. death rate may rise.    c. death rate must fall.
   b. birthrate must fall.    d. birthrate may rise.

96. The unequal heating of Earth’s surface
   a. causes winds that transport heat throughout the biosphere.
   b. has important effects on Earth’s climate regions.
   c. drives wind and ocean currents.
   d. all of the above

97. There are 150 Saguaro cactus plants per square kilometer in a certain area of Arizona desert. To
    which population characteristic does this information refer?
    a. geographic distribution    b. population density
    c. growth rate    d. age structure

98. Which of the following is produced during cellular respiration?
    a. ATP (energy)    b. centrioles    c. NADPH    d. oxygen

99. The average year-after-year conditions of temperature and precipitation in a particular region are
    referred to as the region’s
    a. ecosystem.    b. climate.
    c. weather.    d. latitude.

100. All of the following are problems that growth causes for cells EXCEPT
    a. excess oxygen.    c. expelling wastes.
    b. DNA overload.    d. obtaining enough food.
Test Number: __________

ID: A

Semester Exam - Biology - Bubble in the Scantron (100 pts)

Do not write on this test!

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question. Completely erase any answers that you change.

____ 1. You write that cold weather could slow down the growth of bread mold. This is a(an)
   a. conclusion.  b. hypothesis.  c. experiment.  d. analysis.

____ 2. A controlled experiment allows the scientist to isolate and test
   a. a conclusion.  b. a mass of information.  c. several variables.  d. a single variable.

____ 3. Biology is the study of
   a. the land, water, and air on Earth.  b. the living world.  c. animals and plants only.  d. the environment.

____ 4. Organisms keep their internal conditions relatively stable through
   a. photosynthesis.  b. evolution.  c. metabolism.  d. homeostasis.

____ 5. Which of the following terms describes a substance formed by the combination of two or more
   elements in definite proportions?
   a. compound  b. isotope  c. nucleus  d. enzyme

____ 6. Which of the following makes up a molecule of water?
   a. one atom of hydrogen and one atom of oxygen
   b. one atom of sodium and one atom of chlorine
   c. one atom of hydrogen and two atoms of oxygen
   d. two atoms of hydrogen and one atom of oxygen

____ 7. A covalent bond is formed as the result of
   a. transferring electrons.  b. sharing an electron pair.  c. transferring protons.  d. sharing a proton pair.

____ 8. What type of ion forms when an atom loses electrons?
   a. a neutral ion  b. a positive ion  c. a negative ion  d. possibly a positive or a negative ion

____ 9. Which of the following organic compounds is the main source of energy for living things?
   a. proteins  b. lipids  c. nucleic acids  d. carbohydrates

____ 10. Which of the following is NOT a function of proteins?
    a. store and transmit heredity  b. help to fight disease  c. control the rate of chemical reactions and regulate cell processes  d. build tissues such as bone and muscle

____ 11. What is the term used to describe the energy needed to get a reaction started?
    a. adhesion energy  b. activation energy  c. cohesion energy  d. chemical energy

____ 12. Which of the following statements is true about catalysts?
    a. Catalysts slow down the rate of chemical reactions.
    b. All catalysts are enzymes.
    c. Catalysts are used up during a chemical reaction.
    d. Catalysts lower the activation energy of a chemical reaction.
13. Prokaryotes do not have
   a. cytoplasm. b. a cell membrane. c. genetic material. d. a nucleus

14. The main function of the cell wall is to
   a. support and protect the cell. b. store DNA. c. direct the activities of the cell. d. help the cell move.

