The Effect of Proximity, Explicitness, and Representation of Basic Science Information on Student Clinical Problem-Solving

Kimberly Ann Smith
University of Texas Health Science Center at Houston

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The Effect of Proximity, Explicitness, and Representation of Basic Science Information on Student Clinical Problem-Solving

A

DISSERTATION

Presented to the Faculty of
The University of Texas
School of Health Information Sciences
at Houston
in Partial Fulfillment
of the Requirements

for the Degree of
Doctor of Philosophy

by

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Dedication

For my husband, Ed Akin, who always believed in me even when I did not believe in myself.
Acknowledgements

First and foremost, my deepest appreciation goes to my committee, who I am quite certain heard more than they ever wanted to know about the life cycles of parasites. They guided my thought processes and helped me blend aspects of human cognition, education, taxonomy, and biology into this research. Dr. Robert Vogler, my committee chair, guided me through the difficult process of writing this dissertation. Dr. Craig Johnson deserves special praise for his unending patience with my equally unending questions regarding statistics. Dr. Todd Johnson taught me how to critically look at information and data representations; without his courses I would never have questioned whether spatial placement of information in textbooks impacted student learning. Dr. Tom Craig of Texas A&M provided the comment that sparked the entire dissertation topic when I asked him, “Dr. Craig, why are nematode life cycles so hard to learn?” His unceasing enthusiasm, support, and willingness to provide access to his students were invaluable. And finally, thanks to Dr. Cynthia Phelps, who started me on this adventure and who steered me through the candidacy process and data collection.

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Kentucky University, who challenged me in both my general and medical parasitology coursework, also deserves mention.

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I must also acknowledge the contributions of my family, including my mother, who still remembers helping me learn the Linnaean taxonomy in junior high school 35 years ago, as well as my obsession with Latin names; my father, who calls me the “walking dictionary”, and my brother and sister who (erroneously) seem to believe I know everything.

But in the end, it is my husband who deserves the greatest thanks. Not only did he encourage me to apply to graduate school, but also he supported me mentally, emotionally, and financially throughout this long process. Ed, thank you.
Abstract

Title: The Effect of Proximity, Explicitness, and Representation of Basic Science Information on Student Clinical Problem-Solving

Problem: Medical and veterinary students memorize facts but then have difficulty applying those facts in clinical problem solving. Cognitive engineering research suggests that the inability of medical and veterinary students to infer concepts from facts may be due in part to specific features of how information is represented and organized in educational materials. First, physical separation of pieces of information may increase the cognitive load on the student. Second, information that is necessary but not explicitly stated may also contribute to the student’s cognitive load. Finally, the types of representations – textual or graphical – may also support or hinder the student’s learning process. This may explain why students have difficulty applying biomedical facts in clinical problem solving.

Purpose: To test the hypothesis that three specific aspects of expository text – the spatial distance between the facts needed to infer a rule, the explicitness of information, and the format of representation – affected the ability of students to solve clinical problems.

Setting: The study was conducted in the parasitology laboratory of a college of veterinary medicine in Texas.

Sample: The study subjects were a convenience sample consisting of 132 second-year veterinary students who matriculated in 2007. The age of this class upon admission ranged from 20-52, and the gender makeup of this class consisted of approximately 75% females and 25% males.

Results: No statistically significant difference in student ability to solve clinical problems was found when relevant facts were placed in proximity, nor when an explicit rule was stated. Further,
no statistically significant difference in student ability to solve clinical problems was found when students were given different representations of material, including tables and concept maps.

Findings: The findings from this study indicate that the three properties investigated – proximity, explicitness, and representation – had no statistically significant effect on student learning as it relates to clinical problem-solving ability. However, ad hoc observations as well as findings from other researchers suggest that the subjects were probably using rote learning techniques such as memorization, and therefore were not attempting to infer relationships from the factual material in the interventions, unless they were specifically prompted to look for patterns. A serendipitous finding unrelated to the study hypothesis was that those subjects who correctly answered questions regarding functional (non-morphologic) properties, such as mode of transmission and intermediate host, at the family taxonomic level were significantly more likely to correctly answer clinical case scenarios than were subjects who did not correctly answer questions regarding functional properties. These findings suggest a strong relationship ($p < .001$) between well-organized knowledge of taxonomic functional properties and clinical problem solving ability.

Recommendations: Further study should be undertaken investigating the relationship between knowledge of functional taxonomic properties and clinical problem solving ability. In addition, the effect of prompting students to look for patterns in instructional material, followed by the effect of factors that affect cognitive load such as proximity, explicitness, and representation, should be explored.
# Table of Contents

**DEDICATION** .......................................................................................................................... II  
**ACKNOWLEDGEMENTS** ........................................................................................................ III  
**ABSTRACT** ............................................................................................................................... V  
**TABLE OF CONTENTS** ........................................................................................................... VII  
**LIST OF FIGURES** ................................................................................................................... XI  
**LIST OF TABLES** ..................................................................................................................... XIII  

**CHAPTER 1 INTRODUCTION** .................................................................................................. 1  
  Conceptual Framework ............................................................................................................. 2  
  Research Questions .................................................................................................................. 4  
    Proximity and Explicitness ...................................................................................................... 4  
    Representation and Proximity ............................................................................................... 4  
    Attitude Toward Taxonomy ................................................................................................... 5  
  Hypotheses ................................................................................................................................ 5  
    Proximity and Explicitness ...................................................................................................... 5  
    Representation and Proximity ............................................................................................... 6  
  Null Hypotheses ..................................................................................................................... 7  
    Proximity and Explicitness ...................................................................................................... 7  
    Representation and Proximity ............................................................................................... 7  
  Definitions of Terms .............................................................................................................. 8  
  Assumptions and Limitations ................................................................................................. 10  
  Summary ................................................................................................................................. 10  

**CHAPTER II REVIEW OF THE LITERATURE** ..................................................................... 11  
  Introduction ............................................................................................................................. 11  
  Textbooks, Experts, Authors, and Learners ......................................................................... 11  
  Learning Theories .................................................................................................................. 17  
    Adult Learning Theory .......................................................................................................... 18  
    Constructivist Learning Theory ........................................................................................... 18  
    Cognitive Load Theory and the Proximity Compatibility Principle ...................................... 19  
  Graphical representation - concept maps ............................................................................. 21  
  The Study Domain and the Importance of Biological Taxonomy ........................................ 23  
    Taxonomy and Biology ......................................................................................................... 23  
    Taxonomy and Veterinary Parasitology .............................................................................. 26
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxonomy and Veterinary Education</td>
<td>27</td>
</tr>
<tr>
<td>Data, Information, Knowledge, and Wisdom</td>
<td>30</td>
</tr>
<tr>
<td>Summary</td>
<td>32</td>
</tr>
<tr>
<td><strong>CHAPTER III METHODOLOGY</strong></td>
<td>33</td>
</tr>
<tr>
<td>Introduction</td>
<td>33</td>
</tr>
<tr>
<td>Subjects</td>
<td>33</td>
</tr>
<tr>
<td>Human Subjects Protection</td>
<td>34</td>
</tr>
<tr>
<td>Setting</td>
<td>34</td>
</tr>
<tr>
<td>Pilot research</td>
<td>34</td>
</tr>
<tr>
<td>Experiment 1: The Effect of Proximity and Explicitness in Textual Representations</td>
<td>36</td>
</tr>
<tr>
<td>Design for Experiment 1</td>
<td>37</td>
</tr>
<tr>
<td>Independent and Dependent Variables</td>
<td>37</td>
</tr>
<tr>
<td>Development of the Intervention Text</td>
<td>38</td>
</tr>
<tr>
<td>Operationalization of the Proximity Independent Variable</td>
<td>40</td>
</tr>
<tr>
<td>Operationalization of the Explicitness Independent Variable</td>
<td>42</td>
</tr>
<tr>
<td>Instruments</td>
<td>43</td>
</tr>
<tr>
<td>Experiment 2: Representation and Proximity</td>
<td>47</td>
</tr>
<tr>
<td>Experimental Design and Variables</td>
<td>48</td>
</tr>
<tr>
<td>Development of the Intervention Text</td>
<td>50</td>
</tr>
<tr>
<td>Development of Intervention Versions</td>
<td>50</td>
</tr>
<tr>
<td>Tables Without and With Detailed Information</td>
<td>51</td>
</tr>
<tr>
<td>Development of Pre- and Posttests</td>
<td>53</td>
</tr>
<tr>
<td>Development of Question Subscales</td>
<td>55</td>
</tr>
<tr>
<td>Attitude Toward Taxonomy Questionnaire</td>
<td>60</td>
</tr>
<tr>
<td>Data Collection Procedure</td>
<td>60</td>
</tr>
<tr>
<td>Data Entry</td>
<td>61</td>
</tr>
<tr>
<td>Data Screening</td>
<td>62</td>
</tr>
<tr>
<td>Data Scoring</td>
<td>62</td>
</tr>
<tr>
<td>Quality Control of Data Scoring</td>
<td>62</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>63</td>
</tr>
<tr>
<td>Summary</td>
<td>64</td>
</tr>
<tr>
<td><strong>CHAPTER IV DATA ANALYSIS AND FINDINGS</strong></td>
<td>65</td>
</tr>
<tr>
<td>Introduction</td>
<td>65</td>
</tr>
<tr>
<td>Experiment 1: Proximity and Explicitness in Textual Representation</td>
<td>65</td>
</tr>
<tr>
<td>Research Questions</td>
<td>65</td>
</tr>
</tbody>
</table>
List of Figures

Figure 1: Conceptual Framework of Factors Affecting Student Ability to Integrate Basic Science in Clinical Problem Solving .......................................................... 3

Figure 2: Analogy for coalescence of discrete knowledge ........................................... 12

Figure 3: Concept map illustrating relationship between taxon (body shape) and presence or absence of an intermediate host ...................................................... 22

Figure 4: Classification of Nematodes Encountered in Dogs and Cats (from Ballweber, 2001, p. 62) .......................................................... 24

Figure 5: Relationship between the disease rabies and the Linnaean taxonomy (drawn by Kimberly Smith from Macdonald, 1995) .................................................. 25

Figure 6: Host-parasite relationships by host common name (white) and parasite genus (gray) .................................................. 28

Figure 7: Host-parasite relationships, by host order and parasite genus. (red=carnivore; green=herbivore; red and green=omnivore) .................................................... 28

Figure 8: Example taxonomy with morphological descriptors (adapted from Olsen, 1986, pp. 43-44) ............................................................ 29

Figure 9: DIKW Hierarchy ........................................................................ 31

Figure 10: Functional DIKW Model (KAS 2009) .................................................................. 31

Figure 11: Knowledge areas required for understanding nematode intermediate host requirements .......................................................... 36

Figure 12: Relationship between intermediate host, taxonomic classification, and body site .................................................. 37

Figure 13: Organism Description Without Proximity of Body Site or Intermediate Host Information .......................................................... 41

Figure 14: Organism Description With Proximity of Body Site and Intermediate Host Information ........................................................................ 41

Figure 15: Version 2 and 4: Partial Entry from Summary, Sorted By Order .................................................. 41

Figure 16: Version 2 and 4: Partial Entry from Summary, Sorted By Intermediate Host .................................................. 41

Figure 17: Organism Description With Proximity of Host Information ........................................................................ 51

Figure 18: Partial Summary Table without Details at Order and Family Levels (Used in Experiment 2, Intervention Version 1) ........................................................................ 51

Figure 19: Partial Summary Table with Details in Proximity to Taxon at Order and Family Levels (Used in Experiment 2, Intervention Versions 2, 3, and 4) ........................................................................ 51

Figure 20: Concept map of class Cestoda (used in Experiment 2, intervention versions 3 and 4) .................................................. 52

Figure 21: Partial concept map of class Cestoda (used in Experiment 2, intervention version 4) .................................................. 53

Figure 22: Example of factual knowledge question for Experiment 2 ........................................................................ 54

Figure 23: Example of clinical problem solving question for Experiment 2 ........................................................................ 54

Figure 24: Data analysis plan ........................................................................ 63
Figure 25: Profile plots of Estimated Marginal Means ................................................................. 68
Figure 26: Profile plot of Estimated Marginal Means................................................................. 79
List of Tables

Table 1: Animals and heart rates, ascending alphabetical order by animal type (from Kahn, 2005, p. 2582) ................................ ................................ ................................ ................................ 13
Table 2: Animals and heart rates, in ascending numerical order by heart rate (from Kahn, 2005, p. 2582) ................................ ................................ ................................ ................................ .... 14
Table 3: Animals and heart rates, in ascending numerical order by heart rate (from Kahn, 2005, p. 2582; mass information derived from Myers, et al., 2006 and Macdonald, 1995) ................. 16
Table 4: Design of Experiment 1 ................................ ................................ ................................ ..37
Table 5: Proximity and Explicitness in Intervention Versions ................................ ........................ 38
Table 6: Comparison of Content for Experiment 1: Original Chapter vs. Control Version ............. 40
Table 7: Experiment 1 Subscale Description ................................ ................................ ................ 44
Table 8: Experiment 1 Pretest ................................ ................................ ................................ ....... 44
Table 9: Design of Experiment 2 ................................ ................................ ................................ ..48
Table 10: Representation Types, by Version ................................ ................................ ................. 48
Table 11: Representation Types, by Intervention ................................ ................................ .......... 49
Table 12: Comparison of content for Experiment 2: Original chapter vs. Intervention version ..... 50
Table 13: Subscale Operationalization for Representation Experiment ................................ ......... 55
Table 14: Experiment 2 Pretest with Subscales and Notes ................................ ............................ 55
Table 15: Coding of Data for Experiment 1-Proximity and Explicitness ................................ ..... 61
Table 16: Coding of Data for Experiment 2-Representation ................................ .......................... 61
Table 17: Descriptive Statistics, GLM Repeated Measures, Pretest Score vs. Posttest Score ........... 66
Table 18: Tests of Within-Subjects Effects ................................ ................................ .................... 67
Table 19: Tests of Between-Subjects Effects .................................................................................. 67
Table 20: Descriptive Statistics, GLM Repeated Measures for Pre- and Posttest Subscales .......... 68
Table 21: Multivariate Statistics, GLM Repeated Measures for Pre- and Post-Test Subscales ...... 71
Table 22: Tests of Between-Subjects Effects, GLM Repeated Measures for Pre- and Post-Test Subscales ............................................................................................................. 72
Table 23: Univariate tests (Measure= Sphericity assumed) ................................ ........................... 73
Table 24: Standardized effect sizes, z-scores, and probabilities .................................................... 75
Table 25: Chi-square results ....................................................................................................... 75
Table 26: Risk Estimate, explicitness x Q1 Post Organ correct ................................ ..................... 76
Table 27: Cross Tabulations, explicitness x Q1 Post Organ correct ................................ .............. 76
Table 28: Tests of Between-Subjects Effects .................................................................................. 78
Table 29: Tests of Within-Subjects Effects .................................................................................. 78
Table 30: Descriptive statistics for tables with vs. without details (version 1 vs. version 2) ........... 81
Table 31: Multivariate tests for V1 versus V2 (tables with vs. without details) .......................... 81
Table 32: Tests of Between-Subjects Effects for V1 versus V2 (tables with vs. without details) ...... 82
Table 33: Descriptive statistics (concept maps vs. concept maps plus partial maps) ................. 84
Table 34: Multivariate tests (concept maps vs. concept maps plus partial maps) ....................... 84
Table 35: Tests of Between-Subjects Effects (concept maps with vs. without partial maps) ........ 85
Table 36: Descriptive statistics for V1+V2 vs. V3+V4 (tables without maps vs. tables with maps) . 87
Table 37: Multivariate tests for V1+V2 vs. V3+V4 (tables vs. tables + maps) ............................... 87
Table 38: Tests of between-subjects effects for V1+V2 versus V3+V4 (tables vs. tables + maps) .. 88
Table 39: Descriptive statistics (maps, partial maps, tables with details vs. tables without details) 90
Table 40: Multivariate Tests (maps, partial maps, tables with details vs. tables without details) ... 90
Table 41: Tests of Between-Subjects Effects (maps, partial maps, tables with details vs. tables w/o
details) ............................................................................................................................................. 91
Table 42: Descriptive statistics: Attitude Toward Taxonomy Questionnaire................................. 94
Chapter 1
Introduction

Research suggests that development of effective clinical problem solving skills depends not only on possessing the requisite knowledge, but that the knowledge also be well-organized in multiple representations (Norman, 2005). However, the sheer volume of material that must be learned limits the time students can spend in learning and developing these mental representations (Lujan & DiCarlo, 2006). Further, Patel showed that medical students do not integrate basic science and clinical material; in fact, they perceive basic science to be a world separate from their clinical knowledge (Patel, Groen, & Scott, 1988; Patel, Groen, & Norman, 1993; Patel, Arocha, & Kaufman, 2001).

In addition to the constraints imposed by time and volume, the inability of medical and veterinary students to effectively integrate and utilize information in clinical problem solving may be due in part to specific aspects of text in educational materials. First, if students must mentally incorporate two or more pieces of information together in order to infer certain heuristics or rules, then physical separation or lack of spatial proximity of pieces of information increases the cognitive load on the student. Second, information that is necessary but not explicitly stated also contributes to the cognitive load on the student’s working memory. Finally, the types of representations – textual or graphical – may also support or hinder the student’s learning process. These factors may contribute to the cognitive load on the student, reducing the likelihood of the student developing appropriate conceptual inferences.

However, little attention has been paid to the most basic form of information delivery in education -- the printed texts used in medical or veterinary school. Therefore, the purpose of this
research was to investigate these three specific aspects of expository text – the spatial distance between the facts needed to infer a rule, the explicitness of information, and the format of representation – on the ability of students to develop knowledge necessary for effective clinical problem solving.

**Conceptual Framework**

The conceptual framework for this research, shown in Figure 1, draws from two main bodies of literature. The first body is the informatics literature, particularly in the areas of cognitive science and psychology, and the second body is the education and learning assessment literature. This framework is applied in the domain of veterinary parasitology.
Figure 1: Conceptual Framework of Factors Affecting Student Ability to Integrate Basic Science in Clinical Problem Solving
Research Questions

This research addressed the following research questions:

Proximity and Explicitness

Q1. Do learning materials with textual representations that place appropriate information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, when compared to learning materials with textual representations that do not place this information in close spatial proximity?

Q2. Do learning materials with textual representations that provide explicit information significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, when compared to learning materials with textual representations that do not provide explicit information?

Representation and Proximity

Q3. Do learning materials with tables that include detailed information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials with tabular representations that do not include detailed information?

Q4. Do learning materials with partial concept maps that place a subset of information in proximity to the appropriate text significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials without partial concept maps?
Q5. Do learning materials with graphical representations (concept maps) that place appropriate information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials that include tabular representations?

Q6. Do learning materials with tables with detailed information, full concept maps, and partial concept maps, significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials that include no concept maps and tables without detailed information?

**Attitude Toward Taxonomy**

Finally, because taxonomy is integral to the particular domain used in this study, the last question to be addressed in this research was:

Q7. What are student attitudes and preconceptions concerning taxonomy?

**Hypotheses**

Students may resort to rote learning because information necessary to develop appropriate conceptual inferences is either not explicitly presented, or is too spatially separated for the student to integrate with existing knowledge. Therefore, the research hypotheses posed in this dissertation were as follows:

**Proximity and Explicitness**

H1. Learning materials that place significant information in proximity will significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, as compared to materials that utilize a typical text representation.
H2. Learning materials that explicitly state relationships between information will significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, as compared to materials that do not explicitly state these relationships.

*Representation and Proximity*

H3. Learning materials with tables that include detailed information in close spatial proximity will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials with tables that do not include elaborations.

H4. When there are tables with detailed information in close spatial proximity, inclusion of both full and partial concept maps will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include only full concept maps.

H5. Learning materials that include graphical representations (concept maps) that place appropriate information in close spatial proximity will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include tabular representations.

H6. Learning materials that include tables with detailed information in close spatial proximity, full concept maps, and partial concept maps will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include no concept maps and tables without detailed information in close spatial proximity.
Null Hypotheses

The corresponding null hypotheses for this research were as follows:

**Proximity and Explicitness**

H₀₁. Learning materials that place significant information in proximity will significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, as compared to materials that utilize a typical text representation.

H₀₂. Learning materials that explicitly state relationships between information will significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, as compared to materials that do not explicitly state these relationships.

**Representation and Proximity**

H₀₃. Learning materials with tables that include detailed information in close spatial proximity will significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials with tables that do not include elaborations.

H₀₄. When there are tables with detailed information in close spatial proximity, inclusion of both full and partial concept maps will significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials that include only full concept maps.

H₀₅. Learning materials that include graphical representations (concept maps) that place appropriate information in close spatial proximity will significantly improve student
learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include tabular representations.

H₀. Learning materials that include tables with detailed information in close spatial proximity, full concept maps, and partial concept maps will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include no concept maps and tables without detailed information in close spatial proximity.

Definitions of Terms

For the purposes of this research, the following terms were defined:

**Basic science:** Basic sciences are defined as biology, chemistry, and physics, and their subdomains such as anatomy, biochemistry, physiology, and taxonomy. All of parasitology was considered to be a biology basic science except for the clinical signs exhibited by the patient, and the methods of treating the patient.

**Clinical problem solving:** Developing an appropriate diagnosis or solution for a health or medical issue.

**Concept map:** Graphical representation composed of concepts linked by phrases to form propositional statements.

**Cognitive load:** The definition used for this research is that of Clark & Lyons, who define cognitive load as “The amount of work imposed on working memory.” (Clark & Lyons, 2004).
Explicitness: For the purposes of this research, whether or not a specific rule was stated in the intervention.

Linnaean taxonomy: A hierarchical classification of organisms, progressing downward from taxons (categories) containing the most loosely related organisms to taxons containing the most closely related organisms. For the purposes of this research, the taxons to be used include (from most general to most specific):

- Kingdom
- Phylum
- Class
- Order
- Superfamily
- Family
- Genus
- Species

Proximity: The physical position of a fact in relation to other facts (spatial proximity). Temporal proximity, or proximity in time, was not considered in this research. Proximity was accomplished in three ways:

1. By placing relevant facts on the same text line, separated only by space
2. Adjacent to other relevant facts in a table
3. Adjacent to other relevant facts in a concept map

Representation: The method used to display information in a textual medium. Examples of representations used are expository text, tables, and graphical concept maps.
**Assumptions and Limitations**

This research assumed that the study subjects possess basic knowledge of the research domain, veterinary parasitology, including the taxonomic structure of that domain. Because this specific domain was used for the research, the research is not generalizable to other domains. Although the research addressed expository text, issues such as text coherence were not considered. The research is also limited by the availability of the student population, as there is only one college of veterinary medicine in the state of Texas. This limitation meant that data collection could occur only once yearly, and it also limited the sample size to the size of the second-year class, resulting in decreased power of the statistical analyses. Finally, temporal proximity of information presentation may have an effect, but was not considered in this research.

**Summary**

This chapter described how well-organized mental representations are necessary for clinical problem solving. The chapter then described the problem of how medical and veterinary students typically fail to integrate basic and clinical knowledge. The basic hypotheses and research questions concerning the effect of spatial proximity, explicitness, and representation on student learning and clinical problem solving were described. This chapter also illustrated the conceptual framework and defined the terms used in the research, and concluded with the assumptions and limitations of the study.
Chapter II
Review of the Literature

Introduction

This chapter presents a review of the literature concerning topics relevant to this study. The chapter begins with a review of data, information, knowledge, and wisdom, which is then followed by a discussion of how novices such as students learn and experts or authors develop and use information. Inferential learning and how information presentation can limit the ability of students to grasp underlying concepts are then discussed. This is followed by learning theories and cognitive issues, including limits of working memory and the impact of spatial separation of material, including the proximity compatibility principle. Next, graphical representations, especially concept maps, are discussed. This is followed by a summary of the importance of the selected research domain, veterinary parasitology, and how a working grasp of taxonomy is essential to meaningful learning in parasitology. Finally, a discussion of Ackoff’s Data-Information-Knowledge-Wisdom model is presented. The chapter then concludes with a summary.

Textbooks, Experts, Authors, and Learners

A textbook used in medical or veterinary education can be considered to be a cognitive artifact, containing external representations of the knowledge schemas of the subject matter expert or experts who authored the text. Students, who by definition are novices, then use this cognitive artifact to learn. Therefore, understanding problems that students might have with inferring concepts from texts requires an understanding of how novices such as students differ from experts, and as well as an understanding of how experts think. In the book “Mind Over Machine”, the philosopher Hubert Dreyfus states
that the transition from novice to expert can be indicated by the progressive loss of the
ability to verbalize how to perform a particular task, as the person moves from a state of
“knowing what” to that of “knowing how” (Dreyfus, Dreyfus, & Athanasiou, 1986).

A representational analogy for this observation can be found in fabrics, as shown in
Figure 2. A novice’s level of expertise can be represented by a large, open-weave fabric,
such as coarse burlap, shown in pane 1 of Figure 2. In this analogy, each rule or discrete
piece of information is represented by the individual threads of the fabric and can be
relatively easily identified, grasped, and extracted. As the novice progresses to an
intermediate level of expertise, the fabric becomes tighter, as in muslin, and the individual
knowledge rules are less apparent but still retrievable, as shown in pane 2 of Figure 2. In
pane 3 of Figure 2, the irregular threads and jumps in the fabric represent heuristics, “rules
of thumb”, and the beginnings of true expertise, yet the individual underlying knowledge
and rules (the fabric threads) are still visible and retrievable. By the time the intermediate
has become an expert, the knowledge has become so ingrained that it has metamorphosed
and coalesced into a chunk. In the final, fourth pane of Figure 2, the fabric representing
this stage is similar to felt, in which the underlying woven substrate essentially no longer
exists and the fabric consists of a nonlinear mesh of apparently random and almost
indecipherable threads.


Figure 2: Analogy for coalescence of discrete knowledge
This chunked or “compiled” knowledge has become tacit knowledge in that it is used at a subconscious level and is often referred to “procedural” knowledge; on the other hand, knowledge available to conscious thought is termed “declarative” knowledge (Musen, 1989). A paradox then exists in that the expert’s ability to verbalize his or her knowledge is inversely proportional to the level of expertise (Garg-Janardan & Salvendy, 1988). This can be problematic when domain experts – who may have little or no training in either information representation or education -- are also authors of texts that are used by novices as textbooks. Books in particular often serve more than one purpose – not only as a textbook to be used by a novice, but also as a reference for use by experts.

Table 1 presents an example of a list of facts or, using Ackoff’s definition, a list of data. The table is an alphabetized list of animal types and their heart rates (Kahn, 2005).

There are no relationships other than simply “Animal X has heart rate Y.”

Table 1: Animals and heart rates, ascending alphabetical order by animal type (from Kahn, 2005, p. 2582)

<table>
<thead>
<tr>
<th>Common name</th>
<th>Heart rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat</td>
<td>120-140</td>
</tr>
<tr>
<td>Dairy cow</td>
<td>48-84</td>
</tr>
<tr>
<td>Dog</td>
<td>70-120</td>
</tr>
<tr>
<td>Elephant</td>
<td>25-40</td>
</tr>
<tr>
<td>Goat</td>
<td>70-80</td>
</tr>
<tr>
<td>Guinea pig</td>
<td>200-300</td>
</tr>
<tr>
<td>Hamster</td>
<td>300-600</td>
</tr>
<tr>
<td>Horse</td>
<td>28-40</td>
</tr>
<tr>
<td>Mouse</td>
<td>450-750</td>
</tr>
<tr>
<td>Pig</td>
<td>70-120</td>
</tr>
<tr>
<td>Rabbit</td>
<td>180-350</td>
</tr>
<tr>
<td>Rat</td>
<td>250-400</td>
</tr>
<tr>
<td>Rhesus monkey</td>
<td>80-300</td>
</tr>
<tr>
<td>Sheep</td>
<td>70-80</td>
</tr>
</tbody>
</table>

This format is perfectly appropriate as a reference for a practicing clinician who simply needs to look up the heart rate for a given species; however, a student is tasked with learning all the heart rates of the various animals. That is, the student must store these data as a mental or internal representation. This can be done by memorization as long as the provided external
version is not too complex (Zhang, 1997). However, by simply sorting the data by heart rate instead of alphabetically by animal (Table 2), it is relatively easy to see that smaller animals have faster heart rates, while larger animals have slower heart rates.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Heart rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elephant</td>
<td>25-40</td>
</tr>
<tr>
<td>Horse</td>
<td>28-40</td>
</tr>
<tr>
<td>Dairy cow</td>
<td>48-84</td>
</tr>
<tr>
<td>Goat</td>
<td>70-80</td>
</tr>
<tr>
<td>Sheep</td>
<td>70-80</td>
</tr>
<tr>
<td>Pig</td>
<td>70-120</td>
</tr>
<tr>
<td>Dog</td>
<td>70-120</td>
</tr>
<tr>
<td>Rhesus monkey</td>
<td>80-300</td>
</tr>
<tr>
<td>Cat</td>
<td>120-140</td>
</tr>
<tr>
<td>Rabbit</td>
<td>180-350</td>
</tr>
<tr>
<td>Guinea pig</td>
<td>200-300</td>
</tr>
<tr>
<td>Rat</td>
<td>250-400</td>
</tr>
<tr>
<td>Hamster</td>
<td>300-600</td>
</tr>
<tr>
<td>Mouse</td>
<td>450-750</td>
</tr>
</tbody>
</table>

In other words, the learner may be able to infer that heart rate is inversely related to body size. This inductive inference, or making a generalization from the data (Tenenbaum, Griffiths, & Kemp, 2006) allows the novice to generate a heuristic or rule of thumb from the information presented. Heuristics are an important tool as they can be helpful “tricks of the trade” that can be used for problem solving (Collins, Brown, & Newman, 1989, p. 478). Rules are more rigid and are defined by Mayer as “an idea unit that expresses a functional relationship among two or more variables, events, and / or components.” (Mayer, 1985, p. 73). Mayer further defines three types of rules: formal quantitative functions, such as Ohm’s law; informal quantitative functions; and informal non-quantitative functions (Mayer, 1985). However, authors of scientific texts may leave rules unstated or omit certain pieces of information, assuming that readers are quite capable of recalling the appropriate rule from prior knowledge or of generating the appropriate inferences. Yet if these texts are used as textbooks, novices lack the background knowledge necessary to bridge any gaps caused by the author’s assumptions, leaving them unable to generate the required inferences (Otero, Leon, & Graesser, 2002).
This example also illustrates the representational effect, which is the “...phenomenon that different isomorphic representations of a common formal structure can cause dramatically different cognitive behaviors.” (Zhang & Norman, 1994). Further, the representational effect can also impact the difficulty of the task being performed (Chuah, Zhang, & Johnson, 2000). In the case of learning, Ainsworth points out that “If a learning environment presents a choice of multiple representations, learners can work with their preferred choice.” (Ainsworth, 1999)

There is yet another issue at work in this example, and that is the role of explicit versus implicit information. While the species and heart rates are explicitly stated in both tables, the typical mass of each species is not given and is therefore implied as a property of the species. A student must be able to perform several tasks in order to generate the correct heuristic regarding the relationship between mass and heart rate.

- First, the learner must recognize that a relationship of some type exists between the species’ mass and its heart rate.

- Second, the learner must recognize each animal; that is, the student must have prior knowledge already stored in long-term memory

- Third, the learner must recall each animal’s approximate mass from long-term memory and place this information in working memory.

- Finally, the learner must then be able to conceptualize the relationship between the implicit (mass) and the explicit (heart rate) information.

If the learner does not have this information already stored in long-term memory, then there is the risk that they will not even realize that any sort of relationship exists between these two sets of information and as a result, they will not develop the heuristic rule that demonstrates conceptual understanding of this relationship. Including the mass of each species in the table, as in
Table 3, makes this data explicit instead of implicit. The mass column also provides a cue that these three columns are related in some way without explicitly stating the relationship between the columns.

Table 3: Animals and heart rates, in ascending numerical order by heart rate (from Kahn, 2005, p. 2582; mass information derived from Myers, et al., 2006 and Macdonald, 1995)

<table>
<thead>
<tr>
<th>Common name</th>
<th>Heart rate (bpm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elephant</td>
<td>25-40</td>
<td>3000-6000</td>
</tr>
<tr>
<td>Horse</td>
<td>28-40</td>
<td>350-700</td>
</tr>
<tr>
<td>Dairy cow</td>
<td>48-84</td>
<td>450-900</td>
</tr>
<tr>
<td>Goat</td>
<td>70-80</td>
<td>9-113</td>
</tr>
<tr>
<td>Sheep</td>
<td>70-80</td>
<td>20-200</td>
</tr>
<tr>
<td>Pig</td>
<td>70-120</td>
<td>50-350</td>
</tr>
<tr>
<td>Dog</td>
<td>70-120</td>
<td>1-70</td>
</tr>
<tr>
<td>Rhesus monkey</td>
<td>80-300</td>
<td>4-12</td>
</tr>
<tr>
<td>Cat</td>
<td>120-140</td>
<td>3-6</td>
</tr>
<tr>
<td>Rabbit</td>
<td>180-350</td>
<td>0.80-1.53</td>
</tr>
<tr>
<td>Guinea pig</td>
<td>200-300</td>
<td>0.26-0.33</td>
</tr>
<tr>
<td>Rat</td>
<td>250-400</td>
<td>0.070-0.300</td>
</tr>
<tr>
<td>Hamster</td>
<td>300-600</td>
<td>0.10-0.125</td>
</tr>
<tr>
<td>Mouse</td>
<td>450-750</td>
<td>0.012-0.030</td>
</tr>
</tbody>
</table>

In short, a textbook that provides only Table 1 and not Table 2 or Table 3 hinders the ability of the learner to infer any conceptual relationship between the presented information. Stated another way by Zhang (1997):

“... for novel and discovery tasks, whose abstract structures are not known, the format of a representation can determine what information can be perceived, what processes can be activated, and what structures can be discovered from the specific representation. This is called representational determinism. Without the change of representational forms, some portion of the task space may never be explored and some structures of the task may never be discovered, due to various constraints such as the complexity of the environment and the limitations of the mind.” (Zhang, 1997).
Another aspect of the relationship between heart rate and mass is “Why is there an inverse relationship between mass and heart rate?” Deriving this answer takes effort and thought on the part of the learner, because this requires understanding of the metabolism of endothermic animals, heat loss, and of Surface Law (Blumberg, 2002a). In short, the learner must be able to form new knowledge, using Ackoff’s definition, from existing knowledge.

Note that this example used a very small set of data consisting of 14 animals and their heart rates; in other words, the problem space was small. Sharps observed that for a heuristic to be successful, the essential features of the problem space had to be understood (Sharps, Hess, Price-Sharps, & Teh, 2008). Now consider a larger set of data that a veterinary student must learn – such as all the parasites of domestic animals of a particular geographic region. The problem space has now grown exponentially, with the number of possible combinations of animals and parasites rapidly exceeding the capacity of human working memory. It is clear that when this level of complexity is encountered, techniques such as memorization and simple heuristics no longer suffice; true understanding of the material is required. Such understanding –“meaningful learning” -- requires the student to construct relationships between material that will allow them to gain new insights and use the material more effectively in problem solving (Mayer, 2002). Meaningful learning as well as specific learning theories are discussed in more detail in the following section.

**Learning Theories**

A variety of theories have been developed in an effort to explain how students learn. This section will discuss the literature regarding learning theories directly related to this dissertation, including adult learning theory, constructivist learning theory, and
cognitive load theory. Even the very definition of learning itself has been debated, and split into types – “meaningful” versus “rote”. Rote learning is generally considered to be memorization, while meaningful learning is defined by Ausubel as "…the nonarbitrary, nonverbatim, substantive incorporation of new ideas into a learner's framework of knowledge (or cognitive structure)." (Mintzes & Wandersee, 1998, p. 39).

**Adult Learning Theory**

Medical and veterinary students are considered adult learners. According to adult learning theory (*andragogy*), “Adults need to know why they need to learn something before undertaking to learn it.” (Knowles, Holton III, & Swanson, 2005, p. 64-65). Stated another way, adults are more willing to invest effort in learning material that is directly relevant to them (MacKeracher, 2004). This is in contrast to the traditional *pedagogical* model, in which the student is a passive recipient of information that is completely controlled by the teacher. If we consider that medical and veterinary students are also adults, then the apparent separation of the taxonomy from clinical relevance may cause students to assume that the taxonomy has no clinical significance and is therefore irrelevant to their learning.

**Constructivist Learning Theory**

One accepted theory of learning is the constructivist learning theory, which has as its basic premise “individuals construct meanings by forming connections between new concepts and those that are part of an existing framework of prior knowledge.” (Mintzes & Wandersee, 1998, p. 47). In other words, learners must fit what they are currently learning into what they already know in order to be able to use this knowledge effectively. The process of fitting this new knowledge into existing knowledge requires reflection and effort on the part of the learner. However, in some circumstances, such as with learners who are anxious or who do not possess the requisite
foundation knowledge, rote learning such as memorization may actually be less difficult than meaningful learning (Ausubel, 1963). With regard to medical education, Regan-Smith found that first- and second-year medical students typically attempt to memorize information instead of trying to understand the information. She also found that memorization without attempting to understand is “likely to produce physicians who are 1) disinterested in science and do/can not ask why, and 2) unable to respond to unique clinical presentations by modifying their practice.” (Regan-Smith, 1992). One can infer that, due to the similarity of the student body and the science-based curriculum, a similar situation exists for veterinary students.

**Cognitive Load Theory and the Proximity Compatibility Principle**

The cognitive load theory considers the limitations of a learner’s working memory, the capabilities of long-term memory, and how information should be structured in order to accommodate both those limitations and capabilities. Specifically, cognitive load theory states:

- (a) Schema acquisition and automation are major learning mechanisms when dealing with higher cognitive activities and are designed to circumvent our limited working memories and emphasize our highly effective long-term memories.
- (b) A limited working memory makes it difficult to assimilate multiple elements of information simultaneously.
- (c) Under conditions where multiple elements of information interact, they must be assimilated simultaneously.
- (d) As a consequence, a heavy cognitive load is imposed when dealing with material that has a high level of element interactivity.
- (e) High levels of element interactivity and their associated cognitive loads may be caused both by intrinsic nature of the material being learned and by the method of presentation.
- (f) If the intrinsic element interactivity and consequent cognitive load are low, the extraneous cognitive load is critical when dealing with intrinsically high element interactivity materials. (Sweller & Chandler, 1994).

Current research in cognitive load theory suggests that novel information must be assimilated into “mental schemas” for efficient utilization (van Merriënboer & Paul, 2005). A schema is “…anything that has been learnt and is treated as a single entity. If learning has
occurred over a long period of time, a schema may incorporate a huge amount of information.” (Kirschner, 2002). This is in agreement with, and could be considered a more detailed specification of, the constructivist school of thought regarding learning of fitting new learning into existing knowledge.

The manner in which information is presented also affects the learner’s cognitive load. Since presentation of information is under the control of its author, this is an extrinsic factor, in contrast to the intrinsic nature of the material itself. Consider a text that uses an encyclopedic approach, discussing each of the species shown in Table 3 on a separate page instead of presenting them together in a single table. The body mass may be explicitly stated along with the heart rate for each species, but is spatially separated from the heart rate and body mass for every other species by one or more pages. The cognitive load theory states that this physical separation results in the “split attention effect”, where learners must split their attention between sources of information (Sweller & Chandler, 1991).

Wickens and Hollands make a similar observation with their proximity compatibility principle, which states that if a task requires mental integration of two or more pieces of data, then they should be displayed in close proximity to each other, not distributed across screens or pages (Wickens & Hollands, 2000). However, educational materials such as textbooks often spatially separate information that needs to be mentally incorporated, thus violating the proximity compatibility principle. Because of this spatial separation of information, learners may find integrating the material difficult or even impossible. Even when two pieces of information are in close proximity, a novice learner may not even realize that the information can be integrated, thwarting the learning process before it begins. This combination of spatial and representational issues may exacerbate learners’ cognitive load, and thus interfere with their ability to develop mental schemas critical for effective clinical problem solving.
Graphical representation - concept maps

One method of placing information in spatial proximity and explicitly defining the relationships between them is through the use of concept maps. The use of concept maps has been validated in a wide variety of educational settings, from elementary school through medical and veterinary school (Cañas, et al., 2003; Edmondson & Smith, 1996; Mahler, Hoz, Fischl, Tov-Ly, & Lernau, 1991; Markow & Lonning, 1998; Yarden, Marbach-Ad, & Gershoni, 2004). Interestingly, while concept maps were originally developed as an instructional tool to be used by teachers, a review of the literature indicates their use in medical education appears to be confined to construction by students for two purposes -- either to develop an understanding of relationships, or to demonstrate their understanding for assessment purposes (Edmondson & Smith, 1996; McGaghie, McCrimmon, Mitchell, Thompson, & Ravitch, 2000; Pinto & Zeitz, 1997; Rendas, Fonseca, & Pinto, 2006; West, Park, Pomeroy, & Sandoval, 2002; West, Pomeroy, Park, Gerstenberger, & Sandoval, 2000). Concept maps could essentially distill many pages of textbook information into a summary representation. Summaries have been shown to be as effective as full text in some circumstances (Mayer, Bove, Bryman, Mars, & Tapangco, 1996).

The concept map in Figure 3 illustrates the use of a concept map, which complies with the proximity compatibility principle and reduces cognitive load by:

- Placing the relevant portions of the taxonomy and information of clinical relevance in close proximity
- Summarizing a large amount of information into a single representation
• Placing all necessary information required for interpretation of the representation into the representation and thus reducing the split-attention effect

• Explicitly illustrating the relationships between specific pieces of data, eliminating the need for the learner to painstakingly mentally develop these relationships

Figure 3: Concept map illustrating relationship between taxon (body shape) and presence or absence of an intermediate host

Some learners may not realize that relationships between certain facts exist, and therefore, these learners will not be able to construct appropriate internal representations of this information. The explicit relationships illustrated in such a map address the issue.
Finally, showing the relationships increases relevance to the adult learner, and reduces the
time required for construction of internal representations.

In the next section, taxonomy and the specific study domain of veterinary parasitology
are discussed.

**The Study Domain and the Importance of Biological Taxonomy**

*Taxonomy and Biology*

In 1735 Linnaeus published his *Systema Naturae*, which was the first systematic taxonomy
of plants and animals and was based on the morphology of organisms. Adaptations of the
Linnaean taxonomy are still in use today, and systematists have now expanded the taxonomy to
utilize genomic data in addition to the morphological data. Because of this systematic process,
taxonomy is a reflection of an organism’s evolutionary heritage, with organisms of similar ancestry
sharing more closely related taxons. Similar organisms grouped together based on morphology
and/or genomics will often share other characteristics as a result of evolution; therefore, their
behavior and responses to biological stimuli will often be similar (Winston, 1999). Taxonomy
provides the foundation for biological and evolutionary understanding as it supplies a model for
visualizing evolutionary relationships among organisms. In this way, taxonomy is as important to
biology as the periodic table is to chemistry. Just as Mendeleev’s periodic table groups chemical
elements together based on physical and chemical properties and can both explain and predict the
behavior of those elements, the Linnaean classification of organisms can help explain and predict
behavior and reactions of those organisms. For example, Yates, Salazar-Bravo, and Dragoo (2004)
describe how analysis of phylogenetic trees was used to theorize that New World mice, the vector
for hantaviruses, evolved concurrently with those hantaviruses, which are responsible for the
highly pathogenic Hantavirus Pulmonary Syndrome (Yates, Salazar-Bravo, & Dragoo, 2004).
Thus, developing an accurate understanding of the particular portion of the taxonomic tree used in one’s studies or work is essential for deriving relationships, similarities, differences, behavior, and adaptation in organisms. However, students in biology courses that include taxonomic data may be overwhelmed by a seemingly incomprehensible and context-free mass of Latin names, such as those shown in Figure 4.

As a result, learners may attempt to memorize the taxonomic relationships without developing a true understanding of those relationships. In a situational context, they attempt to memorize specific characteristics of individual species and when confronted with a new species, they are apparently unable to utilize the taxonomy to extrapolate this information based on what they already know. For a simple example, consider the viral disease rabies, which causes over 50,000 human deaths annually worldwide (Haupt, 1999). The average person is generally aware that rabies is a fatal disease of humans, and that a common route of exposure is via dog or cat bites. These same people may also recognize that bats and skunks are also common vectors of this disease, yet when asked if it is possible that cows, donkeys or horses are susceptible to rabies, they will probably answer “no”. So if we consider a simple Linnaean taxonomy representing these
species, and then add in the taxonomic level at which rabies is known to attack, we can easily extrapolate all of the various families of the class Mammalia, and learn that cows and donkeys are indeed susceptible to rabies (Figure 5); in fact, cattle accounted for 115 (1.7%) of animal rabies cases in the United States in 2004 (Krebs, Mandel, Swerdlow, & Rupprecht, 2005).

Figure 5: Relationship between the disease rabies and the Linnaean taxonomy (drawn by Kimberly Smith from Macdonald, 1995)
In the field of parasitology, and veterinary parasitology in particular, learners must understand the complex relationships that exist between parasites, their environment, and hosts for effective diagnosis, treatment, and control. If the learner learns this information for one species of parasite, and also understands how the Linnaean taxonomy indicates the evolutionary similarity (or dissimilarity) of species, the learner can then extrapolate information about related parasites. This end result is meaningful learning as opposed to simple memorization. However, a review of the literature indicates that very little research has been done on human learning with respect to taxonomic information. In fact, Brisbin observed:

“Most students are taught the existence of scientific schemes of classification. They recognize that lions, tigers, and panthers are all members of the same class that does not include wolves, dogs, and coyotes. Further, students recognize that the larger class, Mammalia, includes all of these. However, few students can provide any theoretical basis as to why these organisms are classified together….Without understanding the mechanisms that have produced the diversity of life on earth, the study of classification becomes nothing more than vocabulary memorization.” (Brisbin, 2000).

In 1979, Morton and Bradely required “…students to separate a selected number of organisms into groups of increasing similarity and to relate these groups directly to the kingdom-species system of classification.”(Morton & Bradely, 1979). Shortly thereafter, Core proposed a problem-solving method for students to analyze taxonomic relationships (Core, 1982). In 1985, Adams evaluated how very young children learned about basic animal taxonomies from their mothers (Adams, 1985). More recently, Lee and Parr have worked extensively on user interaction and taxonomic visualization tools (Lee, Parr, Campbell, & Bederson, 2004). Yet, a review of the literature produced no citations of studies using adult learners -- specifically, medical/veterinary students – who are tasked not only with rapidly assimilating large quantities of taxonomic data, but also with deriving clinical relevance from this information.
**Taxonomy and Veterinary Education**

Veterinary students face a unique problem not encountered by their medical student counterparts: not only must they learn a large volume of information in order to become competent diagnosticians, they must do so for a diverse variety of species, each of which has its own anatomy, physiology, and disease predilections. Therefore, it is to the veterinary student’s advantage – even imperative – that they be able to leverage knowledge about one species in order to reduce the learning curve about another species. Taxonomy is essential to this effort because it provides a model for visualizing evolutionary relationships among organisms and thus provides the foundation for biological and evolutionary understanding. If the student learns about one species, and understands how taxonomy indicates the evolutionary similarity (or dissimilarity) of species, the student can then extrapolate information about related species. This is especially true in veterinary parasitology coursework. Parasitology is a significant part of veterinary education because of the serious health and economic impact of parasites on both animals and humans. Like other areas of medical education, parasitology involves a certain amount of basic science. Yet unlike other areas, that basic science component relies heavily on taxonomy because parasitology is a subject that deals with species – not only the parasites, but also their hosts.

In parasitology, the relationships between host species and parasite species can be defined by two general axioms:

**Axiom 1:** A host can be infected by many species of parasites (a one-to-many relationship exists between a host and its parasites)

**Axiom 2:** A parasite can infect many species of hosts (a one-to-many relationship exists between a parasite and its hosts)
Figure 6 is a visualization of these two axioms, illustrating the relationships between 8 host types and 12 parasite genera.

Using taxonomy as a guide, the eight hosts in Figure 6 can be separated into two general groups (carnivores and herbivores) comprised of three taxonomic orders: Carnivora (the meat-eaters), the Artiodactyla (the even-toed ungulates, such as cattle), and Perissodactyla (the odd-toed ungulates, such as horses), as shown in Figure 7. For comparison, humans are kept separate, as they are usually omnivorous.

Patterns now begin to emerge. For example, *Fasciola* only infects the herbivores, not the carnivores, which should give a hint about *Fasciola*’s life cycle. Conversely, *Taenia*
seems to only infect the carnivores, and *Haemonchus* and *Moniezia* are restricted to the even-toed ungulate herbivores (order Artiodactyla). And finally, humans – at least those who are omnivorous - have some parasites in common with both carnivores and herbivores.

Even with only eight hosts and 12 parasites, the sheer volume of relationships makes the material difficult to learn in a meaningful way. It is clear that when this level of complexity is encountered, techniques such as memorization and simple heuristics no longer suffice. True understanding of the material is required. Such understanding – or meaningful learning – requires the student to construct relationships between material that will allow them to gain new insights and use the material more effectively in problem solving (Mayer, 2002). However, in parasitology coursework, taxonomic information is often presented in ways that separate a parasite’s taxonomy from its clinical relevance. Representations may simply be a list of Latin names with no supporting information, such as the example in Figure 4, or they may list the presence, absence, or number of specific morphological or genetic features that usually are not clinically relevant, as shown in Figure 8.

![Figure 8: Example taxonomy with morphological descriptors (adapted from Olsen, 1986, pp. 43-44)]
Note that while Figure 8 does provide more information, including the specification of the superfamily taxon based on mouth and genital features, these features provide few, if any, affordances to the student to help them construct knowledge linking the taxonomy with clinical information. An affordance is “…the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used…” (Norman, 1990, p. 9). For example, a flat plate on a door affords pushing of the door. The only possible affordance provided in this example is the differentiation of the genera based on the presence or absence of teeth or cutting plates, but nowhere does it explain the clinical importance of those morphological features. Without mental schemas containing well-structured knowledge of the complex interactions of parasites, their hosts, and the diseases, signs, and symptoms parasites cause in those hosts, students will not be as effective in solving problems such as diagnosis, and planning treatment and control strategies.

**Data, Information, Knowledge, and Wisdom**

Although the terms “data”, “information”, and “knowledge” are often used interchangeably in the general research literature, a clear delineation exists between each of these concepts in informatics. According to Ackoff, data are symbols that have no value while information is inferred from data. Ackoff further defines knowledge as “know-how” and states that knowledge is the product of learning, either by instruction or by experience (Ackoff, 1989). As shown in Figure 9, these concepts are commonly represented in a “DIKW hierarchy”, or pyramid with data at the bottom and wisdom at the top (Rowley, 2007, p. 164).
Considering the research in this study and considering the DIKW model in the context of the previous discussion, a variant of the DIKW model is proposed to include functions as well as hurdles to achieving those functions, as shown in Figure 10. In this functional model, “Observing facts” replaces the “Data” layer, “Inferring facts” replaces the Information layer, and “Understanding why” partially combined with “understanding appropriate use” replace the Knowledge and Wisdom layers. Two new layers are added, making explicit cognitive barriers to progression from lower to higher layers. For the purposes of the research in this study, these cognitive barriers include proximity, explicitness, and representation.
Summary

This chapter presented a review of the literature concerning topics relevant to this study. The chapter began with a discussion of how novices such as learners learn and experts or authors develop and use information and then provided a discussion of inferential learning and how information presentation can limit the ability of students to grasp underlying concepts. This was followed by learning theories and cognitive issues, including limits of working memory and the impact of spatial separation of material, including the proximity compatibility principle. Next, the importance of taxonomy in biology, and an overview of the importance of the selected research domain, veterinary parasitology, and how a working grasp of taxonomy is essential to meaningful learning in parasitology. The chapter concluded with a discussion of Ackoff’s Data-Information-Knowledge-Wisdom (DIKW) model and proposed a functional model incorporating aspects of the literature review. The next chapter discusses the methodology used in the research study.
Chapter III
Methodology

Introduction

Discussed in this chapter is the methodology used for this study. This dissertation research consisted of two experiments and an attitude questionnaire. The first experiment was designed to assess whether explicitness and proximity in reading materials significantly affected veterinary students’ ability to infer the rule governing the relationship between parasitic nematodes, taxonomy, body site, and intermediate hosts. The second experiment was designed to assess the effect of representation, by comparing a text-based version against versions that included proximal and explicit information in the form of a graphical representation, a concept map. The attitude questionnaire assessed the students’ attitudes toward taxonomy in parasitology as well as the amount of rote memorization. The chapter concludes with a summary.

Subjects

The study subjects were a convenience sample consisting of the second-year class of veterinary students in a large college of veterinary medicine in the state of Texas who matriculated in 2007. The sole criterion for inclusion was that the subject was a second-year veterinary student enrolled in parasitology in the fall semester of 2008. The sample consisted of 125 students, of which 124 consented to participate in the study, for a 99% participation rate.

According to the university’s web site, 132 students enrolled in 2007. Of these, 31 were male and 101 were female. The average age was 23 years, with a range of 20 to 52 years of age. The average overall GPA was 3.64 on a 4.0 scale. The average GRE score (verbal, quantitative, and analytical) was 505, 658, and 4.56, respectively (Anonymous, 2008). The highest scores possible were 800, 800, and 6.0, respectively ("Understanding Your GRE Scores," 2009).
Human Subjects Protection

The study was reviewed and approved by the institutional review boards of both the University of Texas Health Science Center at Houston, approval number HSC-SHIS-08-0552 (Appendix C: The University of Texas Health Science Center Study Approval Letter), and Texas A&M University, approval number 2008-0552 (Appendix B: Texas A&M University Study Approval Letter).

At the beginning of the session, students were given a consent form (Appendix D: Consent Form) that explained the purpose of the study and were asked to read it. The primary investigator gave a brief verbal overview of the study and was available to answer any questions. All students were required to complete the study materials, but they could decline to have their results included in the study. Students indicated their willingness to participate in the study by signing the form, or declined to participate by not signing the form.

All students who completed the study materials received 10 extra credit class points, whether or not they signed the study consent form. Only the primary investigator had access to the completed consent forms, pre-tests, and post-tests. The course professor did not know which students consented to participate in the study.

Setting

The study was conducted in the parasitology laboratory during regularly scheduled course laboratory hours.

Pilot research

The two experiments required development of instructional interventions using proximity and explicitness in texts and representations that would be compared to readings from typical
texts. Seven small group sessions were held to identify the barriers to understanding that the students experienced in the usual teaching methods. Each group included five to six fourth-year veterinary students who were undergoing their two-week clinical rotation in parasitology. The sessions included:

1. Unstructured group interview. This group was asked to recall what they felt were the most difficult topics during their second-year parasitology coursework as well as their attitudes toward the importance and utility of taxonomy.

2. Individual problem solving. This group was given a list of the major taxons in the class Cestoda, and asked to draw a taxonomic tree that illustrated the taxons in their correct positions.

3. Observations of group problem solving. This group was given a list of the major taxons in the class Cestoda written on sticky notes, and asked to arrange them in the correct taxonomic order as a group activity.

4. Case study quizzes. Two groups were given a case study text concerning a dog infected with Diphyllobothrium latum and then asked to complete a multiple choice quiz. The quiz was then discussed as a group activity.

5. Case studies with group discussion. Two groups were given a case study (one through lecture and one through video and lecture) and asked to try to identify the responsible parasite. The lecture case study concerned an Orthodox Jew with *Taenia solium* neurocysticercosis. The students were asked to identify how the patient had become infected. The video case study concerned identification of *Taenia saginata* cysts in meat. The students were asked to identify how the animal had become infected and to identify whether and how humans could become infected.
The observations from these activities informed the development of the two experiments, which are described below.

**Experiment 1: The Effect of Proximity and Explicitness in Textual Representations**

The purpose of Experiment 1 was to address the following research questions.

1. Do learning materials with textual representations that place appropriate information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, when compared to learning materials with textual representations that do not place this information in close spatial proximity?

2. Do learning materials with textual representations that provide explicit information significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, when compared to learning materials with textual representations that do not provide explicit information?

Three knowledge areas are involved: Intermediate host, taxonomic order, and body site access to the outside world. This can be represented as shown in Figure 11:

![Figure 11: Knowledge areas required for understanding nematode intermediate host requirements](image)

However, knowledge of these areas is one portion of what needs to be evaluated. As shown in Figure 12, the other portion is the conceptual understanding of the interaction of these three knowledge areas. Given any two characteristics from the list of body site, intermediate host, and taxonomic order, the third can usually be correctly predicted. If the student has successfully
inferred this relationship, then the student should be able to correctly solve the clinical scenarios presented in Experiment 1, regardless of the format of the information.

Figure 12: Relationship between intermediate host, taxonomic classification, and body site

**Design for Experiment 1**

As shown in Table 4, Experiment 1 was a randomized four-group pretest-posttest control group true experimental design (Gliner & Morgan, 2000). Students were randomly assigned to one of the four intervention versions at the beginning of a regularly scheduled class laboratory session.

<table>
<thead>
<tr>
<th>Version</th>
<th>Intervention</th>
<th>N</th>
<th>Proximity</th>
<th>Explicitness</th>
<th>Randomization</th>
<th>Pretest</th>
<th>Intervention</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control</td>
<td>31</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>O</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>2</td>
<td>Proximity only</td>
<td>31</td>
<td>+</td>
<td>-</td>
<td>R</td>
<td>O</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>3</td>
<td>Explicitness only</td>
<td>32</td>
<td>-</td>
<td>+</td>
<td>R</td>
<td>O</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>4</td>
<td>Proximity plus explicitness</td>
<td>30</td>
<td>+</td>
<td>+</td>
<td>R</td>
<td>O</td>
<td>X</td>
<td>O</td>
</tr>
</tbody>
</table>

**Independent and Dependent Variables**

As shown in Table 5, there were two between-subject variables, each with two levels, proximity and explicitness. Pre- and posttest occasions constituted the within-subjects independent variable. Pre- and posttest scores on the PET test constituted the within-subjects
dependent variables. Version was the intervention material and there were four levels: 2 levels of proximity (present or absent) and 2 levels of explicitness (present or absent).

<table>
<thead>
<tr>
<th>Proximity</th>
<th>Proximity +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicitness -</td>
<td>Version 1</td>
</tr>
<tr>
<td>Explicitness +</td>
<td>Version 2</td>
</tr>
<tr>
<td>Explicitness -</td>
<td>Version 3</td>
</tr>
<tr>
<td>Explicitness +</td>
<td>Version 4</td>
</tr>
</tbody>
</table>

**Development of the Intervention Text**

This section describes how the reading text was developed for each intervention. To ensure content validity, a chapter from a standard published textbook was used. However, the content was reduced so the students could read the intervention in the allotted time of 30 minutes.

Two subject matter experts, both professors of parasitology, provided a list of 34 veterinary parasitology teaching faculty contacts. These faculty were contacted by email and asked the name and edition of the text(s) used in their courses as well as any internally-developed teaching note sets; whether the text was required or optional; the year (semester) in which the parasitology coursework was taught, and the name and edition of the laboratory manual used. The text most frequently given was Georgi’s Parasitology for Veterinarians, 8th edition, by Dwight Bowman, Randy C. Lynn, Mark L. Eberhard, and Ana Alcaraz, Saunders, St. Louis, Missouri, 2003. Therefore, this text was selected as the source text for both Experiments 1 and 2.

For experiment 1, the chapter on nematodes (pages 153-231) was digitized into portable document format (PDF) using a flatbed scanner (Canon Canoscan 8800F) and VueScan scanning software (http://www.hamrick.com). PDFs were then opened in Adobe Acrobat Professional version 8.1.2 and optical character recognition (OCR) was performed, using the following settings: Primary OCR Language: English (US); PDF Output Style: Searchable Image; Downsampling: Lowest (600 dpi).
The text of each page was then copied and pasted as unformatted text into a Microsoft® Word 2008 for Mac file (Redmond, Washington), using the Paste Special function. This eliminated all figures. Line breaks were then replaced with a space to restore standard paragraph formatting, using Microsoft Word’s Replace function. Page headers, page footers, figure captions, figure labels, and in-text references to figures were removed. The text was then proofread against the original text. In-text citations were removed except where necessary to preserve text cohesion.

The text was then re-read for the presence of seductive details, or “propositions presenting interesting, but unimportant, information”, which where then removed (Garner, Gillingham, & White, 1989). An example of a seductive detail from the selected textbook is given here.

“The progeny of a ram called Violet harbored smaller populations of worms and suffered less reduction in hematocrit than did the progeny of other rams. Unfortunately, one dark and stormy night the electric transmission lines fell on Violet and blew him to glory. Years later, when he retired and turned over his Zeiss photomicroscope, Dr. Whitlock had a brass plate engraved in Violet’s memory and mounted on the microscope.” (Bowman, Lynn, Eberhard, & Alcaraz, 2003, pp. 169-170).

In order to further reduce the content to an amount that could be read by the study subjects in the allotted time, the material was reduced to focus on the material related to the inferential rule: hosts and intermediate hosts, location in the body, and taxonomic classification. Material related to identification, morphology, host resistance, diagnosis, prevention, and treatment and control was removed, as this information was not relevant
to understanding the interaction of intermediate hosts, body site, and taxonomy. Material related to unusual or rarely seen parasites was also removed.

Two domain novices, an informatics graduate student and an informatics professor tested the length of time required to read the intervention. Material was removed until the intervention could be read by novices within the allotted time frame of 30 minutes.

A table of contents was added, showing the basic taxonomic organization of the nematodes. Table 6 demonstrates the content of the original chapter on nematodes compared to the control version of the intervention. The number of words was calculated using the Word Count function of Microsoft Word 2008 for Mac (Redmond, Washington).

Table 6: Comparison of Content for Experiment 1: Original Chapter vs. Control Version

<table>
<thead>
<tr>
<th>Number of:</th>
<th>Original chapter</th>
<th>Intervention version (control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Pages</td>
<td>77</td>
<td>7</td>
</tr>
<tr>
<td>- Words</td>
<td>46,894</td>
<td>4,287</td>
</tr>
<tr>
<td>- Figures</td>
<td>84</td>
<td>2</td>
</tr>
<tr>
<td>- Phyla</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- Orders</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>- Suborders</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>- Superfamilies</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>- Families</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>- Subfamilies</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>- Species</td>
<td>153</td>
<td>42</td>
</tr>
<tr>
<td>- Genera</td>
<td>99</td>
<td>26</td>
</tr>
</tbody>
</table>

**Operationalization of the Proximity Independent Variable**

Operationalization of proximity was achieved as follows. Version 1 (proximity - / explicitness - ), shown in (Appendix G: Experiment 1: Intervention 1 (Control)), served as a control. The organism name was placed in bold type on a separate line at the beginning of the paragraph. No alterations to the location of information regarding body site or intermediate host were made (Figure 13).
Intervention version 2 (proximity + / explicitness - ), shown in (Appendix H: Experiment 1: Intervention 2 (Proximity)), was modified to place organ location and intermediate host information in proximity to the organism name (Figure 14). In addition, all organism entries were collected into two summary tables at the end of the intervention reading, one sorted by taxonomic order (Figure 15), and one sorted by intermediate host (Figure 16).

**Figure 13: Organism Description Without Proximity of Body Site or Intermediate Host Information**

**Figure 14: Organism Description With Proximity of Body Site and Intermediate Host Information**

**Figure 15: Version 2 and 4: Partial Entry from Summary, Sorted By Order**

**Figure 16: Version 2 and 4: Partial Entry from Summary, Sorted By Intermediate Host**
Operationalization of the Explicitness Independent Variable

Operationalization of explicitness was achieved as follows. Intervention versions 3 and 4 contained text that stated as explicitly as possible the inferential concept to be tested. In conjunction with a subject matter expert, Tom Craig, DVM, PhD, a paragraph describing the inferential relationship was developed that stated:

“In general, whether or not a nematode requires an intermediate host is determined by two factors. The first factor is whether the nematode is located in the gastrointestinal tract. Because the gastrointestinal tract provides direct access to the outside world for the nematode's eggs or larvae by way of the feces, these parasites do not require an intermediate host (unless they are members of the order Spirurida). In contrast, nematodes whose adults are found in locations other than the gastrointestinal tract generally do require intermediate hosts. The second factor is the taxonomic order to which the parasite belongs. If the parasite is a member of the order Spirurida or the superfamily Metastrongyloidea, then it requires an intermediate host. An exception to this rule is the metastrongylid Filaroides.”

Intervention version 3 (proximity - / explicitness +), (Appendix I: Experiment 1: Intervention 3 (Explicitness)) contained the explicit text at the beginning of the reading and again at the end. Otherwise, Version 3 was similar to Version 1, in that each organism name was placed in bold type on a separate line at the beginning of the paragraph. No alterations to the location of information regarding body site or intermediate host were made (Figure 13).

Intervention version 4 (proximity + / explicitness +), Appendix J: Experiment 1: Intervention 4 (Proximity + Explicitness) also contained the explicit text at the beginning of the reading and again the end. Otherwise, Version 4 was similar to Version 2, in that organ location and intermediate host information in proximity to the organism name (Figure 14). In addition, all
organism entries were collected into two summary tables at the end of the intervention reading, one sorted by taxonomic order (Figure 15), and one sorted by intermediate host (Figure 16).

**Instruments**

Clinical scenarios for evaluation questions given in the pretest and posttest were developed using reference texts (Ballweber, 2001, Bowman, et al., 2003; Faust, Russell, & Jung, 1970; Foreyt, 2001; Kahn, 2005; Levine, 1968; Marquardt, Demaree, & Grieve, 2000; Olsen, 1986; Samuel, Pybus, & Kocan, 2001), the domain literature (Schantz, et al., 1992), course examinations from Texas A&M’s second-year parasitology course, and a veterinary licensing examination board review text ("Parasitology Review Questions for the National Boards," 2006). Finally, guidelines issued by the American Board of Medical Examiners for writing questions assessing clinical problem solving were reviewed (Case & Swanson, 2002), as was Bloom’s taxonomy of educational objectives (Anderson, et al., 2001).

Questions were also specifically developed to quantify conceptual misunderstandings that were identified during the interviews with the fourth-year veterinary students during the formative research phase. Both the pretest and posttest followed the same format.

A top-down goal analysis based on Figure 12 was used to assure content validity. The concept tested involved four subscales for questions. Three subscales addressed the knowledge areas from the diagram in Figure 12 and one subscale addressed the understanding of the relationships between body site, intermediate host, and taxonomy.

In both the pretest and posttest, the subscales were developed according to Table 7.
### Table 7: Experiment 1 Subscale Description

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Number of items</th>
<th>Number of possible answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1: Conceptual understanding</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Q2: Taxonomy [Genus level] + Intermediate Host</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Q3: Taxonomy [Order level] + Intermediate Host</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Q4: Taxonomy + Body Site</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Q5: Body Site + Intermediate Host</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Q6: Conceptual understanding / Clinical problem solving</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 8 shows the pretest with the question items, knowledge areas, and explanatory notes.