15. Which of the following is a function of the nucleus?
   a. stores DNA b. contains the information needed to make proteins
c. controls most of the cell’s processes d. all of the above

16. Which organelle makes proteins using coded instructions that come from the nucleus?
   a. Golgi apparatus b. mitochondrion c. ribosome d. vacuole

17. Which organelles help provide cells with energy?
   a. mitochondria and chloroplasts b. smooth endoplasmic reticulum
c. rough endoplasmic reticulum d. Golgi apparatus and ribosomes

18. Which organelle would you expect to find only in plant cells?
   a. mitochondrion b. ribosome c. chloroplast
d. smooth endoplasmic reticulum

19. Diffusion is the movement of molecules from
   a. an area of low concentration to an area of high concentration.
b. an area of high concentration to an area of low concentration.
c. an area of equilibrium to an area of high concentration.
d. all of the above

20. Which type of transport requires energy from the cell?
   a. diffusion b. osmosis c. facilitated diffusion
d. active transport

21. The diffusion of water across a selectively permeable membrane is called
   a. osmotic pressure b. osmosis c. facilitated diffusion
d. active transport

22. A gummy bear in water overnight swells in size because
   a. water moved into the gummy bear b. water moved out of the gummy bear
c. solutes moved into the gummy bear d. solutes moved out of the gummy bear

23. Organisms that cannot make their own food and must obtain energy from the foods they eat are called
   a. autotrophs. b. heterotrophs. c. thylakoids. d. plants.
24. In Figure 8-1, between which parts of the ATP molecule must the bonds be broken to form an ADP molecule?
   a. A and B  b. B and C  c. C and D  d. all of these

25. A student is collecting the gas given off from a plant in bright sunlight at a temperature of 27°C. The gas being collected is probably
   a. carbon dioxide.  b. oxygen.  c. ATP  d. vaporized water.

26. Photosynthesis uses sunlight to convert water and carbon dioxide into
   a. oxygen.  b. oxygen and high-energy sugars.  c. ATP and oxygen.  d. high-energy sugars.

27. Most plants appear green because chlorophyll
   a. does not absorb green light.  b. absorbs green light.  c. reflects violet light.  d. none of these

28. Where do the light-dependent reactions take place?
   a. in the stroma  b. outside the chloroplasts  c. in the chlorophyll in the thylakoid membranes  d. in the ribosome

29. The Calvin cycle is another name for
   a. light-independent reactions.  b. light-dependent reactions.  c. photosynthesis.  d. all of these

30. What are the products of the Calvin cycle?
   a. oxygen gas  b. ATP  c. light  d. high-energy sugars

31. If carbon dioxide is removed from a plant's environment, what would you expect to happen to its production of high-energy sugars?
   a. Fewer sugars will be produced.  b. More sugars will be produced.  c. The same number of sugars will be produced but without carbon dioxide.  d. Carbon dioxide does not affect the production of high-energy sugars in plants.

32. Which of the following affects the rate of photosynthesis?
   a. water  b. temperature  c. light intensity  d. all of these
33. Which of the following is produced during cellular respiration?
   a. oxygen  
   b. centrioles  
   c. ATP (energy)  
   d. NADPH

34. What is the correct equation for cellular respiration?
   a. \( 6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{Energy (ATP)} \)
   b. \( 6O_2 + C_6H_{12}O_6 + \text{Energy (ATP)} \rightarrow 6CO_2 + 6H_2O \)
   c. \( 6CO_2 + 6H_2O \rightarrow 6O_2 + C_6H_{12}O_6 + \text{Energy (ATP)} \)
   d. \( 6CO_2 + 6H_2O + \text{Energy (ATP)} \rightarrow 6O_2 + C_6H_{12}O_6 \)

35. Cellular respiration releases energy by breaking down:
   a. water.  
   b. ATP.  
   c. carbon dioxide.  
   d. food molecules.

36. The starting molecule for glycolysis is
   a. glucose.  
   b. pyruvic acid.  
   c. citric acid.  
   d. ADP.

37. One cause of muscle soreness is
   a. alcoholic fermentation.  
   b. glycolysis.  
   c. lactic acid fermentation.  
   d. the Krebs cycle.

38. Which process is used to produce beer and wine?
   a. alcoholic fermentation  
   b. glycolysis  
   c. lactic acid fermentation  
   d. the Krebs cycle

39. How are cellular respiration and photosynthesis almost opposite processes?
   a. Photosynthesis releases energy and cellular respiration stores energy.  
   b. Photosynthesis removes carbon dioxide from the atmosphere and cellular respiration puts it back.  
   c. Photosynthesis removes oxygen from the atmosphere and cellular respiration puts it back.  
   d. all of the above

40. Which of the following undergo cellular respiration?
   a. mushrooms  
   b. dogs  
   c. pine trees  
   d. all of the above

41. The process by which a cell divides into two daughter cells is called
   a. cytokinesis.  
   b. metaphase.  
   c. interphase.  
   d. anaphase.