### Table 8: Experiment 1 Pretest

<table>
<thead>
<tr>
<th>Question</th>
<th>Knowledge Area and Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Choose the factor(s) that most influence whether a nematode has an intermediate host. Indicate your answers with an X in the appropriate blank(s).</td>
<td>Conceptual understanding (Recognition / Recall) &lt;br&gt;Incorrect &lt;br&gt;Item discarded after expert review &lt;br&gt;Incorrect &lt;br&gt;Incorrect &lt;br&gt;Incorrect &lt;br&gt;Incorrect &lt;br&gt;Correct &lt;br&gt;Incorrect &lt;br&gt;Incorrect &lt;br&gt;Incorrect</td>
</tr>
<tr>
<td>___________________________ Size of adult parasite &lt;br&gt;________________________ Size of the parasite's reproductive product (eggs, larvae, microfilariae) &lt;br&gt;________________________ Influence of estrogens / prolactin &lt;br&gt;________________________ Taxonomic group to which the parasite belongs &lt;br&gt;________________________ Organ in which the adult parasite is located in the host &lt;br&gt;________________________ All of the above &lt;br&gt;________________________ None of the above</td>
<td></td>
</tr>
<tr>
<td>2. For each parasite in the left column, indicate whether or not it requires an intermediate host by marking the appropriate <em>yes</em> or <em>no</em> blank in the right column.</td>
<td>Taxonomy [Genus Level] + Intermediate Host (Recognition / Recall) &lt;br&gt;(Taxonomic classification here is at the Genus level; student will need to know which Genera belong to which Orders to determine if the organism is a member of Spirurida; OR will simply have memorized.)</td>
</tr>
<tr>
<td>Ostertagia</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Syngamus</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Parelaphostrongylus</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Dictyocaulus</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Enterobius</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Baylisascaris</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Gnathostoma</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Thelazia</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Habronema</td>
<td>_______ yes</td>
</tr>
<tr>
<td>Onchocerca</td>
<td>_______ yes</td>
</tr>
<tr>
<td>3. Which of the following do not require an intermediate host? Indicate your answers with an X in the appropriate blank(s).</td>
<td>Taxonomy [Order Level] + Intermediate Host (Recognition / Recall) &lt;br&gt;(Taxonomic classification here is at the Order level; should be easier than Q.2)</td>
</tr>
<tr>
<td>___________________________ Ascaridida</td>
<td>_______</td>
</tr>
<tr>
<td>___________________________ Enoplida</td>
<td>_______</td>
</tr>
<tr>
<td>___________________________ Oxyurida</td>
<td>_______</td>
</tr>
<tr>
<td>___________________________ Spirurida</td>
<td>_______</td>
</tr>
<tr>
<td>4. Match each parasite to its usual location in the host by writing the number of the location in the answer blank. Answers may be used more than once or not at all.</td>
<td>Taxonomy + Body Site (Recognition / Recall) &lt;br&gt;(Taxonomic classification here is at the Genus level; student will need to know which Genera belong to which Orders to determine if is a member of Spirurida;</td>
</tr>
<tr>
<td>Trichostrongylus</td>
<td>1. Esophagus, rumen, stomach, or abomasum</td>
</tr>
<tr>
<td>Filaroides</td>
<td>2. Intestine, cecum, or colon</td>
</tr>
<tr>
<td>Oxyuris</td>
<td>3. Lungs, bronchi, or trachea</td>
</tr>
<tr>
<td>Parascaris</td>
<td>4. Skin, connective tissue, or muscle</td>
</tr>
<tr>
<td>Physaloptera</td>
<td>5. Kidney or bladder</td>
</tr>
<tr>
<td>Dracunculus</td>
<td>6. Heart or pulmonary arteries</td>
</tr>
<tr>
<td>Thelazia</td>
<td>7. Conjunctiva or lacrimal sac</td>
</tr>
</tbody>
</table>
5. For each body location in the left column, indicate whether nematodes found in that location require an intermediate host by marking the appropriate "yes" or "no" blank in the right column. If some nematodes in a given body location do require an intermediate host while others do not, mark the "both yes and no" column and give an explanation.

<table>
<thead>
<tr>
<th>Body site + Intermediate Host</th>
<th>Recognition / Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draschia</td>
<td>Nervous system</td>
</tr>
<tr>
<td>Setaria</td>
<td>Serous membranes</td>
</tr>
</tbody>
</table>

OR will simply have memorized.)

6. For nematodes that have an intermediate host, effective control of the parasite usually depends on control of that intermediate host, not the parasite itself. For each of the following clinical observations, predict whether the parasite in question requires an intermediate host by marking either "yes" or "no" in the Intermediate host required column. If there is not enough information to determine whether the parasite requires an intermediate host, mark "need more information".

<table>
<thead>
<tr>
<th>Clinical problem</th>
<th>Knowledge Synthesis or Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. You observe nematode eggs in the feces of a goat.</td>
<td>need more information</td>
</tr>
<tr>
<td>b. You observe larvae in tissue from a horse's cheek.</td>
<td>need more information</td>
</tr>
<tr>
<td>c. You are asked to examine a wound on the leg of a raccoon. You see the tail of a nematode protruding from the wound.</td>
<td>need more information</td>
</tr>
<tr>
<td>d. You observe large white nematodes in the intestine of a horse.</td>
<td>need more information</td>
</tr>
<tr>
<td>e. You are a pathologist examining a muscle biopsy, and you observe coiled nematode larvae.</td>
<td>need more information</td>
</tr>
<tr>
<td>f. You are performing a field necropsy on a cow that died a few hours ago, and you observe nematodes swimming in some ascitic fluid in the abdominal cavity.</td>
<td>need more information</td>
</tr>
<tr>
<td>g. On this same cow, you observe small nematodes in the abomasum.</td>
<td>need more information</td>
</tr>
<tr>
<td>h. On this same cow, you observe serpentine lesions in the mucosa of the rumen.</td>
<td>need more information</td>
</tr>
<tr>
<td>i. You observe microfilaria in a skin biopsy from a cow.</td>
<td>need more information</td>
</tr>
<tr>
<td>j. A family has slaughtered a hog, but want you to examine it before they consume the meat. You observe large nematodes in the hepatic and renal tissues.</td>
<td>need more information</td>
</tr>
</tbody>
</table>

This section described the design, variables, operationalization of variables, and instruments for assessing the effect of proximity and explicitness on student clinical problem

45
solving (experiment 1). The next section describes the design, variables, operationalization of variables, and instruments for assessing the effect of representation and proximity on student clinical problem solving (experiment 2).
Experiment 2: Representation and Proximity

Experiment 2 was designed to test whether graphical representations (concept maps) that placed appropriate information in close spatial proximity improved student learning as measured by student ability to solve clinical case scenarios accurately, when compared to tabular representations. This experiment addressed the research questions:

Q3. Do learning materials with tables that include detailed information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials with tabular representations that do not include detailed information?

Q4. Do learning materials with partial concept maps that place a subset of information in proximity to the appropriate text significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials without partial concept maps?

Q5. Do learning materials with graphical representations (concept maps) that place appropriate information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials that include tabular representations?

Q6. Do learning materials with tables with detailed information, full concept maps, and partial concept maps, significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials that include no concept maps and tables without detailed information?
**Experimental Design and Variables**

Experiment 2 utilized a randomized pretest, posttest design, as shown in Table 9. The groups were approximately equal in size, with 30 to 31 subjects in each group. With each increment in version number an additional representation was included, as shown in Table 10 and Table 11. There were two between-subject variables, each with two levels, textual table and concept map. There was one within-subject variable, the test occasion.

<table>
<thead>
<tr>
<th>Version</th>
<th>Intervention</th>
<th>N</th>
<th>Random-</th>
<th>Pretest</th>
<th>Intervention</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Text with summary table that did not include specific details at each taxon level (Control)</td>
<td>30</td>
<td>R</td>
<td>O</td>
<td>X₁</td>
<td>O</td>
</tr>
<tr>
<td>2</td>
<td>Text with summary table plus specific details at each taxon level</td>
<td>30</td>
<td>R</td>
<td>O</td>
<td>X₂</td>
<td>O</td>
</tr>
<tr>
<td>3</td>
<td>Text with summary table plus specific details at each taxon level plus graphical representation (concept map)</td>
<td>31</td>
<td>R</td>
<td>O</td>
<td>X₃</td>
<td>O</td>
</tr>
<tr>
<td>4</td>
<td>Text with summary table plus specific details at each taxon level plus graphical representation (concept map) plus partial graphical representations</td>
<td>31</td>
<td>R</td>
<td>O</td>
<td>X₄</td>
<td>O</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Version</th>
<th>Textual table without additional details</th>
<th>Textual table with additional details</th>
<th>Concept map without partial maps</th>
<th>Concept map with partial maps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (control)</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
</tbody>
</table>
Table 11: Representation Types, by Intervention

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Table without details</th>
<th>Table with details</th>
</tr>
</thead>
<tbody>
<tr>
<td>No concept map</td>
<td>Version 1</td>
<td>Version 2</td>
</tr>
<tr>
<td>Concept map</td>
<td>--</td>
<td>Version 3</td>
</tr>
<tr>
<td>Concept map with partial maps</td>
<td>--</td>
<td>Version 4</td>
</tr>
</tbody>
</table>

There were four planned comparisons:

1. Table without details (version 1) versus table with details; no concept map (version 2)

2. Concept map without partial maps (version 3) versus concept map with partial maps (version 4). Both versions had table with details.

3. Tables (versions 1 and 2) versus tables plus concept maps (versions 3 and 4)

4. Basic table (version 1) versus table with details plus concept map plus partial maps (version 4)
Development of the Intervention Text

The intervention text used in Experiment 2 was developed using the process described previously, with the exception that a different section of the selected textbook (Georgi’s Parasitology for Veterinarians, 8th edition, by Dwight Bowman, Randy C. Lynn, Mark L. Eberhard, and Ana Alcaraz, Saunders, St. Louis, Missouri, 2003) was used. This was necessary to eliminate any learning effect from the Experiment 1. The text used for Experiment 2 was the chapter on taxonomic class Cestoda, pages 130-153. A comparison of the content of the original chapter against the intervention version is given in Table 12.

Table 12: Comparison of content for Experiment 2: Original chapter vs. Intervention version

<table>
<thead>
<tr>
<th>Number of:</th>
<th>Original chapter</th>
<th>Intervention version (Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Pages</td>
<td>22</td>
<td>7 (not counting cover page)</td>
</tr>
<tr>
<td>- Words</td>
<td>8,607</td>
<td>3,742</td>
</tr>
<tr>
<td>- Figures</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>- Phyla</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- Classes</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- Orders</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>- Families</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>- Genera</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>- Species</td>
<td>31</td>
<td>18</td>
</tr>
</tbody>
</table>

Development of Intervention Versions

Four versions of the intervention were created. Version 1 (text only, tabular summary without taxonomic characteristics in proximity) served as a control. As with Experiment 1, the organism name was placed in bold type on a separate line at the beginning of the paragraph. The text was modified to place organ location, intermediate host (IH), and definitive host (DH) information in proximity to the organism name (Figure 17).
**Family Anoplocephalidae**

The tapeworms of cattle, sheep, and goats all belong to the family Anoplocephalidae. The life histories involve an arthropod intermediate host in which the infective cysticercoid develops. Infection results from the incidental ingestion of these infected arthropods by the grazing animal. Adult tapeworms are relatively nonpathogenic.

<table>
<thead>
<tr>
<th>Moniezia</th>
<th>IH: mites</th>
<th>DH: cattle, sheep, goats</th>
</tr>
</thead>
</table>

*Moniezia* spp. are found in the small intestine of cattle, sheep, and goats (*Moniezia benedeni, Moniezia expansa, and Moniezia caprae*). The egg of *Moniezia* sp. found in cattle feces is one of the few eggs that appears square. Free-living oribatid mites serve as hosts for cysticercoids of *Moniezia* spp. of sheep and cattle.

---

**Tables Without and With Detailed Information**

All organism entries were collected into a summary table at the end of the intervention reading. Two variants of the summary table were developed. The variant used for Version 1 (control) did not include any life cycle information for the taxons at the Order and Family level (Figure 18), while the variant used for Versions 2, 3, and 4 placed specific life cycle information in proximity to the taxon name for the Order and Family (Figure 19).
A concept map (Figure 20) was then developed following the textual taxonomic description from the selected textbook. This concept map was inserted as the first page in intervention versions 3 and 4.

Finally, for intervention version 4, partial concept maps were developed for each taxonomic family, and inserted in the text at the family description. This placed the relevant portion of the graphical representation in proximity to its relevant text, as depicted in Figure 21.

Figure 20: Concept map of class Cestoda (used in Experiment 2, intervention versions 3 and 4)
Development of Pre- and Posttests

Clinical scenarios for question item building and evaluation were developed using the domain literature, course examinations from Texas A&M’s 2nd-year parasitology course, and veterinary licensing examination board review texts. Questions items were also specifically developed to address conceptual misunderstandings that were revealed during the interviews with the fourth-year veterinary students during the formative research phase. The pretest and posttest were identical except for the clinical cases. The clinical cases followed the same structure but used a closely related organism.

Questions were developed to address factual knowledge and clinical problem solving ability. The factual knowledge questions (example in Figure 22) corresponded to the cognitive process of “remembering”, including recognition and recall in Bloom’s revised taxonomy. The clinical problem solving questions (example in Figure 23) corresponded to Bloom’s cognitive process dimension of “understanding”, which includes interpreting, classifying, inferring, and explaining.
2. For each genus listed below, indicate the family that it belongs to by checking the appropriate box. Each row should only have one box checked.

- a. Spirometra
  - Anoplocephalidea
  - Diphyllobothriidae
  - Dipyldidae
  - Hymenolepididae
  - Taeniidae

- b. Echinococcus
  - Anoplocephalidea
  - Diphyllobothriidae
  - Dipyldidae
  - Hymenolepididae
  - Taeniidae

- c. Moniezia
  - Anoplocephalidea
  - Diphyllobothriidae
  - Dipyldidae
  - Hymenolepididae
  - Taeniidae

- d. Thysanosoma
  - Anoplocephalidea
  - Diphyllobothriidae
  - Dipyldidae
  - Hymenolepididae
  - Taeniidae

- e. Vampyroplis
  - Anoplocephalidea
  - Diphyllobothriidae
  - Dipyldidae
  - Hymenolepididae
  - Taeniidae

Figure 22: Example of factual knowledge question for Experiment 2

Your client brought in one of his dogs, a 3-year-old intact male coon hound, because he saw a white ribbon-like object several inches long in the dog’s stool that morning. History reveals that the client - an avid outdoorsman - took the dog on a fishing and hunting trip to southeast Alaska 4 months ago. The dog’s diet consists of commercial dog food occasionally supplemented with raw meat and fish scraps. Physical examination is unremarkable. A CBC and chemistry profile are within normal limits. A fecal examination reveals a few oval, operculated eggs. Assume that the dog is infected with a single species of parasite.

___ 1. What is the most likely parasite?
   - A  Diphyllobothrium
   - B  Dipyldium
   - C  Echinococcus
   - D  Moniezia
   - E  Taenia

___ 2. The type of eggs observed in the fecal examination is also characteristic of what other parasite?
   - A  Whipworms
   - B  Flukes
   - C  Hookworms
   - D  Ascarids
   - E  Kidney worms

___ 3. How did the dog become infected?
   - A  Eating raw fish
   - B  Eating raw meat
   - C  Eating fleas
   - D  Eating food contaminated with animal feces
   - E  None of the above

Figure 23: Example of clinical problem solving question for Experiment 2
Development of Question Subscales

In both the pretest and posttest, the subscales were operationalized according to Table 13.

Table 14 shows the subscales with the question items and explanatory notes.

Table 13: Subscale Operationalization for Representation Experiment

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Number of items</th>
<th>Number of possible answers per item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1: Taxonomic structure: Family – Order relationships</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Q2: Taxonomic structure: Genus – Family relationships</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Q3: Taxonomic properties: Family level</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Q4: Conceptual understanding / Clinical problem solving</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Q5: Conceptual understanding / Clinical problem solving</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Q6: Conceptual understanding / Clinical problem solving</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 14: Experiment 2 Pretest with Subscales and Notes

<table>
<thead>
<tr>
<th>Question</th>
<th>Subscale and Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. For each family listed below, indicate whether it belongs to the order Cyclophyllidea or to the order Pseudophyllidea by checking the appropriate box. Each row should have only one box checked.</td>
<td>Taxonomic structure: Family – Order relationships</td>
</tr>
<tr>
<td>a. Anoplocephalidae</td>
<td>Correct answers are: a. Cyclophyllidea b. Pseudophyllidea</td>
</tr>
<tr>
<td>b. Diphyllobothriidae</td>
<td></td>
</tr>
<tr>
<td>c. Dipylidiidae</td>
<td></td>
</tr>
<tr>
<td>d. Hymenolepididae</td>
<td></td>
</tr>
<tr>
<td>e. Taeniida</td>
<td></td>
</tr>
<tr>
<td>2. For each genus listed below, indicate the family that it belongs to by checking the appropriate box. Each row should only have one box checked.</td>
<td>Taxonomic structure: Genus – Family relationships</td>
</tr>
<tr>
<td>a. Spirometra</td>
<td>Correct answers are: a. Diphyllobothriidae b. Taeniida</td>
</tr>
<tr>
<td>b. Echinococcus</td>
<td></td>
</tr>
<tr>
<td>c. Moniezia</td>
<td></td>
</tr>
<tr>
<td>d. Thysanosoma</td>
<td></td>
</tr>
<tr>
<td>e. Vampirophilus</td>
<td></td>
</tr>
<tr>
<td>a. Anoplocephalida</td>
<td></td>
</tr>
<tr>
<td>b. Diphyllobothriida</td>
<td></td>
</tr>
<tr>
<td>c. Dipylidiida</td>
<td></td>
</tr>
<tr>
<td>d. Hymenolepidida</td>
<td></td>
</tr>
<tr>
<td>e. Taeniida</td>
<td></td>
</tr>
</tbody>
</table>
Question | Subscale and Notes
--- | ---
For each characteristic listed below, check the box(es) for the taxonomic family(ies) that have that characteristic. Each row may have one or more boxes checked.

- **a.** Aquatic food chain
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **b.** Terrestrial food chain
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **c.** Copepod intermediate host
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **d.** Arthropod intermediate host (other than copepods)
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **e.** Mammal intermediate host
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **f.** Definitive host eats meat or fish
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **g.** Has operculated egg
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **h.** One or more species can be found as adult worm in humans
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

- **i.** One or more species can be found as larval form in humans
  - [ ] Anoplocephalidea
  - [ ] Diphyllobothriidae
  - [ ] Dipyldidae
  - [ ] Hymenolepididae
  - [ ] Taeniidae

Correct answers are:
- a. Diphyllobothriidae
- b. All except Diphyllobothriidae
- c. Diphyllobothriidae
- d. All except Diphyllobothriidae, Taeniidae
- e. Taeniidae
- f. Diphyllobothriidae, Taeniidae
- g. Diphyllobothriidae
- h. All except Anoplocephalidae
- i. Taeniidae
4. Your client brought in one of his dogs, a 3-year-old intact male coon hound, because he saw a white ribbon-like object several inches long in the dog's stool that morning. History reveals that the client - an avid outdoorsman - took the dog on a fishing and hunting trip to southeast Alaska 4 months ago. The dog's diet consists of commercial dog food occasionally supplemented with raw meat and fish scraps. Physical examination is unremarkable. A CBC and chemistry profile are within normal limits. A fecal examination reveals a few oval, operculated eggs. Assume that the dog is infected with a single species of parasite.

**Question**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1. What is the most likely parasite?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Dipylobothrius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Diphyllobothrium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Echinococcus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Moniezia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Taenia</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>2. The type of eggs observed in the fecal examination is also characteristic of what other parasite?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Whipworms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Flukes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Hookworms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Ascarids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Kidney worms</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3. How did the dog become infected?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Eating raw fish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Eating raw meat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Eating fleas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Eating food contaminated with animal feces</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>None of the above</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>4. Which of the following is a characteristic of the taxonomic family to which this parasite belongs?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Life cycle requires a predator-prey relationship</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Life cycle requires a mammal intermediate host</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Life cycle requires a snail intermediate host</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Transmission to intermediate host occurs in a terrestrial environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>None of the above</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
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<th></th>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>5. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>It would be eaten by an copepod</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>It would be eaten by a fish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>It would be eaten by a mammal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>It would hatch to release a worm-like stage into the environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>It would hatch to release a ciliated stage into the environment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>6. What is an intermediate host for this parasite?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Fish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Mite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Flea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Mammal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Snail</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Subscale and Notes**

Conceptual understanding / Clinical problem solving

Correct answers are:
1. A
2. B
3. A
4. A
5. A
6. A

The facts of interest are that the parasite is ribbon-like; the eggs are operculated; and that the dog had been fed raw fish.

This question requires an understanding of the life cycle of parasites that require fish as intermediate hosts, as well as the special characteristics of operculated eggs.
5. You are an avid mountain climber and are on an expedition to climb Mount Everest. You are now at advance base camp at approximately 23,000 feet above sea level. During your stay in advance base camp, you notice several yaks (*Bos grunniens*) wandering freely around the camp. You learn that the yaks are "meat on the hoof" – the camp kitchen prepares meals using meat from yaks and that a yak is slaughtered just before the meat is needed for cooking. You are in the camp kitchen watching the cook butcher a side of yak beef when you suddenly notice small white parasite larvae in a cyst in the meat. Assume that the larvae are tapeworm larvae.

**1. What is the most likely parasite?**

- A. *Diphyllobothrium*
- B. *Echinococcus*
- C. *Moniezia*
- D. *Taenia*
- E. *Thysanosoma*

**2. Where would you expect to find the adult form of this tapeworm?**

- A. Yak intestine
- B. Pig intestine
- C. Dog intestine
- D. Human intestine
- E. None of the above

**3. How did the yak become infected?**

- A. Eating food contaminated with booklice
- B. Eating food contaminated with copepods
- C. Eating food contaminated with mites
- D. Eating food contaminated with yak feces
- E. Eating food contaminated with human feces

**4. Which of the following is a characteristic of the taxonomic family to which this parasite belongs?**

- A. Life cycle requires a predator-prey relationship
- B. Life cycle requires an arthropod intermediate host
- C. Life cycle requires a snail intermediate host
- D. Transmission to intermediate host occurs in an aquatic environment
- E. None of the above

**5. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?**

- A. It would be eaten by a copepod
- B. It would be eaten by a mite
- C. It would be eaten by a mammal
- D. It would be eaten by an arthropod (other than a copepod)
- E. None of the above

**6. What is the Intermediate host for this parasite?**

- A. Booklice
- B. Flea
- C. Mite
- D. Human
- E. Yak

**Question**

Conceptual understanding / Clinical problem solving

Correct answers are:
1. D
2. D
3. E
4. A
5. C
6. E

This question requires an understanding of mammals acting as intermediate hosts for human parasites, and that consumption of undercooked meat of the animal is required for infection.
<table>
<thead>
<tr>
<th>Question</th>
<th>Subscale and Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. You are visiting a small farm that specializes in production of organic milk products. The dairyman mentions that while being milked that morning, one of his Jerseys passed a large ribbonlike object in her manure. He saved the object to show it to you since he knew you were coming out that afternoon. You examine the object and determine that it is a length of tapeworm.</td>
<td>Conceptual understanding / Clinical problem solving</td>
</tr>
</tbody>
</table>

1. To what taxonomic family does the parasite belong?
   - A Anoplocephalidae
   - B Diphyllobothriidae
   - C Dipyldidae
   - D Hymenolepididae
   - E Taeniidae

2. How did the cow become infected?
   - A Ingesting booklice while grazing
   - B Ingesting copepods while grazing
   - C Ingesting mites while grazing
   - D Ingesting cow feces while grazing
   - E Ingesting human feces while grazing

3. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?
   - A It would be eaten by a copepod
   - B It would be eaten by a fish
   - C It would be eaten by a mammal
   - D It would be eaten by an arthropod (other than a copepod)
   - E It would hatch to release a ciliated stage into the environment

Correct answers are:
1. A
2. C
3. D

This question requires understanding that all cestode parasites of ruminants belong to one taxonomic family and that a non-aquatic arthropod is the intermediate host for these parasites.
**Attitude Toward Taxonomy Questionnaire**

The Attitude Toward Taxonomy questionnaire was intended to address the research question “What are student attitudes and preconceptions concerning taxonomy?” The Health and Psychosocial Instruments (HAPI) database, PubMed, and Google Scholar were searched, using the keywords taxonomy, evolution, classification, and Linnaean, for any existing instruments that could be used for assessing students’ attitudes toward the Linnaean taxonomy. No appropriate instrument was found. Therefore, a semantic differential scale (Cohen, Manion, & Morrison, 2000) consisting of eight questions regarding attitudes toward taxonomy (Appendix F: Attitude Toward Taxonomy Questionnaire) was developed, based on the comments from the focus groups with the fourth-year veterinary students. Two questions unrelated to taxonomy were also included.

**Data Collection Procedure**

Subjects were randomly assigned to either the control group or to one of the three study groups. Students were given the consent form to read and the primary investigator was present to answer any questions. Upon completion of the consent process, the subjects were instructed to place their consent forms into a 9x12 brown clasp envelope labeled with their subject number. Subjects were then asked to complete the Attitude Toward Taxonomy Questionnaire (see Appendix F, page 127). This was followed by the pretest (see Appendix, page 167). Subjects were given 10 minutes to complete the pretest. The pretest consisted of recall and recognition questions to assess factual recall, as well as short case vignettes intended to assess understanding and knowledge synthesis.

After completing the pretest, students were instructed to place the test into their 9x12 brown envelope. They were then given the intervention study material appropriate for their
randomly assigned study group (see Appendices), and were allowed 30 minutes to review the study material. All four interventions were present in equal numbers and the interventions were randomly distributed to the subjects. Upon completion of the allocated time for the study material, students were instructed to place their intervention materials into their 9x12 brown envelope. A posttest consisting of equivalent questions as the pretest was then administered. Subjects were given 10 minutes to complete the posttest, which was then placed in the 9x12 envelope.

**Data Entry**

All data analyses were performed using SPSS version 17.0 for Mac. For Experiment 1-Proximity and Explicitness, data were entered into SPSS using the coding protocol in Table 15. For Experiment 2-Representation, data were entered into SPSS using the coding protocol in Table 16.

**Table 15: Coding of Data for Experiment 1-Proximity and Explicitness**

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Possible Answer</th>
<th>Coded as</th>
<th>Possible Answer</th>
<th>Coded as</th>
<th>Possible Answer</th>
<th>Coded as</th>
<th>Possible Answer</th>
<th>Coded as</th>
<th>Possible Answer</th>
<th>Coded as</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Blank</td>
<td>0</td>
<td>Checked</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Q2</td>
<td>Unanswered</td>
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<td>Yes</td>
<td>1</td>
<td>No</td>
<td>2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>Q3</td>
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<td>Checked</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Q4</td>
<td>Unanswered</td>
<td>0</td>
<td>1-9</td>
<td>1-9</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Q5</td>
<td>Unanswered</td>
<td>0</td>
<td>Yes</td>
<td>1</td>
<td>No</td>
<td>2</td>
<td>Both yes and no</td>
<td>3</td>
<td>Both yes and no</td>
<td>3</td>
</tr>
<tr>
<td>Q6</td>
<td>Unanswered</td>
<td>0</td>
<td>Yes</td>
<td>1</td>
<td>No</td>
<td>2</td>
<td>Need more information</td>
<td>3</td>
<td>Need more information</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 16: Coding of Data for Experiment 2-Representation**

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Possible Answer</th>
<th>Coded as</th>
<th>Possible Answer</th>
<th>Coded as</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Blank</td>
<td>0</td>
<td>Checked</td>
<td>1</td>
</tr>
<tr>
<td>Q2</td>
<td>Blank</td>
<td>0</td>
<td>Checked</td>
<td>1</td>
</tr>
<tr>
<td>Q3</td>
<td>Blank</td>
<td>0</td>
<td>Checked</td>
<td>1</td>
</tr>
<tr>
<td>Q4</td>
<td>Unanswered</td>
<td>0</td>
<td>A-E</td>
<td>1-5</td>
</tr>
<tr>
<td>Q5</td>
<td>Unanswered</td>
<td>0</td>
<td>A-E</td>
<td>1-5</td>
</tr>
<tr>
<td>Q6</td>
<td>Unanswered</td>
<td>0</td>
<td>A-E</td>
<td>1-5</td>
</tr>
</tbody>
</table>
Data Screening

Accuracy of data entry was checked by double-checking the paper forms against the entered data. The SPSS procedure FREQUENCIES was run to check for out of range values and that sample sizes reported for each variable were correct.

Data Scoring

An answer key for each pretest and posttest was completed by Dr. Thomas Craig of Texas A&M University. Each result was then marked as correct or incorrect by using the SPSS command RECODE to recode each answer into a new variable, named identically to the original variable but with the suffix “_correct” added. Incorrect and blank or unanswered questions were coded as 0 and correct answers were coded as 1. Next, the SPSS procedure COMPUTE was used to calculate the total score for each question; this value was stored in a new variable named according to the following syntax: “Q#”_“Pre or Post”_Score.

Pretest or posttest questions that were left unanswered by the subject were treated in the same manner as they would be on a regular examination; that is, they were assigned a value of 0 (zero) and counted as incorrect. For this reason, no adjustments were made to the data file for missing data.

Quality Control of Data Scoring

The large number of subjects and variables precluded manual checking after executing RECODE and COMPUTE syntaxes. Therefore, quality control of these file manipulations was performed by creating quality control (QC) subjects in the data file. The first QC subject contained answers that matched the answer key. Ten additional QC subjects were added to contain combinations of incorrect answers. The expected result after any recoding or computational manipulation would be that QC subject one would maintain a 100% score, and that all other QC
subjects would maintain a 0% score. After each recode step, the QC subjects were immediately checked to make sure that the expected results were obtained. If unexpected results were obtained, the changes were rolled back and the erroneous syntax was corrected and rerun.

To ensure that these QC subjects were not included in any data analysis, a variable was added to the data file for “Consent form signed?” and this variable was marked as 0 for these subjects. All data analyses were conducted by first using the SPSS command SELECT CASES to select only subjects that had the variable “Consent form signed?” value set to 1, thereby filtering out the QC subjects.

**Data Analysis**

Analysis of data for Experiment 1 and Experiment 2 followed the plan shown in Figure 24. The relationships between pre- and posttest scores were first tested for significance for potential use of the pretest as a covariate. A GLM repeated measures analysis of variance was then performed. Experiment 1 had two between-subjects factors (proximity and explicitness) and one within-subjects factor (occasion) as independent variables, and six subscale scores of the pre- and posttest as dependent variables. Experiment 2 had two between-subject factors (representation
and proximity) and one within-subjects factor (occasion) as independent variables, and four subscale scores of the pre- and posttest as dependent variables. In both experiments, assessment of correlations between subscales and univariate analysis of subscales was performed following any statistically significant multivariate analysis result. The Fisher protected t strategy was used to address alpha level inflation control (Carmer & Swanson, 1973).

Analysis of data from the Attitude Toward Taxonomy questionnaire was limited to descriptive statistics. Number of subjects, mean, and standard deviation were reported along with frequency histograms of percentage of responses.

**Summary**

This chapter described the design and methods for two experiments and one questionnaire that were developed to answer research questions concerning proximity, explicitness, and representation. This chapter also discussed the pilot research that informed the development of the research questions and methods. The study subjects and procedures for data collection and data entry were also described. The next chapter describes the data analysis and findings from the two experiments and questionnaire.
Chapter IV
Data Analysis and Findings

Introduction

This chapter presents the data analysis and findings of Experiment 1, Experiment 2, and the Attitude Toward Taxonomy questionnaire. The study subjects were a convenience sample of 125 second-year veterinary students in a large college of veterinary medicine in the state of Texas and who matriculated in 2007. The study was conducted in the parasitology laboratory during regularly scheduled course laboratory hours.

Experiment 1: Proximity and Explicitness in Textual Representation

Research Questions

Experiment 1 was designed to address the following research questions:

Q1. Do textual representations that place appropriate information in close spatial proximity improve student learning as measured by pretest/posttest scores when compared to textual representations that do not place this information in close spatial proximity?

Q2. Do textual representations that provide explicit information improve student learning as measured by pretest/posttest scores when compared to textual representations that do not provide explicit information?

To address these research questions, both multivariate repeated measures analysis and multivariate analysis of covariance using pretest subscale scores as covariates were implemented.
Pretest vs. Posttest Scores

An analysis of variance using SPSS’s GLM REPEATED MEASURES procedure was performed. Descriptive statistics are given in Table 17. Pre- versus posttest constituted a within-subjects factor, and proximity and explicitness were used as between-subjects factors. Pretest and posttest scores constituted the dependent variables. Levene’s test of equality of error variances indicated the assumption of homogeneity of variances was not violated (pre-test: $F = 1.288, df = 3/120, p > .05$; post-test: $F = 2.011, df = 3/120, p > .05$).

<table>
<thead>
<tr>
<th></th>
<th>Proximity</th>
<th>Explicitness</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pretest score</strong></td>
<td>Absent</td>
<td>Absent</td>
<td>27.06</td>
<td>3.473</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td></td>
<td>26.81</td>
<td>3.763</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>26.94</td>
<td>3.596</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>Present</td>
<td>26.68</td>
<td>4.658</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td></td>
<td>26.70</td>
<td>3.949</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>26.69</td>
<td>4.288</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>Total</td>
<td>26.87</td>
<td>4.079</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td></td>
<td>26.76</td>
<td>3.823</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>26.81</td>
<td>3.937</td>
<td>124</td>
</tr>
<tr>
<td><strong>Posttest score</strong></td>
<td>Absent</td>
<td>Absent</td>
<td>31.35</td>
<td>4.239</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td></td>
<td>33.78</td>
<td>3.210</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>32.59</td>
<td>3.917</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>Present</td>
<td>33.29</td>
<td>4.503</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td></td>
<td>33.53</td>
<td>4.329</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>33.41</td>
<td>4.383</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>Total</td>
<td>32.32</td>
<td>4.446</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td></td>
<td>33.66</td>
<td>3.763</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>32.99</td>
<td>4.156</td>
<td>124</td>
</tr>
</tbody>
</table>
As shown in Table 18, posttest scores were significantly superior to pretest scores at the .05 level ($F=202.845$, $df = 1/120$, $p < .001$). Posttest scores were significantly superior to pretest scores overall by approximately 1.5 standard deviations, meaning the posttest mean was at approximately the 93rd percentile relative to the pretest mean.

Table 18: Tests of Within-Subjects Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>Sig.</th>
<th>Observed Power&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>PreVsPost</td>
<td>2363.884</td>
<td>1</td>
<td>2363.884</td>
<td>202.845</td>
<td>.001</td>
<td>1.000</td>
</tr>
<tr>
<td>PreVsPost * Proximity</td>
<td>18.527</td>
<td>1</td>
<td>18.527</td>
<td>1.590</td>
<td>.210</td>
<td>.240</td>
</tr>
<tr>
<td>PreVsPost * Explicit</td>
<td>32.546</td>
<td>1</td>
<td>32.546</td>
<td>2.793</td>
<td>.097</td>
<td>.381</td>
</tr>
<tr>
<td>PreVsPost * Proximity * Explicit</td>
<td>23.400</td>
<td>1</td>
<td>23.400</td>
<td>2.008</td>
<td>.159</td>
<td>.290</td>
</tr>
<tr>
<td>Error (PreVsPost)</td>
<td>1398.439</td>
<td>120</td>
<td>11.654</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Computed using alpha = .05

However, the results of the repeated measures analysis of variance indicated that neither proximity nor explicitness significantly (alpha=.05) improved test performance in comparison with controls (Table 19).

Table 19: Tests of Between-Subjects Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>Sig.</th>
<th>Observed Power&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>110812.669</td>
<td>1</td>
<td>110812.669</td>
<td>10571.203</td>
<td>.001</td>
<td>1.000</td>
</tr>
<tr>
<td>Proximity</td>
<td>2.733</td>
<td>1</td>
<td>2.733</td>
<td>.261</td>
<td>.611</td>
<td>.080</td>
</tr>
<tr>
<td>Explicit</td>
<td>11.529</td>
<td>1</td>
<td>11.529</td>
<td>1.100</td>
<td>.296</td>
<td>.180</td>
</tr>
<tr>
<td>Proximity * Explicit</td>
<td>7.056</td>
<td>1</td>
<td>7.056</td>
<td>.673</td>
<td>.414</td>
<td>.129</td>
</tr>
<tr>
<td>Error</td>
<td>1257.900</td>
<td>120</td>
<td>10.483</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Computed using alpha = .05
Profile plots of Estimated Marginal Means (Figure 25) indicated that gains were occurring over time.

![Figure 25: Profile plots of Estimated Marginal Means](image)

*Pretest vs. Posttest Subscales*

Although there was no significant difference in total test score for either proximity or explicitness at the test level, the significance of the within-subjects pretest versus posttest scores justified investigating each of the subscales. Multivariate analysis of covariance using pretest subscale scores as covariates was then performed, with pre- versus post as the within-subjects factor and the six subscale scores as dependent variables. Two between-subjects factors, proximity and explicitness, were used. Descriptive statistics are given in Table 20. A preliminary analysis revealed that the response from Q10 from the Attitude Toward Taxonomy Questionnaire, “Did you have any parasitology coursework prior to this semester?”, could not be used as a statistically significant covariate (F=.006, df=1, 119, p = .96).

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Proximity</th>
<th>Explicitness</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1_Pre_Score</td>
<td>Absent</td>
<td>Absent</td>
<td>7.58</td>
<td>.807</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>Present</td>
<td>7.59</td>
<td>.837</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>7.59</td>
<td>.816</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td>Absent</td>
<td>7.39</td>
<td>.803</td>
<td>31</td>
</tr>
<tr>
<td>Proximity</td>
<td>Explicitness</td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
<td>------</td>
<td>----------------</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>7.53</td>
<td>.900</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7.52</td>
<td>.831</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
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<td>.805</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7.52</td>
<td>.831</td>
<td>124</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1_Post_Score</td>
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<td>.790</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>8.94</td>
<td>.246</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8.67</td>
<td>.777</td>
<td>63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>7.97</td>
<td>.875</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>8.67</td>
<td>.711</td>
<td>30</td>
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</tr>
<tr>
<td>Total</td>
<td>8.31</td>
<td>.867</td>
<td>61</td>
<td></td>
<td></td>
</tr>
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<td>7.94</td>
<td>.827</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>8.81</td>
<td>.538</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8.37</td>
<td>.821</td>
<td>124</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>6.26</td>
<td>1.483</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>6.12</td>
<td>2.075</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6.19</td>
<td>1.795</td>
<td>63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>6.13</td>
<td>1.962</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>5.83</td>
<td>2.291</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.98</td>
<td>2.117</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6.19</td>
<td>1.726</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>5.98</td>
<td>2.169</td>
<td>62</td>
<td></td>
<td></td>
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</table>
The between-subjects data (Table 21) showed a significant difference between the presence versus absence of explicitness, $F(6, 115) = 4.70, p < .001$, Wilks’ Lambda = .80; partial eta squared = .197. In contrast, there was no significant difference between the presence versus absence of proximity, $F(6, 115) = 1.497, p = .185$, Wilks’ Lambda = .93; partial eta squared = .07. This indicates that there are significant differences in explicitness that do not depend on proximity.

The within-subjects data shown in Table 21 indicated subjects had a significant gain over time when the interaction of pretest scores, posttest scores, and explicitness was considered $F(6,115) = 6.58, p < .001$, Wilks’ Lambda = .74; partial eta squared = .999. This indicates differential gains for explicitness, present versus absent, and appears to be reflected on at least one question in greater gains for the explicitness present treatment.

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Table 21: Multivariate Statistics, GLM Repeated Measures for Pre- and Post-Test Subscales

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<th>F</th>
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<th>Error df</th>
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a. Exact statistic
As shown in Table 22, gains due to explicitness were localized on Q1, which addressed conceptual understanding ($p < .001$, alpha = .05), and Q3, which addressed the relationship between taxonomy and intermediate host ($p = .041$, alpha = .05).

Table 22: Tests of Between-Subjects Effects, GLM Repeated Measures for Pre- and Post-Test Subscales

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<th>Source</th>
<th>Subscale and Description</th>
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<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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<td>Q5 Body Site + Intermediate Host</td>
<td>.060</td>
<td>1</td>
<td>.060</td>
<td>.133</td>
<td>.716</td>
<td>.065</td>
</tr>
<tr>
<td></td>
<td>Q6 Conceptual understanding / Clinical problem solving</td>
<td>.939</td>
<td>1</td>
<td>.939</td>
<td>1.004</td>
<td>.318</td>
<td>.169</td>
</tr>
<tr>
<td>Explicit</td>
<td>Q1 Conceptual understanding</td>
<td>6.936</td>
<td>1</td>
<td>6.936</td>
<td>19.177</td>
<td>.000</td>
<td>.991</td>
</tr>
<tr>
<td></td>
<td>Q2 Taxonomy [Genus level] + Intermediate Host</td>
<td>.254</td>
<td>1</td>
<td>.254</td>
<td>.128</td>
<td>.721</td>
<td>.065</td>
</tr>
<tr>
<td></td>
<td>Q3 Taxonomy [Order level] + Intermediate Host</td>
<td>2.691</td>
<td>1</td>
<td>2.691</td>
<td>4.274</td>
<td>.041</td>
<td>.536</td>
</tr>
<tr>
<td></td>
<td>Q4 Taxonomy + Body Site</td>
<td>.560</td>
<td>1</td>
<td>.560</td>
<td>.309</td>
<td>.579</td>
<td>.086</td>
</tr>
<tr>
<td></td>
<td>Q5 Body Site + Intermediate Host</td>
<td>.519</td>
<td>1</td>
<td>.519</td>
<td>1.151</td>
<td>.286</td>
<td>.186</td>
</tr>
<tr>
<td></td>
<td>Q6 Conceptual understanding / Clinical problem solving</td>
<td>.120</td>
<td>1</td>
<td>.120</td>
<td>.128</td>
<td>.721</td>
<td>.065</td>
</tr>
<tr>
<td>Proximity * Explicit</td>
<td>Q1 Conceptual understanding</td>
<td>.079</td>
<td>1</td>
<td>.079</td>
<td>.219</td>
<td>.641</td>
<td>.075</td>
</tr>
<tr>
<td></td>
<td>Q2 Taxonomy [Genus level] + Intermediate Host</td>
<td>3.744</td>
<td>1</td>
<td>3.744</td>
<td>1.884</td>
<td>.172</td>
<td>.275</td>
</tr>
<tr>
<td></td>
<td>Q3 Taxonomy [Order level] + Intermediate Host</td>
<td>.000</td>
<td>1</td>
<td>.000</td>
<td>.000</td>
<td>.991</td>
<td>.050</td>
</tr>
<tr>
<td></td>
<td>Q4 Taxonomy + Body Site</td>
<td>.380</td>
<td>1</td>
<td>.380</td>
<td>.210</td>
<td>.648</td>
<td>.074</td>
</tr>
<tr>
<td></td>
<td>Q5 Body Site + Intermediate Host</td>
<td>.147</td>
<td>1</td>
<td>.147</td>
<td>.327</td>
<td>.569</td>
<td>.088</td>
</tr>
<tr>
<td></td>
<td>Q6 Conceptual understanding / Clinical problem solving</td>
<td>.039</td>
<td>1</td>
<td>.039</td>
<td>.042</td>
<td>.838</td>
<td>.055</td>
</tr>
<tr>
<td>Error</td>
<td>Q1 Conceptual understanding</td>
<td>43.402</td>
<td>120</td>
<td>.362</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. Computed using alpha = 0.5
c. Design: Intercept + Proximity + Explicit + Proximity * Explicit Within Subjects Design: PreVsPost
As shown in Table 23, univariate analysis indicated a statistically significant two-way interaction at the .05 level between the pre-versus-post test difference and the level of explicitness for two subscales: Q1 (Conceptual Understanding subscale) and Q3 (Taxonomy + Intermediate Host / Order Level subscale).

Q1: $F(1) = 20.741$, $p < .001$, partial eta squared = .147

Q3: $F(1) = 12.959$, $p < .001$, partial eta squared = .097

Univariate analysis also indicated a statistically significant two-way interaction at the .05 level between the pre-versus-post test difference and the level of proximity for subscale Q2 (Taxonomy [Genus Level] + Intermediate Host subscale).

Q2: $F(1) = 3.910$, $p = .050$, partial eta squared = .032
Effect sizes were calculated for the subscales that showed significant effects, using the following formula, for the explicitness present (versions 3 and 4) and explicitness absent (versions 1 and 2) groups.

Standardized effect size = difference in posttest means / average of post-test standard deviations

Q1 (Basic Concepts subscale)

\[
\text{Standardized effect size} = \frac{8.81 - 7.94}{(0.827 + 0.538)/2} = \frac{0.87}{1.189} = 1.28
\]
Q2 (Taxonomy + Intermediate Host / Genus Level subscale)
Standardized effect size $= \frac{7.97 - 7.94}{(1.983 + 1.668)/2} = 0.03$  
Standardized effect size $= \frac{(1.983 + 1.668)/2}{1.826}$

Q3 (Taxonomy + Intermediate Host / Order Level subscale)
Standardized effect size $= \frac{4.39 - 3.63}{(1.204 + .998)/2} = 0.76$  
Standardized effect size $= \frac{(1.204 + .998)/2}{1.101}$

The calculated standardized effect sizes were then compared to a table of z-score probabilities (Table 24) (Table of z-score probabilities, retrieved from http://techniques.geog.ox.ac.uk/mod_2/tables/z-score.htm on 7/19/2003).

Table 24: Standardized effect sizes, z-scores, and probabilities

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Z-Score</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>1.28</td>
<td>0.8997</td>
</tr>
<tr>
<td>Q2</td>
<td>0.02</td>
<td>0.5080</td>
</tr>
<tr>
<td>Q3</td>
<td>0.69</td>
<td>0.7549</td>
</tr>
</tbody>
</table>

**Chi-square**

Chi-square tests for independence were performed using SPSS’s CROSSTABS procedure. The two factors, proximity and explicitness, were contrasted with two post-test items from the Q1 Basic Concepts subscale: Taxonomy and Organ. These items were selected specifically because they were the correct responses on the subscale. Yates Continuity Correction was applied because a 2x2 table was used (Pallant, 2007, p. 216).

Table 25: Chi-square results

<table>
<thead>
<tr>
<th></th>
<th>$\chi^2$</th>
<th>df</th>
<th>n</th>
<th>p</th>
<th>phi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxonomy</td>
<td>3.31</td>
<td>1</td>
<td>124</td>
<td>.069</td>
<td>-.190</td>
</tr>
<tr>
<td>Organ</td>
<td>0.10</td>
<td>1</td>
<td>124</td>
<td>.746</td>
<td>-.046</td>
</tr>
<tr>
<td>Explicitness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxonomy</td>
<td>1.38</td>
<td>1</td>
<td>124</td>
<td>.241</td>
<td>.132</td>
</tr>
<tr>
<td>Organ</td>
<td>42.34</td>
<td>1</td>
<td>124</td>
<td>.000</td>
<td>.601</td>
</tr>
</tbody>
</table>

These results indicate no significant association between proximity and either the posttest Taxonomy item or the posttest Organ item. There was also no significant association between explicitness and the Taxonomy item. However, there was a significant association between explicitness and the Organ item, $\chi^2(1, n = 124) = 42.34, p < .000, \phi = .601$. 
The likelihood of answering the Taxonomy question (Q1) correctly when explicitness was present was then reviewed. The risk estimate is given in Table 26 and the cross tabulations are given in Table 27. These tables indicate that when explicitness was present, subjects had odds 22 times those of subjects without explicitness of answering Q1 correctly on the posttest. The implications of this finding are discussed in Chapter 5.

Table 26: Risk Estimate, explicitness x Q1 Post Organ correct

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Odds Ratio for Explicitness (0 / 1)</td>
<td>22.257</td>
<td>7.752</td>
</tr>
<tr>
<td>For cohort Q1 Post Taxonomic correct = 0</td>
<td>8.200</td>
<td>3.473</td>
</tr>
<tr>
<td>For cohort Q1 Post Taxonomic correct = 1</td>
<td>0.368</td>
<td>0.258</td>
</tr>
<tr>
<td>N of valid cases</td>
<td>124</td>
<td></td>
</tr>
</tbody>
</table>

Table 27: Cross Tabulations, explicitness x Q1 Post Organ correct

<table>
<thead>
<tr>
<th>Explicitness</th>
<th>Q1 Post Organ correct</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Count</td>
<td>41</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Expected Count</td>
<td>23.0</td>
<td>39.0</td>
</tr>
<tr>
<td>% within Explicitness</td>
<td>66.1%</td>
<td>33.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td>% within Q1 Post Organ correct</td>
<td>89.1%</td>
<td>26.9%</td>
<td>50.0%</td>
</tr>
<tr>
<td>% of Total</td>
<td>33.1%</td>
<td>16.9%</td>
<td>50.0%</td>
</tr>
<tr>
<td>Residual</td>
<td>18.0</td>
<td>-18.0</td>
<td></td>
</tr>
<tr>
<td>Std. Residual</td>
<td>3.8</td>
<td>-2.9</td>
<td></td>
</tr>
<tr>
<td>Adjusted Residual</td>
<td>6.7</td>
<td>-6.7</td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td>5</td>
<td>57</td>
<td>62</td>
</tr>
<tr>
<td>Expected Count</td>
<td>23.0</td>
<td>39.0</td>
<td>62.0</td>
</tr>
<tr>
<td>% within Explicitness</td>
<td>8.1%</td>
<td>91.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td>% within Q1 Post Organ correct</td>
<td>10.9%</td>
<td>73.1%</td>
<td>50.0%</td>
</tr>
<tr>
<td>% of Total</td>
<td>4.0%</td>
<td>46.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td>Residual</td>
<td>-18.0</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td>Std. Residual</td>
<td>-3.8</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Adjusted Residual</td>
<td>-6.7</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>46</td>
<td>78</td>
</tr>
<tr>
<td>Expected Count</td>
<td>46.0</td>
<td>78.0</td>
<td>124.0</td>
</tr>
<tr>
<td>% within Explicitness</td>
<td>37.1%</td>
<td>62.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td>% within Q1 Post Organ correct</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>% of Total</td>
<td>37.1%</td>
<td>62.9%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Experiment 2: Representation and Proximity

Research Questions

Experiment 2 was designed to address the following research questions:

Q3. Do learning materials with tables that include detailed information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials with tabular representations that do not include detailed information?

Q4. Do learning materials with graphical representations (concept maps) that place appropriate information in close spatial proximity significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials that include tabular representations?

Q5. Do learning materials with partial concept maps that place a subset of information in proximity to the appropriate text significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials without partial concept maps?

Q6. Do learning materials with tables with detailed information, full concept maps, and partial concept maps, significantly improve student learning, as measured by the student’s ability to solve clinical case scenarios accurately, compared to materials that include no concept maps and tables without detailed information?
Results for Pretest vs. Posttest Scores

An analysis of variance using SPSS’s GLM REPEATED MEASURES procedure was performed with pre- and posttest scores as the dependent variables. Pre- versus posttest occasion constituted a within-subjects factor, and reading intervention version was used as the between-subjects factor. Levene’s test of equality of error variances indicated the assumption of homogeneity of variances was not violated (pretest: $F = .173, df = 3/118, p > .05$; posttest: $F = .586, df = 3/118, p > .05$).

As shown in Table 28 and Table 29, the results of the repeated measures analysis of variance indicated that the intervention version was not significant at the .05 level, but pretest and posttest scores were significantly different at the .05 level ($F = 400.643, df = 1/118, p < .001$).

Table 28: Tests of Between-Subjects Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>Sig.</th>
<th>Observed Power$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>255001.579</td>
<td>1</td>
<td>255001.579</td>
<td>8379.572</td>
<td>.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Version</td>
<td>61.096</td>
<td>3</td>
<td>20.365</td>
<td>.669</td>
<td>.573</td>
<td>.188</td>
</tr>
<tr>
<td>Error</td>
<td>3590.898</td>
<td>118</td>
<td>30.431</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using alpha = .05

Table 29: Tests of Within-Subjects Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>Sig.</th>
<th>Observed Power$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PreVsPost</td>
<td>11606.932</td>
<td>1</td>
<td>11606.932</td>
<td>400.643</td>
<td>.000</td>
<td>1.000</td>
</tr>
<tr>
<td>PreVsPost * Version</td>
<td>148.393</td>
<td>3</td>
<td>49.464</td>
<td>1.707</td>
<td>.169</td>
<td>.437</td>
</tr>
<tr>
<td>Error (PreVsPost)</td>
<td>3418.546</td>
<td>118</td>
<td>28.971</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using alpha = .05

Figure 26 shows a plot of pre- and posttest means for the four intervention versions.
The following four planned comparisons among intervention versions were then performed to test individual hypotheses:

- **Version 1 versus version 2 (table without details versus table with details).** This comparison tested Hypothesis 3: learning materials with tables that include detailed information in close spatial proximity will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials with tables that do not include elaborations.

- **Version 3 versus version 4 (concept map versus concept maps plus partial concept maps).** This comparison tested Hypothesis 4: when there are tables with detailed information in close spatial proximity, inclusion of both full and partial concept maps will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include only full concept maps.
• Version 1 combined with version 2 versus version 3 combined with version 4 (tables without concept maps versus tables with concept maps). This comparison tested Hypothesis 5: learning materials that include graphical representations (concept maps) that place appropriate information in close spatial proximity will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include tabular representations.

• Version 1 versus version 4 (tables without details versus tables with details plus concept maps plus partial concept maps). This comparison tested Hypothesis 6: learning materials that include tables with detailed information in close spatial proximity, full concept maps, and partial concept maps will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, compared to materials that include no concept maps and tables without detailed information in close spatial proximity.

Each of these comparisons is discussed in the following section. These analyses revealed a significant relationship between Q3 (functional properties of taxonomic families) on the pretest and Q456 (clinical problem solving) on the posttest. The importance of this serendipitous finding is discussed in detail in Chapter 5.
Results for Tables with details vs. Tables without details (Version 1 vs. Version 2)

Descriptive statistics for the planned comparison of tables with details versus without details are given in Table 30.

Table 30: Descriptive statistics for tables with vs. without details (version 1 vs. version 2)

<table>
<thead>
<tr>
<th>Version</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Q1 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (tables without details)</td>
<td>4.60</td>
<td>1.003</td>
<td>30</td>
</tr>
<tr>
<td>2 (tables with details)</td>
<td>4.87</td>
<td>.571</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>4.73</td>
<td>.821</td>
<td>60</td>
</tr>
<tr>
<td>Post Q2 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.80</td>
<td>1.540</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>3.80</td>
<td>1.562</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>3.80</td>
<td>1.538</td>
<td>60</td>
</tr>
<tr>
<td>Post Q3 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>36.40</td>
<td>4.839</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>37.20</td>
<td>4.730</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>36.80</td>
<td>4.761</td>
<td>60</td>
</tr>
<tr>
<td>Post_Q456</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7.77</td>
<td>2.967</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>7.77</td>
<td>2.515</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>7.77</td>
<td>2.727</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 31 presents results from the multivariate analysis of covariance on the multivariate vector of the four posttest scores, using the pretest scores as covariates. When controlling for pretest scores, the intervention version was not significant at the .05 level (F(4,51) = .489, p = .744, Wilks’ Lambda = .963, partial eta squared = .157). However, the pretest covariate for Q3 was significant at the .05 level (F(4,51) = 4.36, p < .01, Wilks’ Lambda = .745, partial eta squared = .909).

Table 31: Multivariate tests\textsuperscript{c} for V1 versus V2 (tables with vs. without details)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Wilks’ Lambda</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Observed Power\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>.400</td>
<td>19.104\textsuperscript{a}</td>
<td>4.000</td>
<td>51.000</td>
<td>.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Pre_Q1_Score</td>
<td>.942</td>
<td>.782\textsuperscript{a}</td>
<td>4.000</td>
<td>51.000</td>
<td>.542</td>
<td>.233</td>
</tr>
<tr>
<td>Pre_Q2_Score</td>
<td>.948</td>
<td>.703\textsuperscript{a}</td>
<td>4.000</td>
<td>51.000</td>
<td>.594</td>
<td>.212</td>
</tr>
<tr>
<td>Pre_Q3_Score</td>
<td>.745</td>
<td>4.356\textsuperscript{a}</td>
<td>4.000</td>
<td>51.000</td>
<td>\textbf{.004}</td>
<td>.909</td>
</tr>
<tr>
<td>Pre_Q456</td>
<td>.894</td>
<td>1.518\textsuperscript{a}</td>
<td>4.000</td>
<td>51.000</td>
<td>.211</td>
<td>.436</td>
</tr>
<tr>
<td>Version</td>
<td>.963</td>
<td>.489\textsuperscript{a}</td>
<td>4.000</td>
<td>51.000</td>
<td>.744</td>
<td>.157</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Exact statistic \textsuperscript{b} Computed using alpha = .05
\textsuperscript{c} Design: Intercept + Pre_Q1_Score + Pre_Q2_Score + Pre_Q3_Score + Pre_Q456 + Version
Table 32 indicates that a significant multivariate relationship ($p < .001$) existed at the .05 level between the pretest score on Q3 (functional properties of taxonomic families) and the multivariate vector of the four posttest scores, and was localized on post Q456 (clinical problem solving).

Table 32: Tests of Between-Subjects Effects for V1 versus V2 (tables with vs. without details)

<table>
<thead>
<tr>
<th>Source</th>
<th>Dependent Variable</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>Sig.</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>Post Q1 Score</td>
<td>3.678a</td>
<td>5</td>
<td>.736</td>
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<td>MS</td>
<td>F</td>
<td>Sig. Observed Power^b</td>
<td></td>
</tr>
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<td>--------------------</td>
<td>-------------</td>
<td>----</td>
<td>-----</td>
<td>-------</td>
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<td></td>
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<tr>
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<td>59</td>
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</tr>
</tbody>
</table>

a. R Squared = .093 (Adjusted R Squared = .009)

b. Computed using alpha = .05

c. R Squared = .072 (Adjusted R Squared = -.013)

d. R Squared = .119 (Adjusted R Squared = .038)

e. R Squared = .275 (Adjusted R Squared = .208)
Results for Concept maps vs. Concept maps plus partial maps (V3 versus V4)

Descriptive statistics for the planned comparison of interventions with concept maps (intervention version 3) versus interventions with concept maps plus partial concept maps (intervention version 4) are given in Table 33.

Table 33: Descriptive statistics (concept maps vs. concept maps plus partial maps)

<table>
<thead>
<tr>
<th>Version</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Q1 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (without partial maps)</td>
<td>4.48</td>
<td>1.061</td>
<td>31</td>
</tr>
<tr>
<td>4 (with partial maps)</td>
<td>4.61</td>
<td>.989</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>4.55</td>
<td>1.019</td>
<td>62</td>
</tr>
<tr>
<td>Post Q2 Score</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.94</td>
<td>1.263</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>3.94</td>
<td>1.504</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>3.94</td>
<td>1.377</td>
<td>62</td>
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<tr>
<td>Post Q3 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>35.77</td>
<td>4.944</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>36.26</td>
<td>4.837</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
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<td>4.857</td>
<td>62</td>
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<tr>
<td>Post Q456</td>
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<td></td>
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</tr>
<tr>
<td>3</td>
<td>7.35</td>
<td>2.199</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>7.94</td>
<td>2.607</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>7.65</td>
<td>2.410</td>
<td>62</td>
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</tbody>
</table>

Table 34 presents results from the multivariate analysis of covariance on the multivariate vector of the four posttest scores, using the pretest scores as covariates. The pretest score for Q3 was significant at the .05 level ($F(4,53) = 5.09, p < .01$, Wilks’ Lambda = .722, partial eta squared = .951).

Table 34: Multivariate tests\(^a\) (concept maps vs. concept maps plus partial maps)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Wilks’ Lambda</th>
<th>$F$</th>
<th>Hypothesis $df$</th>
<th>Error $df$</th>
<th>Sig.</th>
<th>Observed Power(^b)</th>
</tr>
</thead>
<tbody>
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<td>7.240(^a)</td>
<td>4.000</td>
<td>53.000</td>
<td>.000</td>
<td>.993</td>
</tr>
<tr>
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<td>.980</td>
<td>.268(^a)</td>
<td>4.000</td>
<td>53.000</td>
<td>.897</td>
<td>.104</td>
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<tr>
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<td>.884</td>
<td>1.747(^a)</td>
<td>4.000</td>
<td>53.000</td>
<td>.153</td>
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<tr>
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<td>5.092(^a)</td>
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<td>53.000</td>
<td>.002</td>
<td>.951</td>
</tr>
<tr>
<td>Pre_Q456</td>
<td>.901</td>
<td>1.456(^a)</td>
<td>4.000</td>
<td>53.000</td>
<td>.229</td>
<td>.421</td>
</tr>
<tr>
<td>Version</td>
<td>.984</td>
<td>.221(^a)</td>
<td>4.000</td>
<td>53.000</td>
<td>.925</td>
<td>.094</td>
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</tbody>
</table>

\(^a\) Exact statistic  \(^b\) Computed using alpha = .05  
\(^c\) Design: Intercept + Pre_Q1_Score + Pre_Q2_Score + Pre_Q3_Score + Pre_Q456 + Version
Table 35 indicates that a significant multivariate relationship ($p < .001$) existed at the .05 level between the pretest score on Q3 (functional properties of taxonomic families) and the multivariate vector of the four posttest scores, and was localized on post Q1 (taxonomic structure at the order level).

Table 35: Tests of Between-Subjects Effects (concept maps with vs. without partial maps)

<table>
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<tr>
<th>Source</th>
<th>Dependent Variable</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>Sig</th>
<th>Observed Power</th>
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</thead>
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<td>2.836</td>
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<tr>
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<td>271.844</td>
<td>56</td>
<td>4.854</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Total</td>
<td>Post Q1 Score</td>
<td>1346.000</td>
<td>62</td>
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</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>1076.000</td>
<td>62</td>
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</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>81863.000</td>
<td>62</td>
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</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>3978.000</td>
<td>62</td>
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<td></td>
</tr>
<tr>
<td>Source</td>
<td>Dependent Variable</td>
<td>Type III SS</td>
<td>df</td>
<td>MS</td>
<td>F</td>
<td>Sig.</td>
<td>Observed Power</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
<td>-------------</td>
<td>----</td>
<td>-------</td>
<td>----</td>
<td>------</td>
<td>----------------</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>Post Q1 Score</td>
<td>63.355</td>
<td>61</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>115.742</td>
<td>61</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>1438.984</td>
<td>61</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Post Q456</td>
<td>354.194</td>
<td>61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. R Squared = .224 (Adjusted R Squared = .155)
b. Computed using alpha = .05
c. R Squared = .083 (Adjusted R Squared = .001)
d. R Squared = .065 (Adjusted R Squared = -.019)
e. R Squared = .232 (Adjusted R Squared = .164)
Results for Tables without concept maps vs. Tables with concept maps (V1+V2 versus V3+V4)

Descriptive statistics for the planned comparison of interventions with tables without concept maps (interventions versions 1 and 2) versus interventions with tables and maps (intervention versions 3 and 4) are given in Table 36.

Table 36: Descriptive statistics for V1+V2 vs. V3+V4 (tables without maps vs. tables with maps)

<table>
<thead>
<tr>
<th>Version</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Q1 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version 1 and 2 combined</td>
<td>4.73</td>
<td>.821</td>
<td>60</td>
</tr>
<tr>
<td>Version 3 and 4 combined</td>
<td>4.55</td>
<td>1.019</td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>4.64</td>
<td>.928</td>
<td>122</td>
</tr>
<tr>
<td>Post Q2 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version 1 and 2 combined</td>
<td>3.80</td>
<td>1.538</td>
<td>60</td>
</tr>
<tr>
<td>Version 3 and 4 combined</td>
<td>3.94</td>
<td>1.377</td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>3.87</td>
<td>1.454</td>
<td>122</td>
</tr>
<tr>
<td>Post Q3 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version 1 and 2 combined</td>
<td>36.80</td>
<td>4.761</td>
<td>60</td>
</tr>
<tr>
<td>Version 3 and 4 combined</td>
<td>36.02</td>
<td>4.857</td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>36.40</td>
<td>4.806</td>
<td>122</td>
</tr>
<tr>
<td>Post Q456</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version 1 and 2 combined</td>
<td>7.77</td>
<td>2.727</td>
<td>60</td>
</tr>
<tr>
<td>Version 3 and 4 combined</td>
<td>7.65</td>
<td>2.410</td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>7.70</td>
<td>2.561</td>
<td>122</td>
</tr>
</tbody>
</table>

Table 37 presents results from the multivariate analysis of covariance on the multivariate vector of the four posttest scores, using the pretest scores as covariates. The pretest score for Q3 was significant at the .05 level ($F(4,113) = 3.94$, $p < .01$, Wilks' Lambda = .878, partial eta squared = .894).

Table 37: Multivariate tests\(^c\) for V1+V2 vs. V3+V4 (tables vs. tables + maps)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Wilks' Lambda</th>
<th>$F$</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Observed Power(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>.547</td>
<td>23.428(^a)</td>
<td>4.000</td>
<td>113.000</td>
<td>.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Pre_Q1_Score</td>
<td>.987</td>
<td>.364(^a)</td>
<td>4.000</td>
<td>113.000</td>
<td>.834</td>
<td>.131</td>
</tr>
<tr>
<td>Pre_Q2_Score</td>
<td>.929</td>
<td>2.146(^a)</td>
<td>4.000</td>
<td>113.000</td>
<td>.080</td>
<td>.619</td>
</tr>
<tr>
<td>Pre_Q3_Score</td>
<td>.878</td>
<td>3.943(^a)</td>
<td>4.000</td>
<td>113.000</td>
<td><strong>.005</strong></td>
<td>.894</td>
</tr>
<tr>
<td>Pre_Q456</td>
<td>.929</td>
<td>2.171(^a)</td>
<td>4.000</td>
<td>113.000</td>
<td>.077</td>
<td>.625</td>
</tr>
<tr>
<td>Version12vs34</td>
<td>.986</td>
<td>.407(^a)</td>
<td>4.000</td>
<td>113.000</td>
<td>.803</td>
<td>.141</td>
</tr>
</tbody>
</table>

\(^a\) Exact statistic  \(^b\) Computed using alpha = .05  \(^c\) Design: Intercept + Pre_Q1_Score + Pre_Q2_Score + Pre_Q3_Score + Pre_Q456 + Version12vs34
Table 38 indicates that a significant multivariate relationship existed at the .05 level between the pretest score on Q3 and the multivariate vector of the four posttest scores, and was localized on post Q1 (taxonomic structure at the order level) \((p < .05)\) and post Q456 (case scenarios) \((p < .001)\). A similar significant multivariate relationship also existed between the pretest score on Q456 and the four posttest scores, and was localized on post Q456 \((p < .05)\).