42. Which event occurs during interphase?
   a. The cell grows.  
   c. Spindle fibers begin to form.  
   d. Centromeres divide.

43. The structure labeled A in Figure 10-2 is called the
   a. centriole.  
   b. centromere.  
   c. sister chromatid.  
   d. spindle.
44. The structure labeled B in Figure 10-2 are called
   a. centromeres.  b. centrioles.  c. spindles.  d. sister chromatids.

45. During which phase of mitosis do the chromosomes line up along the middle of the dividing cell?
   a. prophase  b. telophase  c. metaphase  d. anaphase

46. During normal mitosis, a parent cell having 46 chromosomes will produce two daughter cells, each containing
   a. 23 chromosomes.  c. 79 chromosomes.
   b. 46 chromosomes.  d. 92 chromosomes.

47. The rate at which wastes are produced by a cell depends on the cell’s
   a. ratio of surface area to volume.  c. volume.
   b. environment.  d. surface area.

48. All of the following are problems that growth causes for cells EXCEPT
   a. DNA overload.  c. obtaining enough food.
   b. excess oxygen.  d. expelling wastes.

49. The process by which a cell divides into two daughter cells is called
   a. cell division.  c. interphase.
   b. metaphase.  d. mitosis.

50. What are the reactants in the equation for cellular respiration?
   a. oxygen and lactic acid  c. glucose and oxygen
   b. carbon dioxide and water  d. water and glucose

51. The branch of biology dealing with interactions among organisms and between organisms and their environment is called
   a. economy.  c. recycling.
   b. modeling.  d. ecology.

52. The combined portions of Earth in which all living things exist is called the
   a. biome.  c. ecosystem.
   b. community.  d. biosphere.

53. Plants are
   a. producers.  c. herbivores.
   b. consumers.  d. omnivores.

54. What is the original source of almost all the energy in most ecosystems?
   a. carbohydrates  c. water
   b. sunlight  d. carbon
55. The algae at the beginning of the food chain in Figure 3–1 are
   a. consumers.
   b. decomposers.
   c. producers.
   d. heterotrophs.

56. An organism that uses energy to produce its own food supply from inorganic compounds is called a(an)
   a. heterotroph.
   b. consumer.
   c. detritivore.
   d. autotroph.

57. Which of the following organisms does NOT require sunlight to live?
   a. chemosynthetic bacteria
   b. algae
   c. trees
   d. photosynthetic bacteria

58. What is an organism that feeds only on plants called?
   a. carnivore
   b. herbivore
   c. omnivore
   d. detritivore

59. All the interconnected feeding relationships in an ecosystem make up a food
   a. interaction.
   b. chain.
   c. network.
   d. web.

60. The total amount of living tissue within a given trophic level is called the
   a. organic mass.
   b. trophic mass.
   c. energy mass.
   d. biomass.

61. What is the term for each step in the transfer of energy and matter within a food web?
   a. energy path
   b. food chain
   c. trophic level
   d. food pyramid

62. Which of the following is NOT recycled in the biosphere?
   a. water
   b. nitrogen
   c. carbon
   d. energy

63. What is the process by which bacteria convert nitrogen gas in the air to ammonia?
   a. nitrogen fixation
   b. excretion
   c. decomposition
   d. denitrification

64. If a nutrient is in such short supply in an ecosystem that it affects an animal’s growth, the
   a. animal becomes a decomposer.
   b. substance is a limiting nutrient.
   c. nutrient leaves the food chain.
   d. ecosystem will not survive.

65. The average year-after-year conditions of temperature and precipitation in a particular region are referred to as the region’s
   a. weather.
   b. latitude.
   c. ecosystem.
   d. climate.
66. The greenhouse effect is
   a. the result of an excess of carbon dioxide in the atmosphere.
   b. a natural phenomenon that maintains Earth’s temperature range.
   c. the result of the differences in the angle of the sun’s rays.
   d. an unnatural phenomenon that causes heat energy to be radiated back into the atmosphere.