Table 38: Tests of between-subjects effects for V1+V2 versus V3+V4 (tables vs. tables + maps)

<table>
<thead>
<tr>
<th>Source</th>
<th>Dependent Variable</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>Sig.</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>Post Q1 Score</td>
<td>8.743</td>
<td>5</td>
<td>1.749</td>
<td>2.127</td>
<td>.067</td>
<td>.685</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>11.733</td>
<td>5</td>
<td>2.347</td>
<td>1.115</td>
<td>.356</td>
<td>.385</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>195.444</td>
<td>5</td>
<td>39.089</td>
<td>1.744</td>
<td>.130</td>
<td>.584</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>173.408</td>
<td>5</td>
<td>34.682</td>
<td>6.489</td>
<td>.000</td>
<td>.997</td>
</tr>
<tr>
<td>Intercept</td>
<td>Post Q1 Score</td>
<td>20.639</td>
<td>1</td>
<td>20.639</td>
<td>25.099</td>
<td>.000</td>
<td>.999</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>8.184</td>
<td>1</td>
<td>8.184</td>
<td>3.888</td>
<td>.051</td>
<td>.498</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>1489.015</td>
<td>1</td>
<td>1489.015</td>
<td>66.436</td>
<td>.000</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>.046</td>
<td>1</td>
<td>.046</td>
<td>.009</td>
<td>.926</td>
<td>.051</td>
</tr>
<tr>
<td>Pre_Q1_Score</td>
<td>Post Q1 Score</td>
<td>.823</td>
<td>1</td>
<td>.823</td>
<td>1.001</td>
<td>.319</td>
<td>.168</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>.982</td>
<td>1</td>
<td>.982</td>
<td>.467</td>
<td>.496</td>
<td>.104</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>19.984</td>
<td>1</td>
<td>19.984</td>
<td>.892</td>
<td>.347</td>
<td>.155</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>.793</td>
<td>1</td>
<td>.793</td>
<td>.148</td>
<td>.701</td>
<td>.067</td>
</tr>
<tr>
<td>Pre_Q2_Score</td>
<td>Post Q1 Score</td>
<td>2.055</td>
<td>1</td>
<td>2.055</td>
<td>2.499</td>
<td>.117</td>
<td>.348</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>3.549</td>
<td>1</td>
<td>3.549</td>
<td>1.686</td>
<td>.197</td>
<td>.251</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>.037</td>
<td>1</td>
<td>.037</td>
<td>.002</td>
<td>.968</td>
<td>.050</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>12.734</td>
<td>1</td>
<td>12.734</td>
<td>2.383</td>
<td>.125</td>
<td>.334</td>
</tr>
<tr>
<td>Pre_Q3_Score</td>
<td>Post Q1 Score</td>
<td>4.892</td>
<td>1</td>
<td>4.892</td>
<td>5.950</td>
<td>.016</td>
<td>.677</td>
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<tr>
<td></td>
<td>Post Q2 Score</td>
<td>2.331</td>
<td>1</td>
<td>2.331</td>
<td>1.107</td>
<td>.295</td>
<td>.181</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>77.126</td>
<td>1</td>
<td>77.126</td>
<td>3.441</td>
<td>.066</td>
<td>.452</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>71.889</td>
<td>1</td>
<td>71.889</td>
<td>13.451</td>
<td>.000</td>
<td>.953</td>
</tr>
<tr>
<td>Pre_Q456</td>
<td>Post Q1 Score</td>
<td>.528</td>
<td>1</td>
<td>.528</td>
<td>.642</td>
<td>.425</td>
<td>.125</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>1.229</td>
<td>1</td>
<td>1.229</td>
<td>.584</td>
<td>.446</td>
<td>.118</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>42.093</td>
<td>1</td>
<td>42.093</td>
<td>1.878</td>
<td>.173</td>
<td>.274</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>34.053</td>
<td>1</td>
<td>34.053</td>
<td>6.372</td>
<td>.013</td>
<td>.707</td>
</tr>
<tr>
<td>Version12vs34</td>
<td>Post Q1 Score</td>
<td>.382</td>
<td>1</td>
<td>.382</td>
<td>.465</td>
<td>.497</td>
<td>.104</td>
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<td>.572</td>
<td>1</td>
<td>.572</td>
<td>.272</td>
<td>.603</td>
<td>.081</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>7.383</td>
<td>1</td>
<td>7.383</td>
<td>.329</td>
<td>.567</td>
<td>.088</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>.008</td>
<td>1</td>
<td>.008</td>
<td>.001</td>
<td>.969</td>
<td>.050</td>
</tr>
<tr>
<td>Error</td>
<td>Post Q1 Score</td>
<td>95.388</td>
<td>116</td>
<td>.822</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>244.169</td>
<td>116</td>
<td>2.105</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>2599.875</td>
<td>116</td>
<td>22.413</td>
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</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>619.969</td>
<td>116</td>
<td>5.345</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>Post Q1 Score</td>
<td>2730.000</td>
<td>122</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>2082.000</td>
<td>122</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>164455.000</td>
<td>122</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>8036.000</td>
<td>122</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>Post Q1 Score</td>
<td>104.131</td>
<td>121</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>---------</td>
<td>-----</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Q2 Score</td>
<td>255.902</td>
<td>121</td>
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</tr>
<tr>
<td>Post Q3 Score</td>
<td>2795.320</td>
<td>121</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Post_Q456</td>
<td>793.377</td>
<td>121</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. R Squared = .084 (Adjusted R Squared = .044)  
b. Computed using alpha = .0  
c. R Squared = .046 (Adjusted R Squared = .005)  
d. R Squared = .070 (Adjusted R Squared = .030)  
e. R Squared = .219 (Adjusted R Squared = .185)
**Results for V4 versus V1 (Concept Maps, Partial Maps, Tables with Details vs. Tables without Details)**

Descriptive statistics for the planned comparison of interventions with tables with details plus concept maps plus partial maps (intervention version 4) versus interventions with only tables (no details and no concept maps) (intervention version 1) are given in Table 39.

Table 39: Descriptive statistics (maps, partial maps, tables with details vs. tables without details)

<table>
<thead>
<tr>
<th>Version</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Q1 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (tables w/o details)</td>
<td>4.60</td>
<td>1.003</td>
<td>30</td>
</tr>
<tr>
<td>4 (maps, partial maps, tables w/ details)</td>
<td>4.61</td>
<td>.989</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>4.61</td>
<td>.988</td>
<td>61</td>
</tr>
<tr>
<td>Post Q2 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.80</td>
<td>1.540</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>3.94</td>
<td>1.504</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>3.87</td>
<td>1.511</td>
<td>61</td>
</tr>
<tr>
<td>Post Q3 Score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>36.40</td>
<td>4.839</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>36.26</td>
<td>4.837</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>36.33</td>
<td>4.798</td>
<td>61</td>
</tr>
<tr>
<td>Post Q456</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7.77</td>
<td>2.967</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>7.94</td>
<td>2.607</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>7.85</td>
<td>2.768</td>
<td>61</td>
</tr>
</tbody>
</table>

Table 40 presents results from the multivariate analysis of covariance on the multivariate vector of the four posttest scores, using the pretest scores as covariates. The pretest score for Q3 was significant at the .05 level \(F(4,52) = 3.044, \ p < .05\), Wilks’ Lambda = .810, partial eta squared = .767. The pretest score for Q456 was also significant at the .05 level \(F(4,52) = 2.683, \ p < .05\), Wilks’ Lambda .829, partial eta squared = .706.

Table 40: Multivariate Tests’ (maps, partial maps, tables with details vs. tables without details)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Wilks’ Lambda</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Observed Power&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>.594</td>
<td>8.900a</td>
<td>4.000</td>
<td>52.000</td>
<td>.000</td>
<td>.999</td>
</tr>
<tr>
<td>Pre_Q1_Score</td>
<td>.955</td>
<td>.610a</td>
<td>4.000</td>
<td>52.000</td>
<td>.657</td>
<td>.188</td>
</tr>
<tr>
<td>Pre_Q2_Score</td>
<td>.928</td>
<td>1.003a</td>
<td>4.000</td>
<td>52.000</td>
<td>.415</td>
<td>.295</td>
</tr>
<tr>
<td>Pre_Q3_Score</td>
<td>.810</td>
<td>3.044a</td>
<td>4.000</td>
<td>52.000</td>
<td>.025</td>
<td>.767</td>
</tr>
<tr>
<td>Pre_Q456</td>
<td>.829</td>
<td>2.683a</td>
<td>4.000</td>
<td>52.000</td>
<td>.041</td>
<td>.706</td>
</tr>
<tr>
<td>Version</td>
<td>.974</td>
<td>.351a</td>
<td>4.000</td>
<td>52.000</td>
<td>.842</td>
<td>.123</td>
</tr>
</tbody>
</table>

a. Exact statistic
b. Computed using alpha = .05
c. Design: Intercept + Pre_Q1_Score + Pre_Q2_Score + Pre_Q3_Score + Pre_Q456 + Version
Table 41 indicates that a significant multivariate relationship existed at the .05 level between the pretest score on Q3 (functional properties of taxonomic families) and the multivariate vector of the four posttest scores, and was localized on post Q456 (case scenarios) \( (p < .01) \). A similar significant multivariate relationship also existed between the pretest score on Q456 and the four posttest scores, and was localized on post Q3 \( (p < .05) \).

Table 41: Tests of Between-Subjects Effects (maps, partial maps, tables with details vs. tables w/o details)

<table>
<thead>
<tr>
<th>Source</th>
<th>Dependent Variable</th>
<th>Type III SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>Sig.</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>Post Q1 Score</td>
<td>3.785*</td>
<td>5</td>
<td>.757</td>
<td>.760</td>
<td>.582</td>
<td>.253</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>8.176*</td>
<td>5</td>
<td>1.635</td>
<td>.698</td>
<td>.627</td>
<td>.234</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>265.338*</td>
<td>5</td>
<td>53.068</td>
<td>2.615</td>
<td>.034</td>
<td>.762</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>153.292*</td>
<td>5</td>
<td>30.658</td>
<td>5.504</td>
<td>.000</td>
<td>.984</td>
</tr>
<tr>
<td>Intercept</td>
<td>Post Q1 Score</td>
<td>7.036</td>
<td>1</td>
<td>7.036</td>
<td>7.066</td>
<td>.010</td>
<td>.743</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>6.396</td>
<td>1</td>
<td>6.396</td>
<td>2.732</td>
<td>.104</td>
<td>.369</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>358.510</td>
<td>1</td>
<td>358.510</td>
<td>17.667</td>
<td>.000</td>
<td>.985</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>7.060</td>
<td>1</td>
<td>7.060</td>
<td>1.267</td>
<td>.265</td>
<td>.198</td>
</tr>
<tr>
<td>Pre_Q1_Score</td>
<td>Post Q1 Score</td>
<td>.859</td>
<td>1</td>
<td>.859</td>
<td>.862</td>
<td>.357</td>
<td>.149</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>.213</td>
<td>1</td>
<td>.213</td>
<td>.091</td>
<td>.764</td>
<td>.060</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>41.401</td>
<td>1</td>
<td>41.401</td>
<td>2.040</td>
<td>.159</td>
<td>.289</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>4.394</td>
<td>1</td>
<td>4.394</td>
<td>.789</td>
<td>.378</td>
<td>.141</td>
</tr>
<tr>
<td>Pre_Q2_Score</td>
<td>Post Q1 Score</td>
<td>.807</td>
<td>1</td>
<td>.807</td>
<td>.810</td>
<td>.372</td>
<td>.143</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>2.918</td>
<td>1</td>
<td>2.918</td>
<td>1.246</td>
<td>.269</td>
<td>.195</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>3.196</td>
<td>1</td>
<td>3.196</td>
<td>.158</td>
<td>.693</td>
<td>.068</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>6.381</td>
<td>1</td>
<td>6.381</td>
<td>1.146</td>
<td>.289</td>
<td>.183</td>
</tr>
<tr>
<td>Pre_Q3_Score</td>
<td>Post Q1 Score</td>
<td>2.677</td>
<td>1</td>
<td>2.677</td>
<td>2.688</td>
<td>.107</td>
<td>.364</td>
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<tr>
<td></td>
<td>Post Q2 Score</td>
<td>.003</td>
<td>1</td>
<td>.003</td>
<td>.001</td>
<td>.974</td>
<td>.050</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>97.429</td>
<td>1</td>
<td>97.429</td>
<td>4.801</td>
<td>.033</td>
<td>.576</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>53.811</td>
<td>1</td>
<td>53.811</td>
<td>9.660</td>
<td>.003</td>
<td>.863</td>
</tr>
<tr>
<td>Pre_Q456</td>
<td>Post Q1 Score</td>
<td>.060</td>
<td>1</td>
<td>.060</td>
<td>.061</td>
<td>.806</td>
<td>.057</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>2.451</td>
<td>1</td>
<td>2.451</td>
<td>1.047</td>
<td>.311</td>
<td>.171</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>83.976</td>
<td>1</td>
<td>83.976</td>
<td>4.138</td>
<td>.047</td>
<td>.515</td>
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<tr>
<td></td>
<td>Post Q456</td>
<td>45.501</td>
<td>1</td>
<td>45.501</td>
<td>8.168</td>
<td>.006</td>
<td>.802</td>
</tr>
<tr>
<td>Version</td>
<td>Post Q1 Score</td>
<td>.112</td>
<td>1</td>
<td>.112</td>
<td>.113</td>
<td>.738</td>
<td>.063</td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>.682</td>
<td>1</td>
<td>.682</td>
<td>.291</td>
<td>.592</td>
<td>.083</td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>7.504</td>
<td>1</td>
<td>7.504</td>
<td>.370</td>
<td>.546</td>
<td>.092</td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>8.027</td>
<td>1</td>
<td>8.027</td>
<td>1.441</td>
<td>.235</td>
<td>.218</td>
</tr>
<tr>
<td>Error</td>
<td>Post Q1 Score</td>
<td>54.772</td>
<td>55</td>
<td>.996</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>128.774</td>
<td>55</td>
<td>2.341</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>1116.105</td>
<td>55</td>
<td>20.293</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>306.380</td>
<td>55</td>
<td>5.571</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Post Q1 Score</td>
<td>1353.000</td>
<td>61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>1050.000</td>
<td>61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>81884.000</td>
<td>61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q456</td>
<td>4221.000</td>
<td>61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Dependent Variable</td>
<td>Type III SS</td>
<td>df</td>
<td>MS</td>
<td>F</td>
<td>Sig.</td>
<td>Observed Power</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------------</td>
<td>-------------</td>
<td>----</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>----------------</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>Post Q1 Score</td>
<td>58.557</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q2 Score</td>
<td>136.951</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post Q3 Score</td>
<td>1381.443</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post_Q456</td>
<td>459.672</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Attitude Toward Taxonomy Questionnaire

The Attitude Toward Taxonomy questionnaire (Appendix F: Attitude Toward Taxonomy Questionnaire, page 127) was intended to address the research question “What are student attitudes and preconceptions concerning taxonomy?”

Reliability

Internal consistency of the Attitude Toward Taxonomy Questionnaire was evaluated using SPSS’s Reliability Analysis procedure. Two items, “I flipped back and forth in the book and/or notes when studying”, and “Did you have any parasitology coursework prior to this semester?” were not considered in the reliability assessment of the Attitude Toward Taxonomy questionnaire, as they were included on that instrument simply for ease of data collection. Reliability for the remaining eight items on the Attitude Toward Taxonomy questionnaire showed acceptable internal consistency, with a Cronbach alpha coefficient of .74.

Results

One hundred twenty four (124) valid responses were received. Descriptive statistics are given in Table 42.
Table 42: Descriptive statistics: Attitude Toward Taxonomy Questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>Scale</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. In parasitology class, I felt that I generally:</td>
<td>1</td>
<td>124</td>
<td>2.33</td>
<td>.943</td>
</tr>
<tr>
<td>Q2. I felt that in the parasitology course material, similarities of clinical significance were:</td>
<td>1</td>
<td>124</td>
<td>3.22</td>
<td>.822</td>
</tr>
<tr>
<td>Q3. I believe that learning taxonomy helped me understand similarities and differences among parasites.</td>
<td>1</td>
<td>124</td>
<td>3.58</td>
<td>1.052</td>
</tr>
<tr>
<td>Q4. When studying parasite life cycles, I generally:</td>
<td>1</td>
<td>124</td>
<td>3.08</td>
<td>1.468</td>
</tr>
<tr>
<td>Q5. With respect to what I plan to do after graduation, I think learning about taxonomy will be:</td>
<td>1</td>
<td>124</td>
<td>2.77</td>
<td>1.066</td>
</tr>
<tr>
<td>Q6. I felt that learning about taxonomic information such as superfamilies was:</td>
<td>1</td>
<td>124</td>
<td>3.77</td>
<td>.995</td>
</tr>
<tr>
<td>Q7. I flipped back and forth in the book and/or notes when studying:</td>
<td>1</td>
<td>123</td>
<td>3.99</td>
<td>1.246</td>
</tr>
<tr>
<td>Q8: For me, seeing relationships between taxonomy and clinical findings was:</td>
<td>1</td>
<td>124</td>
<td>2.85</td>
<td>.917</td>
</tr>
<tr>
<td>Q9: I felt that learning about parasites for one type of animal helped me learn about related parasites for another animal.</td>
<td>1</td>
<td>124</td>
<td>3.56</td>
<td>1.030</td>
</tr>
<tr>
<td>Q10. Did you have any parasitology coursework prior to this semester?</td>
<td>(Dichotomous: Yes or No)</td>
<td>124</td>
<td>1.73</td>
<td>.448</td>
</tr>
</tbody>
</table>

Histograms of the frequencies for each question are given on the next page.
Q1. In parasitology class, I felt that I generally:
1 Memorized the material <> 5 Understood the material

Q2. I felt that in the parasitology course material, similarities of clinical significance were:
1 Very obscure <> 5 Very obvious

Q3. I believe that learning taxonomy helped me understand similarities and differences among parasites.
1 Not at all <> 5 Definitely

Q4. When studying parasite life cycles, I generally:
1 Memorized them <> 2 Looked for patterns
Q5: With respect to what I plan to do after graduation, I think learning about taxonomy will be:
1 Very unimportant to me <> 5 Very important to me

Q6. I felt that learning about taxonomic information such as superfamilies was:
1 Very unimportant <> 5 Very important

Q7. I flipped back and forth in the book and/or notes when studying. 1 Not at all <> 5 Frequently

Q8: For me, seeing relationships between taxonomy and clinical findings was:
1 Very difficult <> 5 Very easy
Q9: I felt that learning about parasites for one type of animal helped me learn about related parasites for another animal. 1 Rarely <-> 5 Frequently

Q10. Did you have any parasitology coursework prior to this semester? Yes / No

Summary

This chapter presented the data analysis and findings of the two experiments and the Attitude Toward Taxonomy questionnaire. The study subjects were a convenience sample of 125 second-year veterinary students in a large college of veterinary medicine in the state of Texas and who matriculated in 2007.

The results from Experiment 1 (proximity and explicitness) found no significant difference between the presence or absence of proximity, $F(6, 115) = .775, p = .591$, Wilks’ lambda = .961. In contrast, there was a significant difference between the presence or absence of explicitness, $F(6, 115) = 6.58, p < .001$, Wilks’ lambda = .744. Investigation of the effect of explicitness found that subjects who were given the explicit rule were 22 times more likely to answer the corresponding factual recognition question (Q1) correctly than were subjects not given the explicit rule. Both groups gained significantly over time, but the group with explicitness present gained significantly more. The gains due to explicitness were localized on Q1, which addressed conceptual
understanding ($p < .001$, alpha = .05), and Q3, which addressed the relationship between taxonomy and intermediate host ($p = .041$, alpha = .05). However, these gains had no significant effect on Q6, the clinical problem solving question. The presence of an explicit rule had no significant effect on subjects’ ability to correctly answer the clinical problems posed in Q6. In other words, on the posttest, subjects who had been given the explicit rule were able to correctly recognize the parts of the rule; however, they were not able to correctly implement the rule in clinical problem solving. Even though a significant effect of explicitness was found on the ability of subjects to identify the rule, the two null hypotheses addressed by this experiment concerned the effect of proximity and explicitness on the ability to solve clinical problems. Therefore, these two null hypotheses could not be rejected. Possible reasons for this finding are discussed in the next chapter.

The results from Experiment 2 (representation and proximity) found no significant difference in subjects’ clinical problem solving ability, regardless of the type of representation used. Subjects performed at approximately the same level whether they were given a table with no additional detailed information, a table with details, a table with details and a concept map, or a table with details, a concept map, and partial concept maps placed in proximity to the relevant text passage. Therefore, the four null hypotheses addressed by this experiment, $H_03$, $H_04$, $H_05$, and $H_06$, could not be rejected.

However, Experiment 2 found a powerful relationship ($p < .001$) between the pretest question regarding functional properties of taxonomic families (Q3) and the ability of students to correctly solve the clinical cases (Q456). While not related to the research questions, the significance of this serendipitous finding is discussed in depth in Chapter 5.

The Attitude Toward Taxonomy questionnaire was used to assess student attitudes toward taxonomy. A question regarding proximity of material in their text or class notes was included for
convenience. This question found that using a five-point semantic differential scale of 1=Never and 5=Frequently, a majority of students “flipped back and forth in their book or notes when studying” (mean = 3.99, $SD = 1.246$). Two questions regarding memorization were also included. While one question (Q1) indicated a tendency of students to memorize (mean=2.33, $SD=.943$), another question (Q4) found a fairly even distribution of learning styles, from memorization to looking for patterns.

The next chapter presents conclusions and discussion based on the findings of the research, which investigated the effects of proximity, explicitness, and representation of basic science material on student clinical problem solving. Implications and recommendations for further study are also presented in the following chapter.
Chapter V
Conclusions, Discussion, Implications, and Recommendations

This chapter presents conclusions and discussion based on the findings of the research, which investigated the effects of proximity, explicitness, and representations (PER) of basic science material on student clinical problem solving. Implications and recommendations for further study are presented. The chapter concludes with a summary.

Conclusions

Proximity and Explicitness Experiment (Experiment 1)

The first hypothesis investigated in this study was that learning materials that place significant information in proximity will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, as compared to learning materials that utilize a typical text representation. This study found no significant difference in total test score for proximity at the test level. However, placing the genus and its intermediate host in proximity in text produced a significant effect on student learning for related questions, but not for the ability to solve clinical cases. Therefore, the null hypothesis $H_{01}$ could not be rejected.

The second hypothesis investigated in this study was that learning materials that explicitly state relationships between information will significantly improve student learning, as measured by the student's ability to solve clinical case scenarios accurately, as compared to learning materials that do not explicitly state these relationships. As with the first hypothesis, this study found no significant difference in total test score for explicitness at the test level. Explicitly stating the rule governing the relationship between taxonomy, intermediate host, and body site significantly improved student ability to recognize those factors; however, it did not significantly improve
student ability to solve clinical cases. In other words, students could correctly answer questions about the rule but could not apply the rule in clinical problem solving. The null hypothesis $H_{02}$ could not be rejected.

**Representation and Proximity Experiment (Experiment 2)**

Neither the type of representation nor the proximity of facts in those representations appeared to have any significant effect on clinical problem solving. There was no significant difference in total test score whether students were given simple tables or tables with detailed information, concept maps in addition to detailed tables, or partial concept maps in proximity to text in addition to both concept maps and tables with detailed information. Therefore, none of the four hypotheses regarding representation and proximity, $H_{03}$ through $H_{06}$, could be rejected.

However, a serendipitous finding from this study was a strong correlation ($p < .001$) between students’ scores regarding functional taxonomic properties and their ability to correctly answer questions regarding clinical cases. If the student understood the functional properties of each taxonomic family, the student could apply this knowledge in solving the clinical cases, in effect, bridging the divide between the basic science and clinical problem solving described by Patel in her work with medical students (Patel, et al., 1993). This result also supports Norman’s findings that well-structured knowledge (in this case, the structure and properties of the relevant portion of the Linnaean taxonomy) is necessary for solving clinical problems caused by a given parasite.

**Attitude Toward Taxonomy Questionnaire**

The results of Question 1, “In parasitology class, I felt that I generally [Memorized the material <> Understood the material]” showed that a majority of students were below the mean. This indicates a strong tendency toward memorization. Few students responded that they felt they
generally understood the material. This finding correlates with Regan-Smith’s observations concerning memorization among medical school students (Regan-Smith, 1992).

**Discussion**

The initial premise of this research was that three factors, proximity, representation, and explicitness, are barriers to inferring information from facts, and that those barriers must be overcome before students can achieve meaningful learning, measured in this study by the ability to solve clinical problems. However, neither of the experiments indicated a statistically significant effect on clinical problem solving ability for any of the three factors.

**Proximity and Explicitness Experiment (Experiment 1)**

Consider the proximity and explicitness (PET) experiment in the context of one performed by Wason (Wason, 1960). In that experiment, subjects were given several sets of three numbers, such as 2, 4, and 6. The subjects were then asked to derive the rule governing the sets. An example rule might be “the next number is always 2 more than the last number in the set.” Even with simple sets of three numbers, and being asked to find the rule governing the set, some subjects derived incorrect rules. It is then not surprising that the subjects in the PET experiment were unable to derive a rule from a substantial amount of text.

However, the inability to reject the null hypotheses regarding the use of data in proximity appears to be a direct contradiction to Wickens’ proximity compatibility principle, which states in part that if multiple data need to be considered for deriving information, then those data must be displayed adjacent to each other (Wickens & Hollands, 2000). Therefore, one year after the initial data collection, an informal exercise was conducted using the subsequent class of second-year veterinary students. The exercise consisted of a discussion led by the researcher, who wrote ten parasite names on a blackboard. The class was then asked which animal host each parasite
infected, as well as the location in the host’s body where the adult parasite could be found. The students were then instructed to copy this chart to their notes and to study it. Observation of the students during this exercise suggested to the researcher that the students were concentrating on memorizing the rows in the chart. Not until the students were specifically asked the question, “Do you see a pattern here?” did they notice that certain patterns existed and that they could categorize organisms by host and body location. This anecdotal observation provides insight into the findings from this study. In aggregate, these findings suggest that it is not enough to present the information in proximity, but that there may need to be explicit cues to the student to look for patterns in the presented data. These findings also indicate that the proximity compatibility principle may only apply in an educational context when the learner is actually searching for multiple pieces of data in order to accomplish a specific goal. If the learner does not realize that multiple pieces of data are related, then search for those pieces of data does not occur.

The informal exercise described above also suggests that Regan-Smith’s findings regarding memorization by medical students (Regan-Smith, 1992) may also apply to veterinary students. Aaron and Skakun theorize that pressure and competition for high grade point averages causes undergraduates who are planning to apply to medical school to use rote or “superficial” learning. In other words, they study primarily for passing tests as opposed to working to understand the relationships in material (Aaron & Skakun, 1999). This same phenomenon may also apply to veterinary students, as evidenced by the findings of the Attitudes Toward Taxonomy questionnaire, where the majority of students were below the mean on a question regarding memorization versus understanding. This finding correlates with Regan-Smith’s findings concerning memorization among medical school students (Regan-Smith, 1992). Placing data in proximity may simply have facilitated memorization by the subjects. Further research, perhaps using think-aloud protocols, would need to address whether that is the case.
This experiment also supports Mayer’s position (Mayer, 2004) that learners must be given guidance and not be expected to discover relationships in material on their own. Mayer (2004) summarizes findings by Shulman and Keisler, where “Apparently, some students do not learn the rule or principle under pure discovery methods, so some appropriate amount of guidance is required to help mentally construct the desired learning outcome.” (Mayer, 2004, p. 15).

Finally, the lack of statistically significant results for the inclusion of an explicit rule was unexpected. Subjects given the explicit rule were able to correctly identify the parts of the rule; however, they were unable to apply the rule in solving the clinical cases. This may be due to the fact that correct application of the rule was dependent on the subject possessing knowledge of the parent-child relationships of the taxonomy, specifically, the order Spirurida. Without that knowledge they were unable to solve the clinical cases, regardless of the expression of the rule.

**Representation and Proximity Experiment (Experiment 2)**

The inability to reject the null hypotheses regarding the use of tables and concept maps appears to be a direct contradiction to the representation effect, which states that the type of representation used can have a profound effect on the information that can be derived from that representation. However, it is important to note that the operative word in that statement is “can”. The findings from this study lead to a variety of additional questions. When learners are given pre-developed graphical organizers such as concept maps, do they simply memorize the graphic without investing the effort to understand the represented relationships? Do they simply ignore the graphic and rely on the text instead? Does a graphic organizer cause increased cognitive load if it was not developed by the learner, perhaps due to a decrease in available working memory?

Recent research by Stull & Mayer (2007) addresses the latter question, which they termed “learning by doing versus learning by viewing”. Using a biology text, they reported that either author-provided or learner-developed graphical organizers such as concept maps could be equally
effective in supporting meaningful learning; however, “when the complexity was too high...so much extraneous processing was required that neither of the graphic organizer treatments helped foster deeper learning.” (Stull & Mayer, 2007).

Tracking the visual path of the study subjects may also shed light on their interaction with the graphic representations. Thomas and Lleras found that “those who moved their eyes in a pattern related to the problem’s solution were the most successful problem solvers.” (Thomas & Lleras, 2007). However, in the current study, the subjects were not given a problem in advance, so further study is needed to understand how learners interact with pre-developed graphical representations for learning.

An additional question raised by Experiment 2 is whether the study subjects misinterpreted or did not comprehend the concept map graphic, as graph reading and interpretation is known to be difficult for some learners (Shah, Mayer, & Hegarty, 1999). In fact, one study subject mentioned after the data collection process that the use of the graphic was confusing. Therefore, one year after the initial data collection, an animated Microsoft PowerPoint (Redmond, Washington) was used to present a lecture to the subsequent class of second-year veterinary students. The animation showed a concept map being constructed, in stepwise fashion, to illustrate the relationships between the taxonomic structure and properties for a specific category of parasites. Comments from the students indicated that this method was well received. This approach is supported by Mayer and Moreno’s cognitive theory of multimedia learning (Mayer & Moreno, 2002). This theory has three main components:

1. That information is processed via two channels – an auditory/verbal channel and a visual/pictorial channel; therefore, presentations should include both visual/pictorial representations along with auditory/verbal representations.
2. That each of these channels can actively process a limited number of pieces of information at a time.

3. That meaningful learning only occurs when learners actively work to fit new knowledge into what they already know.

A multimedia approach that explains the relationships between taxonomy and clinical findings, and that incorporates these principles, may be more effective for than a standard text. This may be especially effective for students accustomed to memorizing text passages.

These findings also suggest that a set of cognitive hurdles, in addition to those posed by proximity, explicitness, and representation (PER), may be present. This first set of cognitive hurdles may in fact be encountered before any issues caused by PER, and they may be internal to the learner. They incorporate whether the student first perceives that a pattern or relationship might exist in the material being learned, as well as the learner’s learning style, including tendency toward memorization. Only if the learner overcomes these issues are the hurdles imposed by PER in the cognitive artifact (in this case, a textbook) then encountered by the learner.

The primary external factor in this second set of hurdles is the result of the representation used for a given concept in the cognitive artifact itself (in this study, the textbook). The representation should include all the data required for the learner to infer a pattern or relationship; that is, the data should be in proximity. The internal factors in the second hurdle include whether the learner believes the information is relevant; whether the learner believes the effort required to assimilate the information is worthwhile; and whether the learner actually invests the time required to assimilate the information. The latter two factors are affected by the representation in the cognitive artifact, while the first two factors are derived from adult learning theory.
**Taxonomies and Ontologies**

This study produced a serendipitous finding, in that subject performance on a question regarding properties of certain taxonomic families was a strong predictor of performance on clinical problem solving. This finding not only illustrates the need to incorporate these aspects of the Linnaean taxonomy in any coursework that discusses organisms, but it also supports Wainwright’s position of the importance of “functional” taxonomy as opposed to traditional morphological taxonomy (Wainwright, 1988). In other words, instructional materials in this domain should include not just the morphologic features of an organism, but also the function of those features, especially properties relevant to clinical problem-solving. For example, students may memorize the fact that members of taxonomic order Cyclophyllidea have no uterine pores, but fail to link that morphologic feature to the clinical observation that because of the lack of uterine pores, these parasites shed whole proglottids, not individual eggs. Shulz, Stenzhorn, and Boeker (2008) also point out that biological taxa comprise over 14% of MeSH descriptors (Schulz, Stenzhorn, & Boeker, 2008). Because the Linnaean taxonomy has both structure – parent-child relationships – as well as “is-a” and “has-a” properties, it can be considered an ontology. The informatics literature contains references regarding the use of ontologies for machine reasoning (e.g. Cimino & Zhu, 2006), but a review of the literature discovered few reports regarding the use of either taxonomies or ontologies for student clinical problem solving. It also correlates to Patel, Evans, and Kaufman’s proposal that “a sound disease classification scheme is necessary before biomedical knowledge can facilitate both data-driven and predictive reasoning during clinical problem-solving.” (Patel, Evans, & Kaufman, 1990).

However, the findings from the Attitude Toward Taxonomy questionnaire suggests that even though students regarded taxonomy as important during their coursework, they performed poorly on the questions regarding taxonomic structure and properties in both experiments. There
are several possible explanations for this discrepancy. The first possible explanation may be due to
the lack of preparation at the undergraduate level, in that the majority of the subjects reported
having no prior parasitology coursework. A second possible explanation for this discrepancy may
be due to how taxonomy is presented in undergraduate coursework, as a method for identifying
organisms such as plants, and not for clinical reasoning about pathogenic organisms. Finally, the
majority of subjects reported that they did not believe taxonomy would be important to them after
graduation. This supports a central tenet of adult learning theory, in that adult learners invest time
and effort in learning what they believe is important to them.