67. Cool air over the poles will
   a. rise.  c. absorb heat from the equator.
   b. sink.  d. flow parallel to Earth’s surface.

68. The unequal heating of Earth’s surface
   a. drives wind and ocean currents.
   b. causes winds that transport heat throughout the biosphere.
   c. has important effects on Earth’s climate regions.
   d. all of the above

69. An organism’s niche is
   a. the range of physical and biological conditions in which an organism lives and the way in which it uses those conditions.
   b. all the physical and biological factors in the organism’s environment.
   c. the range of temperatures that the organism needs to survive.
   d. a full description of the place an organism lives.

70. Several species of warblers can live in the same spruce tree ONLY because they
   a. have different habitats within the tree.
   b. eat different foods within the tree.
   c. occupy different niches within the tree.
   d. can find different temperatures within the tree.

71. An interaction in which one organism captures and feeds on another organism is called
   a. competition.  c. mutualism.
   b. symbiosis.  d. predation.

72. Climate conditions in a small area that differ significantly from the climate of the surrounding area are called
   a. natural features.  c. biomes.
   b. microclimates.  d. ecosystems.

73. Which biome is characterized by very low temperatures, little precipitation, and permafrost?
   a. desert  c. tundra.
   b. temperate forest  d. tropical dry forest

74. Which two biomes have the least amount of precipitation?
   a. tropical rain forest and temperate grassland
   b. tropical savanna and tropical dry forest
   c. tundra and desert
   d. boreal forest and temperate woodland and shrubland

75. Aquatic ecosystems are classified by all of the following EXCEPT
   a. depth and flow of the water.
   b. temperature of the water.
   c. organisms that live there.
   d. chemistry of the water.
76. The chemistry of aquatic ecosystems is determined by the
   a. amount of salts, nutrients, and oxygen dissolved in the water.
   b. the number of other organisms present in the water.
   c. amount of rainfall the water receives.
   d. biotic and abiotic factors in the water.

77. Which of the following is NOT one of the factors that play a role in population growth rate?
   a. immigration
   b. death rate
   c. emigration
   d. demography

78. There are 150 Saguaro cactus plants per square kilometer in a certain area of Arizona desert. To
    which population characteristic does this information refer?
   a. growth rate
   b. geographic distribution
   c. age structure
   d. population density

79. What does the range of a population tell you that density does not?
   a. the number that live in an area
   b. the areas inhabited by a population
   c. the births per unit area
   d. the deaths per unit area

80. The movement of organisms into a given area from another area is called
   a. immigration
   b. emigration
   c. population shift
   d. carrying capacity

81. When organisms move out of the population, this is known as
   a. emigration
   b. abandonment
   c. immigration
   d. succession

82. The various growth phases through which most populations go are represented on a(an)
   a. logistic growth curve
   b. exponential growth curve
   c. normal curve
   d. population curve

83. A biotic or an abiotic resource in the environment that causes population size to decrease is a
   a. carrying capacity
   b. limiting nutrient
   c. limiting factor
   d. growth factor

84. Which will reduce competition within a species’ population?
   a. fewer individuals
   b. higher birthrate
   c. fewer resources
   d. higher population density

85. If a population grows larger than the carrying capacity of the environment, the
   a. death rate may rise
   b. birthrate may rise
   c. death rate must fall
   d. birthrate must fall

86. Which of the following is a density-independent limiting factor?
   a. earthquake
   b. disease
   c. emigration
   d. parasitism

87. Human population growth has slowed down in
   a. China
   b. the United States.
   c. India
   d. Africa

88. Demography is the scientific study of
   a. parasitism and disease
   b. modernized countries
   c. human populations
   d. none of the above

89. Demographic transition is change from high birthrates and high death rates to
   a. exponential growth
   b. a low birthrate and a low death rate
   c. a low birthrate and a high death rate
   d. indefinite growth
90. The human population experienced exponential growth after
   a. agriculture began.
   b. plowing and irrigation began.
   c. the bubonic plague began.
   d. the Industrial Revolution began.