The results from this study reinforce the need for well-structured knowledge for clinical
problem solving. Students who performed well on a pretest question intended to assess their
knowledge of the taxonomic properties of specific taxonomic families also performed well on the
clinical problem solving. In other words, well-formed knowledge of taxonomy was a powerful
predictor of their performance on the clinical problem solving cases, regardless of the format of the
intervention used.

**Separation of Basic Science and Clinical Knowledge**

The results from this study also reinforce Patel’s findings that students treat basic science
and clinical knowledge as two separate worlds (Patel, et al., 1993). The students performed at the
same level on the posttests regardless of the type of representation used in the interventions;
however, they were unable to transfer their knowledge to clinical problems. For example, students
who were given an explicit rule were able to identify the relevant parts of the rule on the posttest,
but were not able to apply the rule to solve clinical problems.
Implications

Several implications can be derived from this study. First, if relationships, patterns, or rules exist among facts, and those relationships are important for effective clinical problem solving, then students must be made aware of the existence of those relationships. Students should be cued in advance if they are expected to derive a pattern from the information that is being given to them, and they also need to be cued as to what patterns to look for. This study suggests that students do not derive patterns or relationships regardless of the use of tables or concept maps.

Second, simply explicitly stating the relationship alone may not be effective, as students may memorize the relationship but still not be able to apply it in a clinical situation. And finally, prepared representations such as tables and concept maps may not be helpful for students who are not actively looking for relationships or patterns.

Limitations of the Study

Study Setting and Subjects

This research utilized a particular domain, parasitology, in which to study the problem of spatial proximity and explicitness on inferential learning because of the researcher’s background, knowledge, and training in the domain. However, medical school curricula do not routinely include any in-depth coursework on parasitology, while veterinary school curricula do (Richardson, Gauthier, & Koritko, 2004). Because this specific domain was used, the research is not generalizable to other domains.

This also meant that the study subjects would need to be veterinary students, which led to the next constraint: student availability. There is only one college of veterinary medicine in the entire state of Texas, one in Louisiana, and one in Oklahoma. At the particular college used for the research, veterinary students take one semester of parasitology in the fall of their second year.
Because of the structure of their coursework and because of the general complexity of the necessary underlying knowledge, data collection for this study could only occur during the fall semester, during the last two weeks of October when students were completing their studies of helminths. Therefore, enlarging the study to incorporate additional students would have incurred additional travel costs but should be considered in any future research.

The population of study subjects was not balanced with respect to gender, since approximately 75% of the class was female. Additionally, although the research addressed expository text, issues such as text coherence were not considered. Finally, temporal proximity of information presentation may have an effect, but was not considered in this research.

**Instrumentation**

It is important to note that the instruments used in these experiments were judged by a subject matter expert to have content validity; however, statistical reliability was assessed on only the Attitude Toward Taxonomy questionnaire. Further, due to limitations in access to students with the requisite domain knowledge, instruments were not tested by students prior to their use in this study.

**Data Collection**

Data collection was originally planned to take place in the college’s computer laboratory; however, the computer laboratory is used by all students and cannot be reserved for special functions. An alternate method of data collection using researcher-provided laptops was not viable due to funding limitations. As a result, all data collection took place using paper forms.

Time for reflection on the material was not provided due to time constraints. If time were not an issue, the posttest would not be given on the same day as the pretest and intervention. This would allow time for reflection on the material.


Funding

Finally, financial considerations imposed a limitation on this study as there was no outside funding. The researcher paid all costs associated with this study. External funding or support could allow the study to be conducted at multiple locations as well as remove constraints caused by paper-based interventions and data collection. Funding could also provide compensation for research subjects, permitting data collection to occur outside of standard class time. Funding could permit a longitudinal study design to assess effectiveness of PER over time.

Recommendations

Terminology

In preparing for this research, it was apparent that no consensus exists regarding the meaning of “basic science”, even though the term is widely used and is usually not defined. Along the same lines, the concept “clinical problem solving” appears to be used in a variety of ways in the literature. In this study, “clinical problem solving” incorporated aspects of transmission, diagnosis, treatment, and prevention. At what point does “basic science” end and “clinical problem solving” begin, especially when control of parasitic diseases often relies heavily on understanding the life cycle of intermediate hosts? Conceptual analyses of the terms “basic science” and “clinical problem solving” would clarify these for future researchers.

Likewise, the terms “implicit” and “explicit” are also widely used. However, little is published on methodologies for identifying not only what is implicit or explicit in the context of learning, but to what level of detail should the definition be taken. For example, the term “dog” can convey a large quantity of implicit facts, such as the number and types of teeth it has, the type of food it needs, that it is a mammal and therefore produces milk for its offspring, and so on. Further, the implicit information conveyed by a term can vary based on the existing long-term
knowledge of the recipient. Future research should include a conceptual analysis of these terms as well as a methodology for identifying and quantifying their properties.

**Study Design**

Recommendations for further research on the effect of proximity and representation on clinical problem solving would first and foremost include selection of a more generalizable domain, one that does not require specialized knowledge. For example, discovery of the relationship between heart rate and body mass, where larger species have slower heart rates due to heat conservation and Surface Law (Blumberg, 2002b), might be appropriate for college undergraduates.

Selection of a less complex domain should broaden the availability of study subjects. Not only could the larger number of subjects strengthen the statistical power of the study, but access to local resources would reduce travel time and related expenses.

Further research assessing the impact of proximity and representation on student clinical problem solving should also investigate the effect of first prompting students to look for specified patterns or relationships.

**Instrumentation**

Validation of the instruments by a broader range of students is recommended. Addition of more problem solving cases as well as functional taxonomic properties would also be suggested for any further investigations regarding the relationship between those properties and clinical problem solving.

Multimedia, animated presentations of concept maps should be explored as a way of presenting concept maps in a stepwise fashion. This could demonstrate to students how facts are
incorporated into a specific reasoning process. Such a presentation could also mitigate the load on working memory and help reduce cognitive load.

Methodology

The use of computerized data collection would eliminate many hours of manual data entry. It could also eliminate possible errors introduced during the data entry process.

The length of time allocated for subjects to read the intervention texts compared to the length of the intervention texts was problematic. The subjects were given thirty minutes to read nine pages of text. Although several pages were used in the intervention text in an effort to simulate the quantity of reading students are required to do in limited time, the study findings suggest that no improvement in clinical problem-solving ability occurs even when facts are adjacent on the same page. Therefore, additional research on PER could use shorter text interventions.

The amount of time allocated for reading also had an unintended consequence, in that students read at different speeds. Some subjects read rapidly and then became bored, as evidenced by drawings and doodles on the study materials, while others read too slowly to complete the reading before being given the posttest. Shorter interventions would not alleviate the problem of boredom encountered by faster readers. Utilizing on-line data collection would allow each subject to read completely through the intervention material and then progress to the posttest at his or her own pace.

Investigation of the effect of pre-developed concept maps on cognitive load and working memory, as well as the amount of time spent by subjects attending to pre-developed concept maps compared to other representations, should also be explored. The use of a learning styles inventory, such as that developed by Kolb (Kolb, 1981) to identify each subject’s preferred learning style
would allow correlation of the learning style with the clinical problem solving outcomes for each type of representation used.

How much time subjects spend actually looking at different representations could be answered by using an eye tracker system. This would gather data on which portions of representations the subjects actually attended to. Similarly, online data collection would allow tracking the amount of time spent on each screen. Audio recording of any comments made by students while studying the materials and answering questions could also provide insight into their thought processes.

**General Recommendations**

The issue of reference materials versus learning materials must be addressed. Informatics literature indicates that displays should be tailored to fit the task the user is attempting to perform (Johnson, Johnson, & Zhang, 2005; Zhang, Patel, Smith, Johnson, & Malin, 2002). In this case, the users are students enrolled in post-graduate coursework, and the displays are textbooks written by experts in a specialized domain. These same textbooks may continue to serve as references even after the students complete their academic coursework and enter practice. Does this mean that the textbooks need to be rewritten to address learning tasks as opposed to reference tasks? If so, then the role of the text as a reference is compromised. The more attractive solution to this paradox is that supplemental materials incorporating principles of data display and learning theories should be developed. Such supplemental materials should explicitly describe any rules, patterns, or relationships between facts that students are expected to learn. Pending further research regarding including use-case examples of these rules and relationships, this research suggests that inclusion of use-case examples is necessary for effective application of basic science rules into clinical problem solving.
Finally, this study imposed a rigid methodology on the study subjects, forcing them to study the intervention individually and without group interaction. This approach might not reflect their actual study habits. Kirschner et al. (2009) state “Cognitive load theory is based on the cognitive architecture of individual learners.” (Kirschner, Paas, & Kirschner, 2009, p. 35). In a review of the literature, they found that when dealing with complex problem solving, groups outperformed individuals because of the larger cognitive capacity of the group. This suggests that, at least for the particular domain used in this research, students could be encouraged to work in study groups.

Summary

The initial premise of this research was that three factors, proximity, representation, and explicitness, in learning materials are barriers to inferring information from facts, and that those barriers must be overcome before students can achieve meaningful learning. However, the findings from this study indicate that these factors produce no significant effect on meaningful learning as measured by student clinical problem solving ability. Further observation suggests that students primarily memorize material, and that another barrier to inferential learning may actually be encountered prior to any effects imposed by proximity, explicitness, or representation. This barrier is whether the student even perceives that patterns or relationships may exist. A primary implication of this research is that if relationships in learning material exist, then those relationships must be stated; students do not derive the relationship regardless of the type of representation used. Otherwise, expecting students to realize that these relationships exist, especially given the volume of information in certain textbooks, is tantamount to expecting a student to derive the rules of grammar by memorizing the dictionary. This research also suggests that simply providing a rule without examples does not produce improved clinical problem solving capability.
References


## Appendix A: Vita

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<th>Institution</th>
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<td>University of Texas Health Science Center at Houston</td>
</tr>
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</tr>
<tr>
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<td>ASCP</td>
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<td>1983</td>
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<td>1981</td>
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<td>Eastern Kentucky University</td>
</tr>
</tbody>
</table>
Appendix B: Texas A&M University Study Approval Letter

TECHAM UNIVERSITY
DIVISION OF RESEARCH AND GRADUATE STUDIES - OFFICE OF RESEARCH COMPLIANCE
1186 TAMU, General Services Complex
College Station, TX 77843-1186
730 Agronomy Road, #2601

DATE: 25 Sep 2008

MEMORANDUM

TO: CRAIG, THOMAS M

FROM: Office of Research Compliance
Institutional Review Board

SUBJECT: Initial Review

Protocol Number: 2008-5552

Title: The Effect of Proximity and Explicitness in Learning Materials on Student Ability to Utilize Basic Science Knowledge in Clinical Problem-Solving

Review Category: Exempt from IRB Review

It has been determined that the referenced protocol application meets the criteria for exemption and no further review is required. However, any amendment or modification to the protocol must be reported to the IRB and reviewed before being implemented to ensure the protocol still meets the criteria for exemption.

This determination was based on the following Code of Federal Regulations:
(http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.htm)

45 CFR 46.111(b)(2) Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (a) research on regular and special education instructional strategies, or (b) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Provisions:

This electronic document provides notification of the review results by the Institutional Review Board.
Appendix C: The University of Texas Health Science Center Study Approval Letter

Dr. Kimberly Smith
UT-H - SHIS - Health Informatics

October 16, 2008

HSC-SHIS-08-0519 - The Effect of Proximity and Explicitness in Learning Materials on Student Ability to Utilize Basic Science Knowledge in Clinical Problem-Solving

The above named project is determined to qualify for exempt status according to 45 CFR 46.101(b)

CATEGORY #1: Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as:

a. research on regular and special education instructional strategies,

b. research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

CHANGES: Should you choose to make any changes to the protocol that would involve the inclusion of human subjects or identified data from humans, please submit the change via IRIS to the Committee for the Protection of Human Subjects for review.

Should you have any questions, please contact the Office of Research Support Committees at 713-500-7943.

Thank you for submitting your protocol for review.

Cynthia Edmonds
IRB Manager
Appendix D: Consent Form

CONSENT FORM

The Effect of Proximity and Explicitness in Learning Materials on Student Ability to Utilize Basic Science Knowledge in Clinical Problem-Solving

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. If you decide to participate in this study, this form will also be used to record your consent.

You have been asked to participate in a research study investigating how information presentation affects students’ ability to use that information in clinical problem solving. The purpose of this study is to evaluate two factors, organization of information and explicitness of information, and whether or not these factors affect student learning. You were selected to be a possible participant because you are a student in the College of Veterinary Medicine.

What will I be asked to do?

If you agree to participate in this study, you will be asked to take two pre-tests, read two chapters, and then take two post-tests. You will also be asked to complete a questionnaire concerning your perceptions of specific coursework. This study will take two sessions during your regularly scheduled class time. Each session will take approximately an hour. You may refuse to answer any question.

What are the risks involved in this study?

The risks associated in this study are minimal, and are not greater than risks ordinarily encountered in daily life.

What are the possible benefits of this study?

The possible benefit of participation is a better understanding of the specific material presented in the study, and improved course materials for future students.

Do I have to participate?

No. Your participation is voluntary. Your grade will not be affected whether or not you participate in this study. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University or with the University of Texas Health Science Center being affected.

Will I be compensated?

You will receive 10 extra credit class points for participating in this study. You will receive the points after you complete both sessions.

If you do not want to participate in the study but still want to obtain class points, you can complete the study activities
but indicate that you do not want your materials used in the study by not signing the consent form.

**Who will know about my participation in this research study?**

This study is confidential. Your professor will not know whether or not you participated in the study. The records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only Kimberly Smith of the University of Texas will have access to the records.

**Whom do I contact with questions about the research?**

If you have questions regarding this study, you may contact:

Thomas M. Craig, DVM, PhD, 979-845-9191, tcraig@cvm.tamu.edu or
Kimberly A. Smith, MS, MT(ASCP), 713-417-4151, Kimberly.a.smith@uth.tmc.edu

**Whom do I contact about my rights as a research participant?**

This research study has been reviewed by the Human Subjects’ Protection Program and/or the Institutional Review Board at Texas A&M University and by the Committee for the Protection of Human Subjects (CPHS) of the University of Texas Health Science Center at Houston. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979) 458-4067 or irb@tamu.edu. You may also contact the University of Texas Health Science Center at Houston Committee for the Protection of Human Subjects at (713) 500-7943.

**Signature**

Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in this study.

Signature of Participant: ____________________________________ Date and Time: ___________

Printed Name: ________________________________________________

Signature of Person Obtaining Consent: __________________________ Date: ___________

Printed Name: ________________________________________________
Appendix E: Data Collection Script

I am a PhD student at the UT Health Science Center in Houston. I'm interested in how information is presented for learning, and how we can re-design class materials to make learning easier and more efficient.

So, I would like to invite each of you to be part a study to help me test some materials today. I've got 4 variations of information on nematodes and I'm trying to find out if one version is better than the others in making information about life cycles and intermediate hosts easier and faster to learn.

It will take 1 hour of your time today and 1 hour this time next week. You will be given a short test, then some material to study, followed by another short test.

I am handing out a packet with a consent form for you to read. If you want to participate, sign the form and put it back in the envelope. If you would like to have a copy for your records, extra copies are available.

The study is confidential, meaning your individual data will not be available to anyone besides me. Participating or not participating will not affect your grade. Dr. Craig will never see your test materials – only I will.

If you complete all the tasks of the study, you will receive 10 extra credit points regardless of if you choose to participate.

If you do not want to be a study subject, you can do that; just don't sign the consent form and I will discard your test information after you turn it in.

If you participate in the study I will share with you the general results of my study.

And remember, what I am testing is the effectiveness of the MATERIALS, not you!

Are there any questions?

Good. Let's get started.

I am handing out a short questionnaire. You will have 5 minutes to complete it. Please DO NOT write your name on it!

[5 minutes]

OK, please put the questionnaire into your brown envelope.

Now I am handing out a short test. You will have 10 minutes to complete the test. Please DO NOT write your name on the test!

[10 minutes]

OK, please put the test into your brown envelope.

Now I am handing out the study material. You will have 30 minutes to review this material. You are free to mark in the booklets.

[30 minutes]

OK, please put the study booklet into your brown envelope. Stand up and stretch for a minute!

Now for the last step. I am handing out the second test. You will have 10 minutes to complete the test. Please DO NOT write your name on the test!

[10 minutes]

OK, please put the test into your brown envelope.
If you have changed your mind regarding whether you want me to use your test data in my research study, you can revise your consent form at this point – either sign it or strike through your name. Be sure to put the form back in your brown envelope when you are done.

Thank you for your time. I'll collect the brown envelopes now, and we'll do a similar experiment this time next week.
Appendix F: Attitude Toward Taxonomy Questionnaire

Please think carefully about each question. There is no "right" or "wrong" answer to these questions.

1. In parasitology class, I felt that I generally
   Memorized the material  ○  ○  ○  ○  →  Understood the material  ○  ○  ○  ○

2. I felt that in the parasitology course material, similarities of clinical significance among related parasites were
   Very obscure  ○  ○  ○  ○  →  Very obvious  ○  ○  ○  ○

3. I believe that learning taxonomy helped me understand similarities and differences among parasites.
   Not at all  ○  ○  ○  ○  →  Definitely  ○  ○  ○  ○

4. When studying parasite life cycles, I generally
   Memorized them  ○  ○  ○  ○  →  Looked for patterns  ○  ○  ○  ○

5. With respect to what I plan to do after graduation, I think learning about taxonomy will be
   Very unimportant to me  ○  ○  ○  ○  →  Very important to me  ○  ○  ○  ○

6. I felt that learning about taxonomic information such as superfamilies was
   Very unimportant  ○  ○  ○  ○  →  Very important  ○  ○  ○  ○

7. I flipped back and forth in the book and/or notes when studying.
   Not at all  ○  ○  ○  ○  →  Frequently  ○  ○  ○  ○

8. For me, seeing relationships between taxonomy and clinical findings was:
   Very difficult  ○  ○  ○  ○  →  Very easy  ○  ○  ○  ○

9. I felt that learning about parasites for one type of animal helped me learn about related parasites for another animal.
   Rarely  ○  ○  ○  ○  →  Frequently  ○  ○  ○  ○

10. Did you have any parasitology coursework prior to this semester?
    ○  Yes  ○  No
    If yes, please describe:
## Table of Contents

- **Order Strongylida** .................................................................................................................. 2
  - Superfamily Trichostrongyloidea .............................................................................................. 3
    - Trichostrongylidae .................................................................................................................. 3
      - Ostertagia ......................................................................................................................... 3
      - Haemonchus ....................................................................................................................... 3
      - Nematodirus ....................................................................................................................... 3
    - Strongylidae .......................................................................................................................... 4
      - Stephanurus ....................................................................................................................... 4
      - Syngamus ........................................................................................................................... 4
    - Superfamily Metastrongyloidea ............................................................................................... 4
      - Metastrongyidae ................................................................................................................. 4
    - Family Protostrongylidae ....................................................................................................... 4
      - Protostrongylidae ................................................................................................................ 4
    - Family Filarioididae .............................................................................................................. 5
      - Filariidae ............................................................................................................................ 5
  - Order Oxyurida .......................................................................................................................... 5
    - Oxyurida equi ...................................................................................................................... 5
    - Enterobius vermicularis ....................................................................................................... 5
  - Order Ascaridida ....................................................................................................................... 5
    - Ascaris .................................................................................................................................. 5
    - Parascaris ............................................................................................................................ 5
    - Toxocara .............................................................................................................................. 5
    - Baylisascaris ........................................................................................................................ 6
  - Order Spirurida .......................................................................................................................... 6
    - Dracunculidae ...................................................................................................................... 6
      - Onchocerca .......................................................................................................................... 6
    - Filaroididae ........................................................................................................................... 7
      - Dorylaimidae ...................................................................................................................... 7
      - Strongylida ........................................................................................................................ 7
      - Oesophagostomidae .......................................................................................................... 7
        - Oesophagostomum ........................................................................................................... 7
    - Family Detraziaidae ............................................................................................................. 7
      - Detrazia ............................................................................................................................... 7
      - Dipetalogasteridae ............................................................................................................. 9
        - Dipetalogaster ................................................................................................................ 9
  - Order Enoplida ......................................................................................................................... 9
    - Enoplida .................................................................................................................................. 9

Appendix G: Experiment 1: Intervention 1 (Control)

**PHYLUM NEMATODA**

All control effects are based on an understanding of the life history and behavior of both host and parasite. A general outline of the ontogenetic development of a nematode is shown in Figure 1. What appears to be a rich and confusing diversity of life histories among various orders of nematodes can all be related and rationalized according to this basic pattern.

![Figure 1: Stages and transitions in the ontogenetic development of a nematode.](image)

**Order Strongylida**

The order Strongylida is composed of four superfamilies: (1) Strongylidea, the large bowel "strongyles" of horses and the nodular worms of ruminants, swine, and primates, (2) Trichostrongylidea, the abdominal and small intestinal "hairworms" of ruminants, (3) Ancylostomatoidea, the "hookworms" of diverse mammals, and (4) Metastrongylidea, the "lungworms." One of the most important genera of lungworms falls within the Trichostrongylidea rather than the Metastrongylidea, but there are always exceptions to be resolved.

The life histories of superfamilies Strongylidea, Trichostrongylidea, and Ancylostomatoidea are typically direct, with free-living microtuberculous first and second larval stages and an infective third larval stage (Figure 2). Females of all three superfamilies lay typical "strongyle eggs" (i.e., eggs with smooth-surfaced, ellipsoidal shells that contain an embryo in the morula stage of development when laid and passed out with the feces). Such eggs are produced by all members of the order Strongylida, except certain genera in the superfamily Metastrongylidea. The morula develops into a first-stage larva that hatches from the egg within a day or two. After feeding, this larva undergoes its first molt to become a second-stage larva. Both first- and second-stage larvae remain in the feces, where they feed on bacteria. In the second molt, the cuticle of the second stage is temporarily retained as a protective "sheath" about the infective third-stage larva and will not be shed until this larva enters a suitable host. In about a week, these "sheathed" third-stage larvae begin to migrate out of the fecal mass and into the water film covering the surrounding soil particles and vegetation. Infection occurs when these "sheathed larvae" are ingested by grazing animals.

Metastrongylidea typically require a molluscan or annelid intermediate host for development from the first stage to the infective third stage, and infection of the definitive host occurs through ingestion of snails' slugs, or earthworms containing infective third-stage larvae. *Filaroides oederi* and *Filaroides hiriki*, both directly infective to the dog in the first larval stage, form important exceptions to this rule.
Superfamily Trichostrongyliinae

Trichostrongylid nematodes are especially common and pathogenic in grazing ruminants, but swine, horses, cats, and birds also host important species. The abomasum and small intestine are the usual locations in ruminants, but one aberrant genus, Ditylenchus, causes immunity in the air passages.

*Trichostrongylus*

*Trichostrongylus axei* parasitizes the simple stomach or abomasum of a wide range of hosts including ruminants and horses. Other species are parasitic of the small intestine of ruminants and display a higher order of host specificity. *Trichostrongylus* spp. infective third-stage larvae survive the winter on pasture, and ruminants are exposed to infection when they are turned to pasture in spring. As the weather becomes warmer, the infective larvae die off, and by summer the overwintering generation is essentially gone. However, egg production from new infections rapidly reconstitutes the pasture and continues well into fall to produce the next season's overwintering population of *Trichostrongylus* spp.

*Ostertagia*

*Ostertagia* spp. are found in the abomasum of ruminants. The eggs are typical strongylid eggs. Infective third-stage larvae resemble those of *Trichostrongylus* spp. in overwintering on northern pastures and in thus infecting ruminants during the early grazing season. However, arrested development of parasitic larvae is also very well developed in *Ostertagia* spp. *O. ostertagiae* causes chronic abomasitis in young cattle, a disease marked by profuse watery diarrhea, anemia, and hypoproteinemia manifested clinically as submandibular edema.

*Haemonchus*

*Haemonchus* are parasites of the abomasum of ruminants. The white, egg-filled uterus of the female spirals around the blood-filled gut, giving rise to the so-called barber pole appearance.

At peak infection, naturally acquired populations of *Haemonchus contortus* may remove one fifth of the circulating erythrocyte volume per day from lambs and may remove an average of one tenth of the circulating erythrocyte volume per day over the course of normal infections lasting two months. The pathogenic effects of *H. contortus* result from the inability of the host to compensate for blood loss. The cardinal sign of haemorrhosis is pallor of the skin and mucous membranes. Individuals older ewes may succumb in late spring to the overwhelming challenge imposed by hordes of larvae simultaneously emerging from developmental arrest.

*Nematodirus*

The life history and epidemiology of *Nematodirus* species infecting domestic ruminants are distinctly different from those of most other trichostrongylids. The larva develops to the infective third stage within the eggshell, and hatching depends on extrinsic stimuli, at least in certain species. For example, the infective larva of *Nematodirus battus* must usually be...
subjected to freezing followed by warmer weather before it will hatch. This property tends to concentrate hatching of infective larvae in the spring, to limit reproduction to one generation per year, and to generate a single wave of infection and disease in late spring.

**Dictyocaulus**

Adult *Dictyocaulus* worms are found in the respiratory passages of ruminants and horses. The egg contains a first-stage larva, which hatches when ingested. Adult *Dictyocaulus* spp. live in the lumen of the bronchial tree, where they cause chronic bronchitis and localized obstruction of the bronchial tree with arthritis. *Dictyocaulus viviparous* is the only nematode that reaches maturity in the lungs of cattle. The freshly laid egg contains a vermiform embryo that usually hatches before being eliminated in the feces. When ingested, the infective larvae migrate by way of the mesenteric lymph nodes and thoracic duct.

**Superfamily Strongyloidea**

Strongyloid infections are typical of the order, but significant variations occur in certain groups. For example, *Syngamus* sp. the "gapeworm" of domestic and wild birds, and *Stephanurus* sp., the "kidney worm" of swine, use earthworms as paratenic hosts.

**Strongyulus**

*Strongyulus vulgaris* is a parasite of the horse. The adult worms are found in the cecum and colon.

The extrahost development of *S. vulgaris* is typical of strongylids in general (see Figure 2). When ingested by a horse, the infective third-stage larvae of *S. vulgaris* enter the wall of the cecum and ventral colon. The larvae penetrate nearby small arterioles and wander in these vessels and progressively larger branches of the cranial mesenteric artery. The rapidly migrating larvae reach the colic and cecal arteries and the cranial mesenteric artery. Some of the larvae push on into the aorta and its branches, where they may cause important pathological changes.

The migrations of fourth-stage *S. vulgaris* larvae cause arteritis, thrombosis, and embolism of the cranial mesenteric artery and its branches.

**Stephanurus**

*Stephanurus denarius*, the kidney worm of swine, is a stout parasite of the hepatic, renal, and renal parenchymal tissues, axial musculature, and spinal cord of swine and sometimes of cattle.

Earthworms serve as intermediate hosts. The life history may be direct or could involve earthworms as facultative intermediate hosts, infection occurring by ingestion or skin penetration of third-stage larvae or by ingestion of infected earthworms. Once in the body of the pig, the larvae enter the liver and wander destructively there. Some are trapped by an encapsulating tissue reaction, but the rest migrate to the hepatic parenchyma surrounding the kidneys and ureters. Eggs appear in the urine. Pigslets may become infected in utero.

**Syngamus**

The genus *Syngamus* are parasites of the upper respiratory tract in birds. Males and females of *Syngamus* spp. are fused permanently in copula. *Syngamus* species infections have caused the death of farmed birds. Earthworms serve as intermediate hosts.

**Superfamily Metastrongyloidea**

*Metastrongyloides* are parasites of the respiratory, vascular, and nervous systems of mammals. Most species require a small or large intermediate host. However, *Metastrongyloides* spp. develop to the infective stage in earthworms, and *F. ovinae* and *F. hepatica* infect their definitive hosts directly.

**Metastrongyulus**

These are large white parasites of the bronchi and bronchioles of swine. Oviparous females lay eggs containing first-stage larvae. These eggs do not hatch or develop into infective larvae unless they are ingested by an earthworm.

**Family Protostrongylidae**

Females deposit unsegmented eggs in the surrounding lung, vascular, or neural tissues. These eggs develop into first-stage larvae before they appear in the feces. If these first-stage larvae are ingested by any of a wide range of smalls and smalls, they develop in these intermediate hosts into doubly shelled third-stage infective larvae.
Appendix G: Experiment 1: Intervention 1 (Control)

Parasites of the Meninges

Parasites of the meninges include those that affect the white-tailed deer, in which species it rarely if ever causes disease. However, in abnormal hosts such as sheep, goats, llama, camel, moose, reindeer, wapiti, fallow deer, and mule deer, *P. tenuis* tends to invade the nervous tissue proper, causing serious or fatal neurological disease. Because *P. tenuis* rarely matures in these hosts, larvae are not shed in the feces. Therefore diagnosis is presumptive and based on the appearance of neurological signs in ruminants that share their pastures with white-tailed deer.

Family Filaroididae

Filaroids

Do not confuse the family Filaroididae with the very distant superfamily Filaroididae. The canine parasites, *F. ascari* and *F. hooki* occur in nodules within the epithelium of the trachea and bronchi or within the lung parenchyma, respectively.

The ovo-viviparous females deposit delicate, thin-shelled eggs containing first-stage larvae that hatch before being voided in the host's feces. Unlike other metacercoidic hosts, most all of which require a molluscan or annelid intermediate host to develop into the infective third larval stage, *Filaroides* spp. are directly infective as first-stage larva, and development through all five stages is completed in the lung tissue of the dog. Because these larvae are released within the host, auto-infection is inevitable and the degree of resulting infection is apparently governed solely by the host's immune reactions. First-stage larvae pass up the trachea and out with the feces, and transmission occurs principally by coprophagy. Cannibalism and regurgitative feeding provide other mechanisms.

Order Oxyurida

Oxyuris equi

Adult *O. equi* are found principally in the small colon, although occasional specimens may be found in the large colon. Instead of simply discharging her eggs in the feces, the gravid female *O. equi* migrates down the colon and rectum and out through the anus to cement her eggs in masses to the skin of the anus and its immediate surroundings. The eggs develop to the infective stage in 4 or 5 days. The most common affliction perpetrated by *O. equi* on the horse is pruritus ani caused by the adhesive egg masses deposited on the perilonal skin by the female worm. In its efforts to relieve the itching, the horse will persistently rub its tail against posts, mangers, and the like.

Enterobius vermicularis

This is the small pinworm of humans and great apes. The gravid *E. vermicularis* female migrates through the anal opening to cement her eggs to the horse's perianal skin. The eggs develop to the infective stage within hours and are ready to reinfect the host by contamination of the hands, to infect other individuals by contamination of bedding or other fomites, or to become airborne on dust particles. Infection may be suspected in children who have pruritus ani and insomnia.

Order Ascaridida

Ascarids are among the largest and most familiar nematode parasites infecting the intestinal tract of domestic animals.

The single cell develops into an infective larva inside the eggs which, within several days or weeks, depending on the species of worm and the ambient temperature. Ascarid eggs are remarkably resistant to chemical and physical insults, especially after they have arrived at the infective stage. The single most important fact to remember in relation to the epidemiology of ascarids is that the eggs remain infective in soil for many years. The larval stage hatching from the egg of these ascarids is a third-stage larva. Ascarid eggs are relatively thick walled.

**Ascaris**

*A. suum* is a parasite of swine. The adult worms are about 30 cm long and white to cream colored.

**Parascaris**

*Parascaris equorum* is the very large ascarid parasite of the horse.

**Toxascaris**

*Toxascaris leonina* is a parasite of cats and dogs in the cooler climates of the world. Because of the direct life cycle of this parasite, the worm tends to be found in animals older than the hosts of *T. canis* or *T. cati*.
Appendix G: Experiment 1: Intervention 1 (Control)

The restricted mucosal migration of *T. leonina* in dogs and cats precludes the development of somatic larval burdens and the transmission of infection by way of the placenta and mammary gland. Ingestion of infective eggs and paratenic hosts seems to be the only means by which cats and dogs acquire *T. leonina* infection.

**Toxocara**

*Toxocara* is a genus of rather large ascarids that as adults are parasites in the small intestine of various mammals. *T. canis* and *T. cati* are two of the most commonly observed parasites of the dog and cat, respectively.

*Toxocara* and *Toxascaris* eggs are very resistant to environmental adversity and remain infective for years, especially in poorly drained clay and silt soils.

**Baylisascaris**

Species of *Baylisascaris* common in North American wildlife include *Baylisascaris procyonis* of the raccoon, *Baylisascaris cebonaris* of the monkey, and *Baylisascaris invadens* of the woodchuck.

**Order Spirurida**

Members of the order Spirurida require either an insect or a crustacean intermediate host for development to the infective stage. The definitive host acquires spirurid infection by ingesting infected arthropods or paratenic hosts that have fed on such arthropods. The superfamily Filarioidea requires as its intermediate host a blood-feeding arthropod that becomes infected while taking its blood meal and that vectors the parasite when taking another blood meal.

**Draconulus**

*Dracunculus* is a parasite of the subcutaneous tissues of carnivores and man. When the female *Dracunculus* has been fertilized, a shallow ulcer forms in the host's skin at the location of the anterior end of the worm. When water wets this ulcer, the female projects her body and protracts a length of uterine, which then bursts to discharge a host of larvae. Then she retreats to await the next wetting.

If they are ingested by a copepod of the genus *Cyclops*, the larvae discharged into the water develop to the infective third larval stage in about 2 weeks. The definitive host becomes infected by ingesting these *Cyclops* in the drinking water. *Dracunculus invadens* is a parasite of raccoons and other carnivores, including the dog and cat in North America. *Dracunculus medinensis* is a parasite of man in the Middle East and India.

**Gnathostoma**

*Gnathostoma* spp. adults are found in cystic nodules in the stomach walls of wild and domestic carnivores. Eggs are passed in the one-to-two-cell stage and develop to the second larval stage in water. These larvae hatch and develop to the infective third stage only if ingested by copepods (*Cyclops*). A variety of amphibians, snakes, and fishes may serve as paratenic hosts to convey the gnathostome from the copepod to the definitive host. The migrations of *gnathostome* larvae in the liver and other organs of the definitive host are destructive.

**Physaloptera**

*Physaloptera* spp. are parasites of the stomach of carnivores. The female worm lays thick-walled eggs that develop to the infective stage in various cestodephagous beetles. The adult worms tend to live with the anterior end embedded in the mucosa.

**Thelazia**

*Thelazia* spp. are parasites of the conjunctival and lacrimal sacs of cattle and horses. The female *Thelazia* worm deposits thin-shelled eggs containing larvae that develop to the infective stage in the face fly, *Musca autumnalis*.

**Coneylonema**

*Coneylonema* spp. can usually be found woen in a remarkably regular sinuate tract in the mucous membrane of the host's esophagus or rectum. Eggs containing first-stage larvae are passed on the host's feces and, if ingested by a dung beetle or a cockroach, develop to the infective stage in about a month. The definitive host becomes infected by ingesting the infected insect.

**Spirocerca lupi**

*Spirocerca lupi* is found in fibrous nodules in the wall of the esophagus or stomach of dogs. The very small egg contains a verruform embryo when shed in the feces. If ingested by a cestodephagous beetle, this verruform embryo develops into a larva capable of infecting dogs and a broad range of paratenic hosts. When infective larvae are ingested by a dog, they
migrate in the adventitia of the visceral arteries and sort to the walls of the esophagus and stomach. Reproductive adults are normally found in cystic nodules that communicate with the lumen of the esophagus or stomach through fistulas. Dysphagia and vomiting, esophageal neoplasia, aortic aneurysm or rupture, and secondary pulmonary osteoarthropathy may be associated with canine S. lupi infection.

**Dracasia and Habronema**

*Dracasia megastoma*, *Habronema muscae*, and *Habronema microstoma* are parasites of the equine stomach. Larvae hatch from the eggs soon after they are laid. If ingested by maggots (*Muscis domestica* for *D. megastoma* and *H. muscae*, *Sarcophaga calcitrans* for *H. microstoma*), these develop to the infective third-stage larvae in a little more than a week.

The infective larvae migrate to the head of the fly and collect in the labium. When a fly alights on a warm, moist surface such as the muzzle, ocular conjunctiva, or cutaneous wounds of a horse, the larvae change hosts. Those larvae that are swallowed presumably complete their life histories, whereas those that enter wounds have probably reached an impasse. However, these aberrant larvae are extremely important because of the granulomas they induce. Typical cutaneous habronemasis lesions are characterized by an initial rapid production of granulation tissue that steadily refuses to resolve during fly season, by the subsequent appearance of caseo-calculous nodules in this granulation tissue, and by the presence of *Dracasia* or *Habronema* larvae.

**Superfamily Filarioidea**

Filaroids tend to be rather long and thin white- to cream-colored worms. They are found typically in tissue spaces and body cavities, or sometimes within the vasculature or lymphatic system. All filaroids are transmitted by bloodsucking insects in which vermiform embryos called microfilariae develop into infective third-stage larvae. The microfilariae either circulate in the blood of the definitive host (e.g., *Dirofilaria* and *Setaria* spp.) or accumulate in the dermal connective tissues (e.g., *Onchocerca* spp.). In either case, the microfilariae are ingested and the infective larvae deposited when the insect feeds on the definitive host.

**Dirofilaria**

*D. immitis* is the canine heartworm. The dog and its close relatives are the natural hosts, but infection also occurs in cats and ferrets. Adult heartworms normally are found in the pulmonary arteries. In heavy infections, worms may be found in the right heart. When dead, the worms are carried deeper into the lungs where they occlude the pulmonary arterial branches and produce infarcts. Endemic areas exist in all parts of the United States. The life history may involve several species of mosquitoes as intermediate hosts. Only when mosquito populations are sufficiently reduced will heartworm disappear.

The life cycle of *D. immitis* is initiated when the dog is bitten by an infected mosquito. Fertilized females contain fully developed microfilariae within the sixth month after infection. Microfilariae typically are not found in the peripheral blood for several more weeks. Mosquitoes are infected when they bite an infected dog.

**Setaria**

*Setaria latipapillosa* and *Setaria equina* are large white parasites of the serous membranes of cattle and horses, respectively. Microfilariae of *Setaria* spp. show up on blood smears, and the adult parasites are likely to be encountered during abdominal surgery or on the killing floor or necropsy table. Migrating *Setaria* larvae occasionally invade the central nervous system and cause serious neurological disease, especially in species other than their natural host.

**Onchocerca**

*Onchocerca* spp. adults, although large, are intricately woven into the deep connective tissues. *Onchocerca cervicalis* adults are found in the nuchal ligament of the neck, and the microfilariae are widely distributed in the dermis and other connective tissues including those of the ocular conjunctivae.

In North American cattle, *Onchocerca gutturosa* adults are found in connective tissues about the nuchal ligament, and *Onchocerca lienalis* are found in the connective tissue between the spleen and rumen. Microfilariae of both species are found in the dermis. The intermediate hosts of bovine *Onchocerca* species may involve simulid or helobid (ceratopogonid) flies.

**Parafilaria**

*Parafilaria* spp. of horses and cattle live in the subcutaneous and intermuscular connective tissues and when sexually mature, produce crops of pedicled nodules that bleed through a tiny pore. The blood escapes in fine drops, runs off in streaks along the hairs, and dries in brown crusts. Eggs and microfilariae of *Parafilaria* spp. may be demonstrated in this material but never in samples from the circulation. Active bleeding occurs only during daylight hours and especially when
horses are exposed to direct sunshine. The activity of the lesions suggests an adaptation on the part of *Pantolopsia* spp., to the habits of flies that feed on blood.

**Dipetalonema**

The canine parasite *Dipetalonema reconditum* is small, usually few in number, and lies inconspicuously in the connective tissues. The microfilariae, on the other hand, are rather commonly seen and easy to confuse with those of *D. immitis*. *D. reconditum* develops in the infective stage in the flea *Ctenocephalides felis* and in the ameloblastic mouse *Heterodus spathiger*.

About 90% of the adults are located in subcutaneous tissues, but a small percentage can be found in the peritoneal cavity. The microfilariae circulate in the blood, usually at low densities.

**Order Enoplida**

**Dicrotophymin**: *Dicrotophymin renale*, the "giant kidney worm" of carnivores, swine, and sometimes man, is one of the largest species of nematodes. Mink are the principal definitive hosts. The female *D. renale* produces brownish, thick-shelled eggs with bipolar plugs. The eggs are passed in the urine in the one- or two-cell stage and develop in water, to the first larval stage in a month or longer. Larvalized eggs are infective to oligochaete annelid worms in which they develop to the infective third larval stage. If infected oligochaetes are ingested by fish or frogs, the larvae invade the tissues of these parasite hosts but do not undergo development. However, if the infected oligochaete (or parasite host) is ingested by a dog, the *D. renale* larvae mature and complete the cycle. In the dog, *D. renale* may be found in the peritoneal cavity of the right kidney or free in the abdominal cavity.

**Trichinella**

The tiny adults of *Trichinella spiralis* are found embedded in the mucosa of the small intestine of swine, carnivores, and man.

Predation has provided an efficient channel for the evolutionary development of many parasites. In most instances, the larval parasite lies encysted in the tissues of the prey, and the reproductive adults inhabit the alimentary tract of the predator. Thus in most systems, the predator becomes infected by eating the prey, and the prey becomes infected by ingesting eggs passed in the feces of the predator. However, in the unique life history of *Trichinella spiralis*, both adult and larval stages occur in sequence in the same host, the tiny adults lying among the villi of the small intestine and the larvae curled up in cysts in the striated muscle.

First-stage larvae of *T. spiralis*, liberated from their cysts by digestive enzymes of the host, invade the intestinal mucosa. Both sexes reach maturity about 2 days after the infected meat is eaten. The viviparous females give birth to prelarvae, which enter the lymphatics and later the bloodstream to be transported to the muscles. These prelarvae invade striated muscle cells. After 2 or 3 weeks they have developed into first-stage larvae and will up in spirals, or like pretzels become enveloped in cysts and are then infective.

Almost all mammals can be experimentally infected with *T. spiralis*, but carnivores and omnivores are more likely to become naturally infected; infection occurs through predation, cannibalism, and carrion feeding. The larvae encysted in muscles are exceptionally resistant to external conditions, including extreme putrefaction. Human trichinosis usually results from eating raw or undercooked pork, beef, or seal.

**Trichurus**

The adult is embedded in the wall of the large intestine, with the posterior end lying free in the lumen. The egg is lemon-shaped with a distinct plug at each pole and contains a single cell when passed in the feces. An infective first-stage larva develops inside the egg but does not hatch unless swallowed by a suitable host. Once eggs are ingested, all development occurs within the epithelium of the intestine (i.e., there is no extraintestinal migration).

Infective *T. vulpis* eggs survive in soil for a long time, and dogs kept in contact with contaminated soils tend to become reinfected after treatment.
Appendix H: Experiment 1: Intervention 2 (Proximity)

Table of Contents

Order Strongylida .................................................................................................................. 2
  Superfamily Trichostrongyliidae .......................................................................................... 3
    Trichostrongylus ............................................................................................................... 3
    Ostertagia ........................................................................................................................ 3
    Haemonchus ...................................................................................................................... 3
    Nematodirus .................................................................................................................... 3
    Dictyocaulus .................................................................................................................... 4
  Superfamily Strongylidea .................................................................................................... 4
    Strongylus ........................................................................................................................ 4
    Stephanurus ...................................................................................................................... 4
    Syngamus ........................................................................................................................ 4
  Superfamily Metastrongylidea ............................................................................................ 4
    Metastrongylus ................................................................................................................ 4
    Family Protostrongylidae ............................................................................................... 4
    Parelaphostrongylus ....................................................................................................... 5
    Family Filaroididae ......................................................................................................... 5
    Filaroides spp ................................................................................................................... 5

Order Oxyurida ....................................................................................................................... 5
  Oxyuris equi ....................................................................................................................... 5
  Enterobius vermicularis .................................................................................................... 5

Order Ascaridida ..................................................................................................................... 5
  Ascaris ................................................................................................................................ 5
  Parasascaris ....................................................................................................................... 5
  Toxascaris .......................................................................................................................... 5
  Toxocara ............................................................................................................................ 6
  Baglifascaris ....................................................................................................................... 6

Order Spirurida ......................................................................................................................... 6
  Dracunculus ....................................................................................................................... 6
  Gnathostoma ...................................................................................................................... 6
  Physaloptera ...................................................................................................................... 6
  Thelazia .............................................................................................................................. 6
  Gongylonema ..................................................................................................................... 6
  Spirocerca lupi .................................................................................................................... 6
  Dracunculus and Hebronema ........................................................................................... 7

Superfamily Filarioidea ......................................................................................................... 7
  Dirofilaria .......................................................................................................................... 7
  Setaria ................................................................................................................................ 7
  Onchocerca ........................................................................................................................ 7
  Parafilaria ............................................................................................................................ 7
  Dipetalonema ..................................................................................................................... 8

Order Enoplida ......................................................................................................................... 8
  Diplotophyme .................................................................................................................... 8
  Trichinella .......................................................................................................................... 8
  Trichuris ............................................................................................................................. 8
Appendix H: Experiment 1: Intervention 2 (Proximity)

PHYLUM NEMATODA

All control efforts are based on an understanding of the life history and behavior of both host and parasite. A general outline of the ontogenetic development of a nematode is shown in Figure 1. What appears to be a rich and confusing diversity of life histories among various orders of nematodes can all be related and rationalized according to this basic pattern.

FIGURE 1 Stages and transitions in the ontogenetic development of a nematode.

Order Strongylida

The order Strongylida is composed of four superfamilies: (1) Strongylidea, the large bowel "strongyloids" of horses and the nodular worms of ruminants, swine, and primates, (2) Trichostrongylidea, the abomasal and small intestinal "hairworms" of ruminants, (3) Ancylostomatidea, the "hookworms" of diverse mammals, and (4) Metastrongylidea, the "lungworms." One of the most important genera of lungworms falls within the Trichostrongylidea rather than the Metastrongylidea, but there are always exceptions to be resolved.

The life histories of superfamilies Strongylidea, Trichostrongylidea, and Ancylostomatidea are typically direct, with free-living microbivorous first and second larval stages and an infective third larval stage (Figure 2). Females of all three superfamilies lay typical "strongyle eggs" (i.e., eggs with smooth-surfaced, ellipsoidal shells that contain an embryo in the morula stage of development when laid and passed out with the feces). Such eggs are produced by all members of the order Strongylida, except certain genera in the superfamily Metastrongylidea. The morula develops into a first-stage larva that hatches from the egg within a day or two. After feeding, this larva undergoes its first molt to become a second-stage larva. Both first and second-stage larvae remain in the feces, where they feed on bacteria. In the second molt, the cuticle of the second stage is temporarily retained as a protective "sheath" about the infective third-stage larva and will not be shed until this larva enters a suitable host. In about a week, these "sheathed" third-stage larvae begin to migrate out of the fecal mass and into the water film covering the surrounding soil particles and vegetation. Infection occurs when these "sheathed larvae" are ingested by grazing animals.

Metastrongylids typically require a molluscan or annelid intermediate host for development from the first stage to the infective third stage, and infection of the definitive host occurs through ingestion of snails, slugs, or earthworms containing infective third-stage larvae. *Filaroides ostrii* and *Filaroides hiriki*, both directly infective to the dog in the first larval stage, form important exceptions to this rule.
Appendix H: Experiment 1: Intervention 2 (Proximity)

Superfamily Trichostrongyloidea

Trichostrongyloid nematodes are especially common and pathogenic in grazing ruminants, but swine, horses, cats, and birds also host important species. The abomasum and small intestine are the usual locations in ruminants, but one aberrant genus, *Dictyocaulus*, reaches maturity in the air passages.

*Trichostrongylus*  
Stomach, abomasum, small intestine  
No intermediate host

*Trichostrongylus axei* parasitizes the simple stomach or abomasum of a wide range of hosts including ruminants and horses. Other species are parasites of the small intestine of ruminants and display a higher order of host specificity. *Trichostrongylus* spp. infective third-stage larvae survive the winter on pasture, and ruminants are exposed to infection when they are turned to pasture in spring. As the weather becomes warmer, the infective larvae die off, and by summer the overwintering generation is essentially gone. However, egg production from new infections rapidly recontaminates the pasture and continues well into fall to produce the next season’s overwintering population of *Trichostrongylus* spp.

*Ostertagia*  
Abomasum  
No intermediate host

*Ostertagia* spp. are found in the abomasum of ruminants. The eggs are typical strongyloid eggs. Infective third-stage larvae resemble those of *Trichostrongylus* spp. in overwintering on northern pastures and in thus infecting ruminants during the early grazing season. However, arrested development of parasitic larvae is also very well developed in *Ostertagia* spp. *O. ostertagi* causes chronic abomasitis in young cattle, a disease marked by profuse watery diarrhoea, anemia, and hypoproteinemia manifested clinically as submaxillary edema.

*Haemonchus*  
Abomasum  
No intermediate host

*Haemonchus* spp. are parasites of the abomasum of ruminants. The white, egg-filled uterus of the female spirals around the blood-filled gut, giving rise to the so-called barber pole appearance.

At peak infection, naturally acquired populations of *Haemonchus contortus* may remove one fifth of the circulating erythrocyte volume per day from lambs and may remove an average of one tenth of the circulating erythrocyte volume per day over the course of nonfetal infections lasting two months. The pathogenic effects of *H. contortus* result from the inability of the host to compensate for blood loss. The cardinal sign of haemonchosis is pallor of the skin and mucous membranes. Individual older ewes may succumb in late spring to the overwhelming challenge imposed by hordes of larvae simultaneously emerging from developmental arrest.

*Nematocephalus*  
Intestine  
No intermediate host

The life history and epidemiology of *Nematocephalus* species infecting domestic ruminants are distinctly different from those of most other trichostrongyloids. The larva develops to the infective third stage within the eggshell, and hatching depends on extrinsic stimuli, at least in certain species. For example, the infective larva of *Nematocephalus battus* must usually be
subjected to freezing followed by warmer weather before it will hatch. This property tends to concentrate hatching of infective larvae in the spring, to limit reproduction to one generation per year, and to generate a single wave of infection and disease in late spring.

Dicteocaulus

<table>
<thead>
<tr>
<th>Branchial tree</th>
<th>No intermediate host</th>
</tr>
</thead>
</table>

Adult *Dicteocaulus* worms are found in the respiratory passages of ruminants and horses. The egg contains a first-stage larva when laid. Adult *Dicteocaulus* spp. live in the lumen of the bronchial tree, where they cause chronic bronchitis and localized occlusion of the bronchial tree with mucus. *Dicteocaulus viviparus* is the only nematode that reaches maturity in the lungs of cattle. The freely laid egg contains a vermiform embryo that usually hatches before being eliminated in the feces. When ingested, the infective larvae migrate by way of the mesenteric lymph nodes and thoracic duct.

Superfamily Strongyloidea

Strongyloid life histories are typical of the order, but significant variations occur in certain groups. For example, *Syngamus* sp., the "papeworm" of domestic and wild birds, and *Stephanurus* sp., the "kidney worm" of swine, use earthworms as paratenic hosts.

Strongyloides

<table>
<thead>
<tr>
<th>Cecum, colon</th>
<th>No intermediate host</th>
</tr>
</thead>
</table>

*Strongyloides* is a parasite of the horse. The adult worms are found in the cecum and colon.

The extrahost development of *S. vulgaris* is typical of strongylids in general (see Figure 2). When ingested by a horse, the infective third-stage larvae of *S. vulgaris* enter the wall of the cecum and ventral colon. The larvae penetrate nearby small arteries and wander in these vessels and progressively larger branches of the cranial mesenteric artery. The rapidly migrating larvae reach the colic and cecal arteries and the cranial mesenteric artery. Some of the larvae push on into the aorta and its branches, where they may cause important pathological changes.

The migrations of fourth-stage *S. vulgaris* larvae cause arteritis, thrombosis, and embolism of the cranial mesenteric artery and its branches.

Stephanurus

<table>
<thead>
<tr>
<th>Hepatic, renal, perirenal tissue</th>
<th>No intermediate host or earthworms</th>
</tr>
</thead>
</table>

*Stephanurus dentatus*, the kidney worm of swine, is a stout parasite of the hepatic, renal, and perirenal tissues, axial musculature, and spinal canal of swine and sometimes of cattle.

Earthworms serve as intermediate hosts. The life history may be direct or could involve earthworms as facultative intermediate hosts, infection occurring by ingestion or skin penetration of third-stage larvae or by ingestion of infected earthworms. Once in the body of the pig, the larvae enter the liver and wander destructively there. Some are trapped by an encapsulating tissue reaction, but the rest migrate to the retroperitoneal tissues surrounding the kidneys and ureters. Eggs appear in the urine. Piglets may become infected in utero.

Syngamus

<table>
<thead>
<tr>
<th>Trachea</th>
<th>Earthworm</th>
</tr>
</thead>
</table>

The genus *Syngamus* are parasites of the upper respiratory tract in birds. Males and females of *Syngamus* spp. are fused permanently in copula. *Syngamus* trachea infections have caused the deaths of farmed rhea. Earthworms serve as intermediate hosts.

Superfamily Metastrongyloidea

Metastrongylids are parasites of the respiratory, vascular, and nervous systems of mammals. Most species require a snail or slug intermediate host. However, *Metastrongylus* spp. develop to the infective stage in earthworms, and *F. oesleri* and *F. kirkii* infect their definitive hosts directly.

Metastrongylus

<table>
<thead>
<tr>
<th>Bronchi</th>
<th>Earthworm</th>
</tr>
</thead>
</table>

These are large white parasites of the bronchi and bronchioles of swine. Oviparous females lay eggs containing first-stage larvae. These eggs do not hatch or develop into infective larvae unless they are ingested by an earthworm.

Family Prostomarylidae

Females deposit unsegmented eggs in the surrounding lung, vascular, or neural tissues. These eggs develop into first-stage larvae before they appear in the feces. If these first-stage larvae are ingested by any of a wide range of snails and slugs, they develop in these intermediate hosts into doubly ephaphoid third-stage infective larvae.
Appendix H: Experiment 1: Intervention 2 (Proximity)

*Parelaphostrongylus* Meninges Snails, slugs
*Parelaphostrongylus tenuis* is normally a parasite of the meninges of the white-tailed deer, in which species it rarely if ever causes disease. However, in abnormal hosts such as sheep, goats, llama, camel, mouse, caribou, reindeer, woolly bear, and musk deer, *P. tenuis* tends to invade the nervous tissue proper, causing serious or fatal neurological disease. Because *P. tenuis* rarely matures in these hosts, larvae are not shed in the feces. Therefore diagnosis is presumptive and based on the appearance of neurological signs in ruminants that share their pastures with whitetailed deer.

**Family Filaroididae**

*Filaroides* Lung No intermediate host
Do not confuse the family Filaroididae with the very distantly related superfamily Filaroididea. The canine parasites, *F. canis* and *F. kiribi* occur in nodules within the epithelium of the trachea and bronchi or within the lung parenchyma, respectively.

The ovoviviparous females deposit delicate, thin-shelled eggs containing first-stage larvae that hatch before being voided in the host's feces. Unlike other metostrongyloids, most or all of which require a mollusc or annelid intermediate host to develop into the infective third larval stage, *Filaroides* spp. are directly infective as first-stage larva, and development through all five stages is completed in the lung tissue of the dog. Because these larvae are released within the host, autoinfection is inevitable and the degree of resulting infection is apparently governed solely by the host's immune reactions. First-stage larvae pass up the trachea and out with the feces, and transmission occurs principally by coprophagy. Cannibalism and regurgitative feeding provide other mechanisms.

**Order Oxyurida**

*Oxyuris equi* Colon No intermediate host
Adult *O. equi* are found principally in the small colon, although occasional specimens may be found in the large colon. Instead of simply discharging her eggs in the fecal stream, the gravid female *O. equi* migrates down the colon and rectum and out through the anus to cement her eggs in masses to the skin of the anus and its immediate surroundings. The eggs develop to the infective stage in 4 or 5 days. The most common affliction perpetrated by *O. equi* on the horse is pruritus ani caused by the adhesive egg masses deposited on the perineal skin by the female worm. In its efforts to relieve the itching, the horse will persistently rub its tail against posts, mangers, and the like.

*Enterobius vermicularis* Colon No intermediate host
This is the small pinworm of humans and great apes. The gravid *E. vermicularis* female migrates through the anal opening to cement her eggs to the host's perianal skin. The eggs develop to the infective stage within hours and are ready to reinfect the host by contamination of the hands, to infect other individuals by contamination of bedclothing or other fomites, or to become airborne on dust particles. Infection may be suspected in children who have pruritus ani and insomnia.

**Order Ascaridida**

Ascaris are among the largest and most familiar of nematode parasites infecting the intestinal tract of domestic animals.

The single cell develops into an infective larva inside the eggshell within several days or weeks, depending on the species of worm and the ambient temperature. Ascarid eggs are remarkably resistant to chemical and physical insults, especially after they have arrived at the infective stage. The single most important fact to remember in relation to the epidemiology of ascariasis is that the eggs remain infective in soil for many years. The larval stage hatching from the egg of these ascaridoids is a third-stage larva. Ascarid eggs are relatively thick walled.

*Ascaris* Intestine No intermediate host
*A. suum* is a parasite of swine. The adult worms are about 30 cm long and white to cream colored.

*Parascaris* Intestine No intermediate host
*Parascaris equorum* is the very large ascarid parasite of the horse.

*Toxascaris* Intestine No intermediate host
*Toxascaris leonina* is a parasite of cats and dogs in the cooler climates of the world. Because of the direct life cycle of this parasite, the worm tends to be found in animals older than the hosts of *T. canis* or *T. cati*.
The restricted mucosal migration of *T. leonina* in dogs and cats precludes the development of somatic larval burdens and the transmission of infection by way of the placenta and mammary gland. Ingestion of infective eggs and paratenic hosts seems to be the only means by which cats and dogs acquire *T. leonina* infection.

<table>
<thead>
<tr>
<th><strong>Toxocara</strong></th>
<th>Intestine</th>
<th>No intermediate host</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Toxocara</em> is a genus of rather large ascaridoids that as adults are parasites in the small intestine of various mammals. <em>T. canis</em> and <em>T. cati</em> are two of the most commonly observed parasites of the dog and cat, respectively.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Baylisascaris</strong></th>
<th>Intestine</th>
<th>No intermediate host</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species of <em>Baylisascaris</em> common in North American wildlife include <em>Baylisascaris procyonis</em> of the raccoon, <em>Baylisascaris columbiae</em> of the skunk, and <em>Baylisascaris laevis</em> of the woodchuck.</td>
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</tbody>
</table>

**Order Spirurida**

Members of the order Spirurida require either an insect or a crustacean intermediate host for development to the infective stage. The definitive host acquires spirurid infection by ingesting infected arthropods or paratenic hosts that have fed on such arthropods. The superfamily Filarioidea requires as its intermediate host a blood-feeding arthropod that becomes infected while taking its blood meal and that vectors the parasite when taking another blood meal.

<table>
<thead>
<tr>
<th><strong>Dracunculus</strong></th>
<th>Subcutaneous tissue</th>
<th>Copod</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Dracunculus</em> is a parasite of the subcutaneous tissues of carnivores and man. When the female <em>Dracunculus</em> has been fertilized, a shallow ulcer forms in the host's skin at the location of the anterior end of the worm. When water wets this ulcer, the female projects her body and prolapses a length of uterus, which then bursts to discharge a horde of larvae. Then she retires to await the next watering.</td>
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</table>

If they are ingested by a copod of the genus *Cyclops*, the larvae discharged into the water develop to the infective third larval stage in about 3 weeks. The definitive host becomes infected by ingesting these *Cyclops* in the drinking water. *Dracunculus insignis* is a parasite of raccoons and other carnivores, including the dog and cat in North America. *Dracunculus medinensis* is a parasite of man in the Middle East and India.

<table>
<thead>
<tr>
<th><strong>Gnathostoma</strong></th>
<th>Stomach wall</th>
<th>Copod</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Gnathostoma</em> spp. adults are found in cystic nodules in the stomach walls of wild and domestic carnivores. Eggs are passed in the one-to-two-cell stage and develop to the second larval stage in water. Those larvae hatch and develop to the infective third stage only if ingested by copepods (<em>Cyclops</em>). A variety of amphibians, snakes, and fishes may serve as paratenic hosts to convey the gnathostome from the copepod to the definitive host. The migrations of gnathostome larvae in the liver and other organs of the definitive host are destructive.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Physaloptera</strong></th>
<th>Stomach</th>
<th>Beetle</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Physaloptera</em> spp. are parasites of the stomach of carnivores. The female worm lays thick-walled eggs that develop to the infective stage in various cophagous beetles. The adult worms tend to live with the anterior end embedded in the mucosa.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Thelazia</strong></th>
<th>Conjunctival, lacrimal sacs</th>
<th>Face fly</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Thelazia</em> spp. are parasites of the conjunctival and lacrimal sacs of cattle and horses. The female <em>Thelazia</em> worm deposits thin-shelled eggs containing larvae that develop to the infective stage in the face fly, <em>Musca autumnalis</em>.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Gonyleonema</strong></th>
<th>Esophagus, rectum</th>
<th>Beetle, cockroach</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Gonyleonema</em> spp. can usually be found woven into a remarkably regular sinusoidal tract in the mucous membrane of the host's esophagus or rectum. Eggs containing first-stage larvae are passed on the host's feces and, if ingested by a dung beetle or a cockroach, develop to the infective stage in about a month. The definitive host becomes infected by ingesting the infected insect.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Spirocerca lupi</strong></th>
<th>Esophagus, stomach</th>
<th>Beetle</th>
</tr>
</thead>
</table>
| *Spirocerca lupi* is found in fibrous nodules in the wall of the esophagus or stomach of dogs. The very small egg contains a verniform embryo when shed in the feces. If ingested by a cophagous beetle, this verniform embryo develops into a larva capable of infecting dogs and a broad range of paratenic hosts. When infective larvae are ingested by a dog, they
migrate in the adventitia of the visceral arteries and aorta to the walls of the esophagus and stomach. Reproductive adults are normally found in cystic nodules that communicate with the lumen of the esophagus or stomach through fistulas. Dysphagia and vomiting, esophageal neoplasia, aortic aneurysm or rupture, and secondary pulmonary oedema may be associated with chronic S. lupi infection.

**Dracchia and Habronema**

Stomach

Fly

*Dracchia megastoma, Habronema muscae, and Habronema microstoma* are parasites of the equine stomach. Larvae hatch from the eggs soon after they are laid. If ingested by maggots (*Musca domestica* for *D. megastoma* and *H. muscae, S. hominivorax celeriae* for *H. microstoma*), these develop to the infective third-stage larvae in a little more than a week.

The infective larvae migrate to the head of the fly and collect in the labium. When a fly alights on a warm, moist surface such as the muzzle, ocular conjunctiva, or cutaneous wounds of a horse, the larvae change hosts. Those larvae that are swallowed proximately complete their life histories, whereas those that enter wounds may probably reach an impasse. However, these aberrant larvae are extremely important because of the granulomas they induce. Typical cutaneous habronemiasis lesions are characterized by an initial rapid production of granulation tissue that steadily refuses to resolve during fly season, by the subsequent appearance of caseous-calcareous nodules in this granulation tissue, and by the presence of *Dracchia* or *Habronema* larvae.

**Superfamily Filarioidea**

Filarioids tend to be rather long and thin white- to cream-colored worms. They are found typically in tissue spaces and body cavities, or sometimes within the vasculature or lymphatic system. All filarioids are transmitted by bloodsucking insects in which vermiform embryos called microfilariae develop into infective third-stage larvae. The microfilariae either circulate in the blood of the definitive host (e.g., *Dirofilaria* and *Setaria* spp.) or accumulate in the dermal connective tissues (e.g., *Onchocerca* spp.). In either case, the microfilariae are ingested and the infective larvae deposited when the insect feeds on the definitive host.

**Dirofilaria**

Pulmonary arteries, heart

Mosquito

*D. immitis* is the canine heartworm. The dog and its close relatives are the natural hosts, but infection also occurs in cats and ferrets. Adult heartworms normally are found in the pulmonary arteries. In heavy infections worms may be found in the right heart. When defecated, the worms are carried deeper into the lungs where they occlude the pulmonary arterial branches and produce infarcts. Endemic areas exist in all parts of the United States. The life history may involve several species of mosquitoes as intermediate hosts. Only when mosquito populations are sufficiently reduced will heartworm disappear.

The life cycle of *D. immitis* is initiated when the dog is bitten by an infected mosquito. Fertilized females contain fully developed microfilariae within the sixth month after infection. Microfilariae typically are not found in the peripheral blood for several more weeks. Mosquitoes are infected when they bite an infected dog.

**Setaria**

Seros membranes

Mosquito

*Setaria laticeps* and *Setaria equina* are large white parasites of the serous membranes of cattle and horses, respectively. Microfilariae of *Setaria* spp. show up on blood smears, and the adult parasites are likely to be encountered during abdominal surgery or on the killing floor or necropsy table. Migrating *Setaria* larvae occasionally invade the central nervous system and cause serious neurological disease, especially in species other than their normal host.

**Onchocerca**

Connective tissue

Fly

*Onchocerca* spp. adults, although large, are intricately woven into the deep connective tissues. *Onchocerca cervicalis* adults are found in the mucus layer of the horse, and the microfilariae are widely distributed in the dermis and other connective tissues including those of the ocular conjunctivae.

In North American cattle, *Onchocerca guentheri* adults are found in connective tissues about the mucus layer, and *Onchocerca lienhartii* are found in the connective tissue between the spleen and rumen. Microfilariae of both species are found in the dermis. The intermediate hosts of bovine *Onchocerca* species may involve simuliid or heleid (ceratopogonid) flies.

**Parafilaria**

Connective tissue

Fly

*Parafilaria* spp. of horses and cattle live in the subcutaneous and intermuscular connective tissues and when sexually mature, produce crops of peazzled nodules that bleed through a tiny pore. The blood escapes in fine drops, runs off in streaks along the hairs, and dries in brown crusts. Eggs and microfilariae of *Parafilaria* spp. may be demonstrated in this material but never in samples from the circulation. Active bleeding occurs only during daylight hours and especially when
Appendix H: Experiment 1: Intervention 2 (Proximity)

Horses are exposed to direct sunshine. The activity of the lesions suggests an adaptation on the part of *Parafilaria* spp. to the habits of flies that feed on blood.

**Dipetalonema**
Connective tissue

The canine parasite *Dipetalonema reconditum* is small, usually few in number, and lies inconspicuously in the connective tissues. The microfilariae, on the other hand, are rather commonly seen and easy to confuse with those of *D. immitis*. *D. reconditum* develops to the infective stage in the flea *Ctenocephalides felis* and in the amblyomeran louse *Heterodoxus spinigera*.

About 90% of the adults are located in subcutaneous tissues, but a small percentage can be found in the peritoneal cavity. The microfilariae circulate in the blood, usually at low densities.