91. Which country has not yet completed the demographic transition?
   a. United States
   b. India
   c. Great Britain
   d. Japan

92. Which has become the most important source of environmental change on Earth?
   a. climate
   b. energy
   c. human activity
   d. conservation biology

93. Why are fossil fuels nonrenewable?
   a. They require hundreds of millions of years to form.
   b. Their ecosystems change forever when they are burned.
   c. They are converted to carbon dioxide when they are burned.
   d. They exist in a very small supply.

94. Using renewable resources while ensuring that they are not depleted is a practice called
   a. sustainable development.
   b. monoculture.
   c. biological magnification.
   d. subsistence hunting.

95. The sulfur and nitrogen compounds in smog combine with water to form
   a. ozone.
   b. ammonia.
   c. acid rain.
   d. chlorofluorocarbons.

96. The wearing away of surface soil by water and wind is known as
   a. deforestation.
   b. desertification.
   c. overgrazing.
   d. soil erosion.

97. Biodiversity is important to human society because it
   a. is a natural resource.
   b. provides food and goods.
   c. provides medicines.
   d. all of the above

98. An endangered species is
   a. a diseased animal.
   b. a dangerous predator.
   c. a group of organisms in danger of extinction.
   d. all organisms at the top of a food chain.

99. As DDT moves up the trophic levels in food chains, or food webs, its concentration
   a. stays the same.
   b. increases.
   c. decreases.
   d. is eliminated.

100. An increase in Earth’s average temperature from the buildup of carbon dioxide and other gases in the
    atmosphere is called
    a. the greenhouse effect.
    b. ozone depletion.
    c. global warming.
    d. particulate dispersal.
Appendix E

Vocabulary Practice Feedback Survey
Vocabulary Practice Feedback

Name: ________________________________  Period: ____  Date: ______________

1. How many minutes did you spend actually working on the vocabulary practice?
   ______ minutes

2. Please respond to the following statement:
   I felt this practice helped me learn the vocabulary.

   1 not true       2 slightly true       3 moderately true       4 mostly true       5 very true

Please respond to this statement as well:

3. This practice motivated me to work on learning the vocabulary.

   1 not true       2 slightly true       3 moderately true       4 mostly true       5 very true
Appendix F

Reduced Instructional Materials Motivation Survey
Name: ________________________________  Period: ____  Date: ______________

Instructional Materials Survey

Instructions

1. There are 12 statements in this questionnaire. Please think about each statement in relation to the instructional materials you studied and indicate how true it is. Give the answer that truly applies to you, and not what you would like to be true, or what you think others want to hear.

2. Think about each statement by itself and indicate how true it is. Do not be influenced by your answers to other statements.

3. Record your responses on this sheet. Thank you.

Use the following values to indicate your response to each item:

<table>
<thead>
<tr>
<th>1 = not true</th>
<th>2 = slightly true</th>
<th>3 = moderately true</th>
<th>4 = mostly true</th>
<th>5 = very true</th>
</tr>
</thead>
</table>

Statements

1. It is clear to me how the content of the material is related to things I already know.

<table>
<thead>
<tr>
<th>1 = not true</th>
<th>2 = slightly true</th>
<th>3 = moderately true</th>
<th>4 = mostly true</th>
<th>5 = very true</th>
</tr>
</thead>
</table>

2. The quality of the writing helped to hold my attention.

<table>
<thead>
<tr>
<th>1 = not true</th>
<th>2 = slightly true</th>
<th>3 = moderately true</th>
<th>4 = mostly true</th>
<th>5 = very true</th>
</tr>
</thead>
</table>

3. As I worked on the material, I was confident that I could learn the content.

<table>
<thead>
<tr>
<th>1 = not true</th>
<th>2 = slightly true</th>
<th>3 = moderately true</th>
<th>4 = mostly true</th>
<th>5 = very true</th>
</tr>
</thead>
</table>

4. I enjoyed working on the material so much that I would like to know more about this topic.

<table>
<thead>
<tr>
<th>1 = not true</th>
<th>2 = slightly true</th>
<th>3 = moderately true</th>
<th>4 = mostly true</th>
<th>5 = very true</th>
</tr>
</thead>
</table>

5. The way the information is arranged helped keep my attention.

<table>
<thead>
<tr>
<th>1 = not true</th>
<th>2 = slightly true</th>
<th>3 = moderately true</th>
<th>4 = mostly true</th>
<th>5 = very true</th>
</tr>
</thead>
</table>
Use the following values to indicate your response to each item:

1 = not true  2 = slightly true  3 = moderately true  4 = mostly true  5 = very true

6. I really enjoyed studying the material.
   not true  2  3  4  5

7. The content and style of writing in the material convey the impression that its content is worth knowing.
   not true  2  3  4  5

8. After working on the material for a while, I was confident that I would be able to pass a test on it.
   not true  2  3  4  5

9. The variety of reading passages, exercises, illustrations, etc., helped keep my attention on the material.
   not true  2  3  4  5

10. The content of the material will be useful to me.
    not true  2  3  4  5

11. The good organization of the content helped me be confident that I would learn this material.
    not true  2  3  4  5

12. It was a pleasure to work on such well-designed material.
    not true  2  3  4  5
Appendix G

Vocabulary Matching Worksheets
Chapter 3 – The Biosphere

Match each word with its definition.

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>____ 1.</td>
<td>Ecology</td>
</tr>
<tr>
<td>_____ 2.</td>
<td>Biosphere</td>
</tr>
<tr>
<td>_____ 3.</td>
<td>Species</td>
</tr>
<tr>
<td>_____ 4.</td>
<td>Food web</td>
</tr>
<tr>
<td>_____ 5.</td>
<td>Biome</td>
</tr>
<tr>
<td>_____ 6.</td>
<td>Heterotroph</td>
</tr>
</tbody>
</table>

a. The combined portions of the planet in which all of life exists, including land, water, and air, or atmosphere.
b. Network of complex interactions formed by the feeding relationships among the various organisms in an ecosystem.
c. Organism that relies on other organisms for its energy and food supply.
d. Group of ecosystems that have the same climate and similar dominant communities.
e. A group of organisms so similar to one another that they can breed and produce fertile offspring.
f. The scientific study of interactions among organisms and between organisms and their environment, or surroundings.
Chapter 3 – The Biosphere

*Match each word with its definition.*

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Ecosystem</td>
<td>Assemblage of different populations that live together in a defined area.</td>
</tr>
<tr>
<td>8. Trophic level</td>
<td>A collection of all the organisms that live in a particular place, together with their nonliving, or physical, environment.</td>
</tr>
<tr>
<td>9. Community</td>
<td>A group of individuals that belong to the same species and live in the same area.</td>
</tr>
<tr>
<td>10. Food chain</td>
<td>Organism that can capture energy from sunlight or chemicals and use that energy to produce food.</td>
</tr>
<tr>
<td>11. Autotroph</td>
<td>A series of steps in which organisms transfer energy by eating and being eaten.</td>
</tr>
</tbody>
</table>
**Chapter 4 – Ecosystems and Communities**

Name: ________________________________  Period: ____  Date: ______________

*Match each word with its definition.*

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Biotic factor</td>
<td>b. A relationship in which one member of the association benefits and the other is neither helped nor harmed.</td>
</tr>
<tr>
<td>3. Mutualism</td>
<td>c. A climate within a small area that differs significantly from the climate around it.</td>
</tr>
<tr>
<td>4. Commensalism</td>
<td>d. An ecosystem in which water either covers the soil or is present at or near the surface of the soil for at least part of the year.</td>
</tr>
<tr>
<td>5. Wetland</td>
<td>e. A relationship in which both species benefit from the relationship.</td>
</tr>
<tr>
<td>6. Microclimate</td>
<td>f. Day-to-day condition of Earth’s atmosphere at a particular time and place.</td>
</tr>
</tbody>
</table>
**Chapter 4 – Ecosystems and Communities**

*Match each word with its definition.*

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Climate</td>
<td>g. The full range of physical and biological condition in which an organism lives and the way in which the organism uses those conditions.</td>
</tr>
<tr>
<td>8. Abiotic factor</td>
<td>h. The average, year-after-year conditions of temperature and precipitation in a particular region.</td>
</tr>
<tr>
<td>9. Niche</td>
<td>i. Organisms that live attached to or near the ocean floor.</td>
</tr>
<tr>
<td>10. Symbiosis</td>
<td>j. A relationship in which one organism lives on or inside another organism and harms it.</td>
</tr>
<tr>
<td>11. Parasitism</td>
<td>k. A relationship in which two species live closely together.</td>
</tr>
<tr>
<td>12. Benthos</td>
<td>l. A physical, or nonliving, factor that shapes an ecosystem.</td>
</tr>
</tbody>
</table>
### Chapter 5 - Populations

Name: ________________________________  Period: ___  Date: _______________

*Match each word with its definition.*

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>_____ 1. Population density</td>
<td>a. The movement of individuals into an area.</td>
</tr>
<tr>
<td>_____ 2. Immigration</td>
<td>b. The largest number of individuals that a given environment can support.</td>
</tr>
<tr>
<td>_____ 3. Emigration</td>
<td>c. The scientific study of human populations.</td>
</tr>
<tr>
<td>_____ 4. Carrying capacity</td>
<td>d. A factor that causes population growth to decrease.</td>
</tr>
<tr>
<td>_____ 5. Limiting factor</td>
<td>e. The movement of individuals out of a population.</td>
</tr>
<tr>
<td>_____ 6. Demography</td>
<td>f. The number of individuals per unit area.</td>
</tr>
</tbody>
</table>
**Chapter 5 - Populations**

*Match each word with its definition.*

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Exponential growth</td>
<td>g. Change in a population from high birth and death rates to low birth and death rates.</td>
</tr>
<tr>
<td>8. Logistic growth</td>
<td>h. Growth pattern in which individuals in a population reproduce at a constant rate.</td>
</tr>
<tr>
<td>9. Demographic transition</td>
<td>i. A limiting factor that affects all populations in similar ways, regardless of population size.</td>
</tr>
<tr>
<td>10. Density-dependent limiting factor</td>
<td>j. Mechanism of population control in which a population is regulated by predation.</td>
</tr>
<tr>
<td>12. Density-independent limiting factor</td>
<td>l. Growth pattern in which a population’s growth slows or stops following a period of exponential growth.</td>
</tr>
</tbody>
</table>
### Chapter 6 – Humans in the Biosphere

Name: ________________________________  Period: ___  Date: ___________

*Match each word with its definition.*

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Renewable resource</td>
<td>a. A mixture of chemicals that occurs as a gray-brown haze in the atmosphere.</td>
</tr>
<tr>
<td>2. Smog</td>
<td>b. When a species disappears from all or part of its range.</td>
</tr>
<tr>
<td>3. Biodiversity</td>
<td>c. Process by which concentrations of a harmful substance increase in organisms at higher trophic levels in a food chain or food web.</td>
</tr>
<tr>
<td>4. Extinction</td>
<td>d. Increase in the average temperature of the biosphere.</td>
</tr>
<tr>
<td>5. Global warming</td>
<td>e. Biological diversity.</td>
</tr>
<tr>
<td>6. Biological magnification</td>
<td>f. A resource that can regenerate and is therefore replaceable.</td>
</tr>
</tbody>
</table>
Chapter 6 – Humans in the Biosphere

*Match each word with its definition.*

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Nonrenewable resource</td>
<td>g. A harmful material that can enter the biosphere through the land, air, or water.</td>
</tr>
<tr>
<td>8. Aquaculture</td>
<td>h. A resource that cannot be replaced by natural processes.</td>
</tr>
<tr>
<td>9. Pollutant</td>
<td>i. Plants and animals that have migrated to places where they are not native.</td>
</tr>
<tr>
<td>10. Genetic diversity</td>
<td>j. A species whose population size is declining in a way that places it in danger of extinction.</td>
</tr>
<tr>
<td>11. Endangered species</td>
<td>k. The sum total of all the different forms of genetic information carried by all organisms living on Earth today.</td>
</tr>
<tr>
<td>12. Invasive species</td>
<td>l. The farming of aquatic organisms.</td>
</tr>
</tbody>
</table>