**Order Enoplida**

**Dictyophyme**

Kidney

Oligochaete annelid worm

*Dictyophyme renale*, the "giant kidney worm" of carnivora, swine, and sometimes man, is one of the largest species of nematodes. Mink are the principal definitive hosts. The female *D. renale* produces brownish, thick-shelled eggs with bipolar plugs. The eggs are passed in the urine in the one- or two-cell stage and develop, in water, to the first larval stage in a month or longer. Larvalated eggs are infective to oligochaete annelid worms in which they develop to the infective third larval stage. If infected oligochaetes are ingested by fish or frogs, the larvae invade the tissues of these paratenic hosts but do not undergo development. However, if the infected oligochaete (or paratenic host) is ingested by a dog, the *D. renale* larvae mature and complete the cycle. In the dog, *D. renale* may be found in the pelvis of the right kidney or free in the abdominal cavity.

**Trichinella**

Intestine

No intermediate host

The tiny adults of *Trichinella spiralis* are found embedded in the mucosa of the small intestine of swine, carnivora, and man.

Predation has provided an efficient channel for the evolutionary development of many parasites. In most instances, the larval parasite lies encysted in the tissues of the prey, and the reproductive adults inhabit the alimentary tract of the predator. Thus, in many systems, the predator becomes infected by eating the prey, and the prey becomes infected by ingesting eggs passed in the feces of the predator. However, in the unique life history of *Trichinella spiralis*, both adult and larval stages occur in sequence in the same host, the tiny adults lying among the villi of the small intestine and the larva curled up in cysts in the striated muscle.

First-stage larvae of *T. spiralis*, liberated from their cysts by digestive enzymes of the host, invade the intestinal mucosa. Both sexes reach maturity about 2 days after the infected meat is eaten. The viviparous females give birth to prelarvae, which enter the lymphatics and later the bloodstream to be transported to the muscles. These prelarvae invade striated muscle cells. After 2 or 3 weeks they have developed into first-stage larvae and roll up in spirals, or like pretzels become enveloped in cysts and are then infective.

Almost all mammals can be experimentally infected with *T. spiralis*, but carnivores and omnivores are more likely to become naturally infected. Infection occurs through predation, cannibalism, and carrion feeding. The larvae encysted in muscles are exceptionally resistant to external conditions, including extreme putrefaction. Human trichinosis usually results from eating raw or undercooked pork, bear, or seal.

**Trichuris**

Intestine

No intermediate host

The adult is embedded in the wall of the large intestine, with the posterior end lying free in the lumen. The egg is lemon-shaped with a distinct plug at each pole and contains a single cell when passed in the feces. An infective first-stage larva develops inside the egg but does not hatch unless swallowed by a suitable host. Once eggs are ingested, all development occurs within the epithelium of the intestine (i.e., there is no extraintestinal migration).

Infected *T. vulpis* eggs survive in soil for a long time, and dogs kept in contact with contaminated soils tend to become reinfected after treatment.
## Appendix H: Experiment 1: Intervention 2 (Proximity)

### Summary, sorted by Order

<table>
<thead>
<tr>
<th>Order</th>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Strongyliida</td>
<td><em>Trichostrongylus</em></td>
<td>Stomach, abomasum, small intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Onchocerca</em></td>
<td>Abomasum</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Haemonchus</em></td>
<td>Abomasum</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Necatorius</em></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Dictyocaulus</em></td>
<td>Bronchial tree</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Strongyloides</em></td>
<td>Cecum, colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Stephanurus</em></td>
<td>Hepatic, renal, peritoneal tissue</td>
<td>No intermediate host, or Earthworm</td>
</tr>
<tr>
<td></td>
<td><em>Syngamus</em></td>
<td>Trachea</td>
<td>Earthworm</td>
</tr>
<tr>
<td></td>
<td><em>Megaspirura</em></td>
<td>Bronchi</td>
<td>Earthworm</td>
</tr>
<tr>
<td></td>
<td><em>Paragonimus</em></td>
<td>Meninges</td>
<td>Snails, slugs</td>
</tr>
<tr>
<td></td>
<td><em>Filarioides</em></td>
<td>Lung</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Order Oxyurida</td>
<td><em>Oxyuris equi</em></td>
<td>Colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Enterobius vermicularis</em></td>
<td>Colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Order Ascaridida</td>
<td><em>Ascaris</em></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Parascaris</em></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Toxascaris</em></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Toxascara</em></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td></td>
<td><em>Baylisascaris</em></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Order Spirurida</td>
<td><em>Dracunculus</em></td>
<td>Subcutaneous tissue</td>
<td>Copepod</td>
</tr>
<tr>
<td></td>
<td><em>Gnathostoma</em></td>
<td>Stomach wall</td>
<td>Copepod</td>
</tr>
<tr>
<td></td>
<td><em>Physaloptera</em></td>
<td>Stomach</td>
<td>Beetles</td>
</tr>
<tr>
<td></td>
<td><em>Thelazia</em></td>
<td>Conjunctival, lacrimalsacs</td>
<td>Face fly</td>
</tr>
<tr>
<td></td>
<td><em>Goniodonopus</em></td>
<td>Esophagus, rumen</td>
<td>Beetle, cockroach</td>
</tr>
<tr>
<td></td>
<td><em>Spicrocerca</em></td>
<td>Esophagus, stomach</td>
<td>Beetle</td>
</tr>
<tr>
<td></td>
<td><em>Dracunculus</em></td>
<td>Stomach</td>
<td>Fly</td>
</tr>
<tr>
<td></td>
<td><em>Habronema</em></td>
<td>Stomach</td>
<td>Fly</td>
</tr>
<tr>
<td></td>
<td><em>Dirofilaria</em></td>
<td>Pulmonary arteries, heart</td>
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<td></td>
<td><em>Setaria</em></td>
<td>Serous membranes</td>
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<td><em>Oechocerca</em></td>
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<td><em>Dipetalonema</em></td>
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<td><em>Dioctophyme</em></td>
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## Appendix H: Experiment 1: Intervention 2 (Proximity)

### Summary, sorted by Intermediate Host

<table>
<thead>
<tr>
<th>Order</th>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
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<td>Spirocerca</td>
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<td>Spirurida</td>
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<td>Habronema</td>
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<td>Fly</td>
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<td>Neumot brius</td>
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<td>Pfeurades</td>
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<td>Strongyliida</td>
<td>Parasthrostrongylus</td>
<td>Meninges</td>
<td>Snails, slugs</td>
</tr>
</tbody>
</table>
Appendix I: Experiment 1: Intervention 3 (Explicitness)

Table of Contents

Order Strongylida

Superfamily Trichostrongyloidea

Trichostrongylus

Ostertagia

Haemonchus

Nematodirus

Dictyocaulus

Superfamily Strongylidea

Strongylus

Stephanurus

Syngamus

Superfamily Metastrongylidea

Metastrongylus

Family Protostrongylidae

Parelaphostrongylus

Family Filaroididae

Filaroides

Order Oxyurida

Oxyurus equi

Enterobius vermicularis

Order Ascaridida

Ascaris

Parascaris

Toxascaris

Toxocara

Baylisascaris

Order Spirurida

Dracunculus

Gnathostoma

Physaloptera

Thelazia

Gonyleptus

Spirocerca lupi

Dracunculus and Habronema

Superfamily Filaroidea

Draffilura

Setaria

Onchocerca

Parafilaria

Dipetalonema

Order Enoplida

Diactophyme

Trichinella

Trichuris
Appendix I: Experiment 1: Intervention 3 (Explicitness)

PHYLUM NEMATODA

All control efforts are based on an understanding of the life history and behavior of both host and parasite. A general outline of the ontogenetic development of a nematode is shown in Figure 1. What appears to be a rich and confusing diversity of life histories among various orders of nematodes can all be related and rationalized according to this basic pattern.

![Diagram of nematode development](image)

**FIGURE 1** Stages and transitions in the ontogenetic development of a nematode.

In general, whether or not a nematode requires an intermediate host is determined by two factors. The first factor is whether the nematode is located in the gastrointestinal tract. Because the gastrointestinal tract provides direct access to the outside world for the nematode's eggs or larvae by way of the feces, these parasites do not require an intermediate host (unless they are members of the order Spirurida). In contrast, nematodes whose adults are found in locations other than the gastrointestinal tract generally do require intermediate hosts.

The second factor is the taxonomic order to which the parasite belongs. If the parasite is a member of the order Spirurida or the superfamily Metastrongylidea, then it requires an intermediate host. An exception to this rule is the metastroglylid *Filaroides*.

**Order Strongylida**

The order Strongylida is composed of four superfamilies: (1) Strongylidea, the large bowel "strongyles" of horses and the nodular worms of ruminants, swine, and primates, (2) Trichostrongylidea, the abomasal and small intestinal "hairworms" of ruminants, (3) Ancylostomatidea, the "hookworms" of diverse mammals, and (4) Metastrongylidea, the "lungworms." One of the most important genera of lungworms falls within the Trichostrongylidea rather than the Metastrongylidea, but there are always exceptions to be resolved.

The life histories of superfamilies Strongylidea, Trichostrongylidea, and Ancylostomatidea are typically direct, with free-living microvorous first and second larval stages and an infective third larval stage (Figure 2). Females of all three superfamilies lay typical "strongyle eggs" (i.e., eggs with smooth-surfaced, ellipsoidal shells that contain an embryo in the morula stage of development when laid and passed out with the feces). Such eggs are produced by all members of the order Strongylida, except certain genera in the superfamily Metastrongylidea. The morula develops into a first-stage larva that hatches from the egg within a day or two. After hatching, this larva undergoes its first molt to become a second-stage larva. Both first- and second-stage larvae remain in the feces, where they feed on bacteria. In the second molt, the cuticle of the second stage is temporarily retained as a protective "sheath" about the infective third-stage larva and will not be shed until this larva enters a suitable host. In about a week, these "sheathed" third-stage larvae begin to migrate out of the fecal mass and into the water film covering the surrounding soil particles and vegetation. Infection occurs when these "sheathed larvae" are ingested by grazing animals.

Metastrongyloids typically require a molluscum or annelid intermediate host for development from the first stage to the infective third stage, and infection of the definitive host occurs through ingestion of snails' slugs, or earthworms containing
Appendix I: Experiment 1: Intervention 3 (Explicitness)

Infective third-stage larvae. *Filaroides ashei* and *Filaroides hirki*, both directly infective to the dog in the first larval stage, form important exceptions to this rule.

![Diagram of parasitic stages and free-living stages]

**FIGURE A** Typical strongyloid life history.

1. Eggs are shed in the feces in the morula stage of development.
2. First-stage larvae develop and hatch in a day or two to feed on microorganisms in the feces. After a molt, the resulting second-stage larvae also feed on microorganisms.
3. The infective third-stage larvae remain encased in the cuticle of the second stage until it is ingested.
4. The sheath is cast off in the abomasum of the sheep and the new parasitic third-stage larva undergoes a molt to the fourth stage. The fourth stage sooner or later molts to the fifth or adult stage, depending on whether it enters a period of arrested development.

**Superfamily Trichostrongylidae**

Trichostrongyloid nematodes are especially common and pathogenic in grazing ruminants, but swine, horses, cats, and birds also host important species. The abomasum and small intestine are the usual locations in ruminants, but one aberrant genus, *Dictyocaulus*, reaches maturity in the air passages.

**Trichostrongylus**

*Trichostrongylus axei* parasitizes the simple stomach or abomasum of a wide range of hosts including ruminants and horses. Other species are parasites of the small intestine of ruminants and display a higher order of host specificity. *Trichostrongylus* spp. infective third-stage larvae survive the winter on pasture, and ruminants are exposed to infection when they are turned to pasture in spring. As the weather becomes warmer, the infective larvae die off, and by summer the overwintering generation is essentially gone. However, egg production from new infections rapidly recontaminates the pasture and continues well into fall to produce the next season’s overwintering population of *Trichostrongylus* spp.

**Ostertagia**

*Ostertagia* spp. are found in the abomasum of ruminants. The eggs are typical strongyloid eggs. Infective third-stage larvae resemble those of *Trichostrongylus* spp. in overwintering on northern pastures and in thus infecting ruminants during the early grazing season. However, arrested development of parasitic larvae is also very well developed in *Ostertagia* spp. *O. ostertagi* causes chronic abomasitis in young cattle, a disease marked by profuse watery diarrhea, anemia, and hypoproteinemia manifested clinically as submaxillary edema.

**Haemonchus**

*Haemonchus* are parasites of the abomasum of ruminants. The white, egg-filled uterus of the femalespirals around the blood-filled gut, giving rise to the so-called barber pole appearance.

At peak infection, naturally acquired populations of *Haemonchus contortus* may remove one fifth of the circulating erythrocyte volume per day from lambs and may remove an average of one tenth of the circulating erythrocyte volume per day over the course of nonfatal infections lasting two months. The pathogenic effects of *H. contortus* result from the inability of the host to compensate for blood loss. The cardinal sign of haemonchosis is pallor of the skin and mucous membranes. Individual older ewes may succumb in late spring to the overwhelming challenge imposed by hordes of larvae simultaneously emerging from developmental arrest.
Appendix I: Experiment 1: Intervention 3 (Explicitness)

**Nematodirus**
The life history and epidemiology of *Nematodirus* species infecting domestic ruminants are distinctly different from those of most other trichostrongyloids. The larva develops to the infective third stage within the eggshell, and hatching depends on extrinsic stimuli, at least in certain species. For example, the infective larva of *Nematodirus battus* must usually be subjected to freezing followed by warmer weather before it will hatch. This property tends to concentrate hatching of infective larvae in the spring, to limit reproduction to one generation per year, and to generate a single wave of infection and disease in late spring.

**Dictyocaulus**
Adult *Dictyocaulus* worms are found in the respiratory passages of ruminants and horses. The egg contains a first-stage larva when laid. Adult *Dictyocaulus* spp. live in the lumen of the bronchial tree, where they cause chronic bronchitis and localized occlusion of the bronchial tree with atelectasis. *Dictyocaulus viviparus* is the only nematode that reaches maturity in the lungs of cattle. The freshly laid egg contains a wormiform embryo that usually hatches before being eliminated in the feces. When ingested, the infective larva migrate by way of the mesenteric lymph nodes and thoracic duct.

**Superfamily Strongyloidea**
Strongyloid life histories are typical of the order, but significant variations occur in certain groups. For example, *Syngamus* sp., the "gape worm" of domestic and wild birds, and *Stephanurus* sp., the "kidney worm" of swine, use earthworms as paratenic hosts.

**Strongylus**
*Strongylus vulgaris* is a parasite of the horse. The adult worms are found in the cecum and colon.

The extrahost development of *S. vulgaris* is typical of strongyloids in general (see Figure 2). When ingested by a horse, the infective third-stage larvae of *S. vulgaris* enter the wall of the cecum and ventral colon. The larvae penetrate nearby small arterioles and wander in these vessels and progressively larger branches of the cranial mesenteric artery. The rapidly migrating larvae reach the colic and cecal arteries and the cranial mesenteric artery. Some of the larvae push on into the aorta and its branches, where they may cause important pathological changes.

The migrations of fourth-stage *S. vulgaris* larvae cause arteritis, thrombosis, and embolism of the cranial mesenteric artery and its branches.

**Stephanurus**
*Stephanurus dentatus*, the kidney worm of swine, is a stout parasite of the hepatic, renal, and perirenal tissues, axial musculature, and spinal canal of swine and sometimes of cattle.

Earthworms serve as intermediate hosts. The life history may be direct or could involve earthworms as facultative intermediate hosts, infection occurring by ingestion or skin penetration of third-stage larvae or by ingestion of infected earthworms. Once in the body of the pig, the larvae enter the liver and wander destructively there. Some are trapped by an encysting tissue reaction, but the rest migrate to the retroperitoneal tissues surrounding the kidneys and ureters. Eggs appear in the urine. Piglets may become infected in utero.

**Syngamus**
The genus *Syngamus* are parasites of the upper respiratory tract in birds. Males and females of *Syngamus* spp. are fused permanently in copula. *Syngamus* trachea infections have caused the deaths of farmed hens. Earthworms serve as intermediate hosts.

**Superfamily Metastrongyloidea**
Metastrongyloids are parasites of the respiratory, vascular, and nervous systems of mammals. Most species require a snail or slug intermediate host. However, *Metastrongylus* spp. develop to the infective stage in earthworms, and *F. oesleri* and *F. kiriki* infect their definitive hosts directly.

**Metastrongylus**
These are large white parasites of the bronchi and bronchioles of swine. Oviparous females lay eggs containing first-stage larvae. These eggs do not hatch or develop into infective larvae unless they are ingested by an earthworm.
Family Protostrongylidae
Females deposit unsegmented eggs in the surrounding lung, vascular, or neural tissues. These eggs develop into first-stage larvae before they appear in the feces. If these first-stage larvae are ingested by any of a wide range of snails and slugs, they develop in these intermediate hosts into doubly enshrathed third-stage infective larvae.

Parelaphostrongylus
Parelaphostrongylus tenuis is normally a parasite of the meninges of the white-tailed deer, in which species it rarely if ever causes disease. However, in abnormal hosts such as sheep, goats, llamas, camel, moose, caribou, reindeer, wapiti, fallow deer, and mule deer, P. tenuis tends to invade the nervous tissue proper, causing serious or fatal neurological disease. Because P. tenuis rarely matures in these hosts, larvae are not shed in the feces. Therefore diagnosis is presumptive and based on the appearance of neurological signs in ruminants that share their pastures with whitetailed deer.

Family Filaroididae
Filaroides
Do not confuse the family Filaroididae with the very distantly related superfamily Filaroides. The canine parasites, F. oviger and F. hirshi occur in nodules within the epithelium of the trachea and bronchi or within the lung parenchyma, respectively.

The ooviviparous females deposit delicate, thin-shelled eggs containing first-stage larvae that hatch before being voided in the host's feces. Unlike other metastrongylids, most or all of which require a molluscous or annelid intermediate host to develop into the infective third larval stage, Filaroides spp. are directly infective as first-stage larva, and development through all five stages is completed in the lung tissue of the dog. Because these larvae are released within the host, autoinfection is inevitable and the degree of resulting infection is apparently governed solely by the host's immune reactions. First-stage larvae pass up the trachea and out with the feces, and transmission occurs principally by coprophagy. Canibalism and regurgitatory feeding provide other mechanisms.

Order Oxyurida
Oxyuris equi
Adult O. equi are found principally in the small colon, although occasional specimens may be found in the large colon. Instead of simply discharging her eggs in the fecal stream, the gravid female O. equi migrates down the colon and rectum and out through the anus to cement her eggs in masses to the skin of the anus and its immediate surroundings. The eggs develop to the infective stage in 4 or 5 days. The most common affliction perpetrated by O. equi on the horse is pruritus ani caused by the adhesive egg masses deposited on the perianal skin by the female worm. In its efforts to relieve the itching, the horse will persistently rub its tail against posts, mangers, and the like.

Enterobius vermicularis
This is the small pinworm of humans and great apes. The gravid E. vermicularis female migrates through the anal opening to cement her eggs to the host's perianal skin. The eggs develop to the infective stage within hours and are ready to infect the host by contamination of the hands, to infect other individuals by contamination of bedclothing or other fomites, or to become airborne on dust particles. Infection may be suspected in children who have pruritus ani and insomnia.

Order Ascaridida
Ascaris are among the largest and most familiar of nematode parasites infecting the intestinal tract of domestic animals.

The single cell develops into an infective larva inside the eggshell within several days or weeks, depending on the species of worm and the ambient temperature. Ascarid eggs are remarkably resistant to chemical and physical insults, especially after they have arrived at the infective stage. The single most important fact to remember in relation to the epidemiology of ascariasis is that the eggs remain infective in soil for many years. The larval stage hatching from the egg of these ascaridoids is a third-stage larva. Ascarid eggs are relatively thick walled.

Ascaris
A. suum is a parasite of swine. The adult worms are about 30 cm long and white to cream colored.

Parascaris
Parascaris equorum is the very large ascarid parasite of the horse.
Appendix I: Experiment 1: Intervention 3 (Explicitness)

**Toxascaris**

*Toxascaris leonina* is a parasite of cats and dogs in the cooler climates of the world. Because of the direct life cycle of this parasite, the worm tends to be found in animals older than the hosts of *T. cantis* or *T. cati*.

The restricted mucosal migration of *T. leonina* in dogs and cats precludes the development of somatic larval burdens and the transmission of infection by way of the placenta and mammary gland. Ingestion of infective eggs and paratenic hosts seems to be the only means by which cats and dogs acquire *T. leonina* infection.

**Toxocara**

*Toxocara* is a genus of rather large ascaridoids that as adults are parasites in the small intestine of various mammals. *T. cantis* and *T. cati* are two of the most commonly observed parasites of the dog and cat, respectively.

*Toxocara* and *Toxascaris* eggs are very resistant to environmental adversity and remain infective for years, especially in poorly drained clay and silt soils.

**Baylisascaris**

Species of *Baylisascaris* common in North American wildlife include *Baylisascaris procyonis* of the raccoon, *Baylisascaris columnaris* of the skunk, and *Baylisascaris laevis* of the woodchuck.

**Order Spirurida**

Members of the order Spirurida require either an insect or a crustacean intermediate host for development to the infective stage. The definitive host acquires spirurid infection by ingesting infected arthropods or paratenic hosts that have fed on such arthropods. The superfamily Filarioidea requires its intermediate host a blood-feeding arthropod that becomes infected while taking its blood meal and that vectors the parasite when taking another blood meal.

**Dracunculus**

*Dracunculus* is a parasite of the subcutaneous tissues of carnivores and man. When the female *Dracunculus* has been fertilized, a shallow ulcer forms in the host's skin at the location of the anterior end of the worm. When water wets this ulcer, the female projects her body and prolapses a length of uterus, which then bursts to discharge a horde of larvae. Then she retires to await the next wetting.

If they are ingested by a copepod of the genus *Cyclops*, the larvae discharged into the water develop to the infective third larval stage in about 3 weeks. The definitive host becomes infected by ingesting these *Cyclops* in the drinking water. *Dracunculus insignis* is a parasite of raccoons and other carnivores, including the dog and cat in North America. *Dracunculus medinensis* is a parasite of man in the Middle East and India.

**Gnathostoma**

*Gnathostoma* spp. adults are found in cystic nodules in the stomach walls of wild and domestic carnivores. Eggs are passed in the one-to two-cell stage and develop to the second larval stage in water. These larvae hatch and develop to the infective third stage only if ingested by copepods (*Cyclops*). A variety of amphibians, snails, and fishes may serve as paratenic hosts to convey the gnathostome from the copepod to the definitive host. The migrations of gnathostome larvae in the liver and other organs of the definitive host are destructive.

**Physaloptera**

*Physaloptera* spp. are parasites of the stomach of carnivores. The female worm lays thick-walled eggs that develop to the infective stage in various coprophagous beetles. The adult worms tend to live with the anterior end embedded in the mucosa.

**Thelazia**

*Thelazia* spp. are parasites of the conjunctival and lacrimal sacs of cattle and horses. The female *Thelazia* worm deposits thin-shelled eggs containing larvae that develop to the infective stage in the face fly, *Musca autumnalis*.

**Gongylonema**

*Gongylonema* spp. can usually be found woven into a remarkably regular sinusoidal tract in the mucous membrane of the host's esophagus or rumen. Eggs containing first-stage larvae are passed on the host's feces and, if ingested by a dung beetle or a cockroach, develop to the infective stage in about a month. The definitive host becomes infected by ingesting the infected insect.
Appendix I: Experiment 1: Intervention 3 (Explicitness)

**Spirocerca lupi**

*Spirocerca lupi* is found in fibrous nodules in the wall of the esophagus or stomach of dogs. The very small egg contains a vermiform embryo when shed in the feces. If ingested by a coprophagous beetle, this vermiform embryo develops into a larva capable of infecting dogs and a broad range of paratenic hosts. When infective larvae are ingested by a dog, they migrate in the adventitia of the visceral arteries and aorta to the walls of the esophagus and stomach. Reproductive adults are normally found in cystic nodules that communicate with the lumen of the esophagus or stomach through fistulas. Dysphagia and vomiting, esophageal neoplasia, aortic aneurysm or rupture, and secondary pulmonary osteoarthropathy may be associated with chronic *S. lupi* infection.

**Dracunculus and Habronema**

*Dracunculus medinensis*, *Habronema muscae*, and *Habronema microstoma* are parasites of the equine stomach. Larvae hatch from the eggs soon after they are laid. If ingested by maggots (*Musca domestica* for *D. medinensis* and *H. muscae*; *Stomoxys calcitrans* for *H. microstoma*), these develop to the infective third-stage larvae in a little more than a week.

The infective larvae migrate to the head of the fly and collect in the labium. When a fly alights on a warm, moist surface such as the muzzle, ocular conjunctiva, or cutaneous wounds of a horse, the larvae emerge. Those larvae that are swallowed presumably complete their life histories, whereas those that enter wounds have probably reached an impasse. However, these aberrant larvae are extremely important because of the granulomas they induce. Typical cutaneous habronemiasis lesions are characterized by an initial rapid production of granulation tissue that steadfastly refuses to resolve during fly season, by the subsequent appearance of caseo-calcareous nodules in this granulation tissue, and by the presence of *Dracunculus* or *Habronema* larvae.

**Superfamily Filarioidea**

Filaroids tend to be rather long and thin white- to cream-colored worms. They are found typically in tissue spaces and body cavities, or sometimes within the vasculature or lymphatic system. All filaroids are transmitted by bloodsucking insects in which vermiform embryos called microfilariae develop into infective third-stage larvae. The microfilariae either circulate in the blood of the definitive host (e.g., *Dirofilaria* and *Setaria* spp.) or accumulate in the dermal connective tissues (e.g., *Onchocerca* spp.). In either case, the microfilariae are ingested and the infective larvae deposited when the insect feeds on the definitive host.

**Dirofilaria**

*D. immitis* is the canine heartworm. The dog and its close relatives are the natural hosts, but infection also occurs in cats and ferrets. Adult heartworms normally are found in the pulmonary arteries. In heavy infections worms may be found in the right heart. When defecated, the worms are carried deeper into the lungs where they occlude the pulmonary arterial branches and produce infarcts. Endemic areas exist in all parts of the United States. The life history may involve several species of mosquitoes as intermediate hosts. Only when mosquito populations are sufficiently reduced will heartworm disappear.

The life cycle of *D. immitis* is initiated when the dog is bitten by an infected mosquito. Fertilized females contain fully developed microfilariae within the sixth month after infection. Microfilariae typically are not found in the peripheral blood for several more weeks. Mosquitoes are infected when they bite an infected dog.

**Setaria**

*Setaria latiseta* and *Setaria equina* are large white parasites of the serous membranes of cattle and horses, respectively. Microfilariae of *Setaria* spp. show up on blood smears, and the adult parasites are likely to be encountered during abdominal surgery or on the killing floor or necropsy table. Migrating *Setaria* larvae occasionally invade the central nervous system and cause serious neurological disease, especially in species other than their normal host.

**Onchocerca**

*Onchocerca* spp. adults, although large, are intricately woven into the deep connective tissues. *Onchocerca cervicalis* adults are found in the nuchal ligament of the horse, and the microfilariae are widely distributed in the dermis and other connective tissues including those of the ocular conjunctiva.

In North American cattle, *Onchocerca cervicalis* adults are found in connective tissues about the nuchal ligament, and *Onchocerca lienalis* are found in the connective tissue between the spleen and rumen. Microfilariae of both species are found in the dermis. The intermediate hosts of bovine *Onchocerca* species may involve simulid or heleid (ceratopogonid) flies.
**Parafilaria**

*Parafilaria* spp. of horses and cattle live in the subcutaneous and intermuscular connective tissues and when sexually mature, produce crops of pea-sized nodules that bleed through a tiny pore. The blood escapes in fine drops, runs off in streaks along the hairs, and dries in brown crusts. Eggs and microfilariae of *Parafilaria* spp. may be demonstrated in this material but never in samples from the circulation. Active bleeding occurs only during daylight hours and especially when horses are exposed to direct sunshine. The activity of the lesions suggests an adaptation on the part of *Parafilaria* spp. to the habits of flies that feed on blood.

**Dipetalonema**

The canine parasite *Dipetalonema reconditum* is small, usually few in number, and lies inconspicuously in the connective tissues. The microfilariae, on the other hand, are rather commonly seen and easy to confuse with those of *D. immitis*. *D. reconditum* develops to the infective stage in the flea *Ctenocephalides felis* and in the amblycercan louse *Heterodoxus spiniger*.

About 90% of the adults are located in subcutaneous tissues, but a small percentage can be found in the peritoneal cavity. The microfilariae circulate in the blood, usually at low densities.

**Order Enoplida**

**Dioctophyme**

*Dioctophyme renale*, the "giant kidney worm" of carnivora, swine, and sometimes man, is one of the largest species of nematodes. Mink are the principal definitive hosts. The female *D. renale* produces brownish, thick-shelled eggs with bipolar plugs. The eggs are passed in the urine in the one- or two-cell stage and develop, in water, to the first larval stage in a month or longer. Larvated eggs are infective to oligochaetae annelid worms in which they develop to the infective third larval stage. If infected oligochaetae are ingested by fish or frogs, the larvae invade the tissues of these paratenic hosts but do not undergo development. However, if the infected oligochaetae (or paratenic host) is ingested by a dog, the *D. renale* larvae mature and complete the cycle. In the dog, *D. renale* may be found in the pelvis of the right kidney or free in the abdominal cavity.

**Trichinella**

The tiny adults of *Trichinella spiralis* are found embedded in the mucosa of the small intestine of swine, carnivora, and man.

Predation has provided an efficient channel for the evolutionary development of many parasites. In most instances, the larval parasite lies encysted in the tissues of the prey, and the reproductive adults inhabit the alimentary tract of the predator. Thus in most systems, the predator becomes infected by eating the prey, and the prey becomes infected by ingesting eggs passed in the feces of the predator. However, in the unique life history of *Trichinella spiralis*, both adult and larval stages occur in sequence in the same host, the tiny adults lying among the villi of the small intestine and the larvae curled up in cysts in the striated muscle.

First-stage larva of *T. spiralis*, liberated from their cysts by digestive enzymes of the host, invade the intestinal mucosa. Both sexes reach maturity about 2 days after the infected meat is eaten. The viviparous females give birth to prelarvae, which enter the lymphatics and later the bloodstream to be transported to the muscles. These prelarvae invade striated muscle cells. After 2 or 3 weeks they have developed into first-stage larvae and roll up in spirals, or like pretzels become enveloped in cysts and are then infective.

Almost all mammals can be experimentally infected with *T. spiralis*, but carnivores and omnivores are more likely to become naturally infected. Infection occurs through predation, cannibalism, and carrion feeding. The larvae encysted in muscles are exceptionally resistant to external conditions, including extreme putrefaction. Human trichinosis usually results from eating raw or undercooked pork, bear, or seal.

**Trichuris**

The adult is embedded in the wall of the large intestine, with the posterior end lying free in the lumen. The egg is lemon-shaped with a distinct plug at each pole and contains a single cell when passed in the feces. An infective first-stage larva develops inside the egg but does not hatch unless swallowed by a suitable host. Once eggs are ingested, all development occurs within the epithelium of the intestine (i.e., there is no extraintestinal migration).

Infected *T. vulpis* eggs survive in soil for a long time, and dogs kept in contact with contaminated soils tend to become reinfected after treatment.
Appendix I: Experiment 1: Intervention 3 (Explicitness)

Summary

In general, whether or not a nematode requires an intermediate host is determined by two factors. The first factor is whether the nematode is located in the gastrointestinal tract. Because the gastrointestinal tract provides direct access to the outside world for the nematode's eggs or larvae by way of the feces, these parasites do not require an intermediate host (unless they are members of the order Spirurida). In contrast, nematodes whose adults are found in locations other than the gastrointestinal tract generally do require intermediate hosts.

The second factor is the taxonomic order to which the parasite belongs. If the parasite is a member of the order Spirurida or the superfamily Metastrongyloidea, then it requires an intermediate host. An exception to this rule is the metastrongylid *Filaroides*. 
Appendix J: Experiment 1: Intervention 4 (Proximity + Explicitness)

Table of Contents

Order Strongylida ................................................................. 2
   Superfamily Trichostrongylidae .............................................. 3
      Trichostrongylus .......................................................... 3
      Ostertagia ................................................................. 3
      Hemonchus .............................................................. 3
      Nematodirus ............................................................... 4
      Dictyocaulus ............................................................... 4
   Superfamily Strongylidea ....................................................... 4
      Strongylus ................................................................. 4
      Stephanurus ............................................................... 4
      Syngamus ................................................................. 4
   Superfamily Metastrongylidea ................................................ 4
      Metastrongylus .......................................................... 4
      Family Protostomidae ................................................... 5
      Parelaphostrongylus ....................................................... 5
      Family Filaroididae ....................................................... 5
      Filaroides spp .......................................................... 5
Order Oxyurida ................................................................. 5
   Oxyuris equi ................................................................. 5
   Enterobius vermicularis ...................................................... 5
Order Ascaridida ............................................................. 5
   Ascaris ................................................................. 5
   Parascaris ................................................................. 5
   Toxascaris ................................................................. 6
   Toxocara ................................................................. 6
   Baylisascaris ............................................................. 6
Order Spirurida .............................................................. 6
   Dracunculus ................................................................. 6
   Gnathostoma ............................................................... 6
   Physaloptera ............................................................... 6
   Thelazia ................................................................. 6
   Gongylonema ............................................................... 6
   Spiricercus hepatis ....................................................... 7
   Dracunculus medinensis .................................................... 7
Order Enoplida .............................................................. 8
   Dipetalonema ............................................................ 8

Page 1

157
Appendix J: Experiment 1: Intervention 4 (Proximity + Explicitness)

**PHYLUM NEMATODA**

All control efforts are based on an understanding of the life history and behavior of both host and parasite. A general outline of the ontogenetic development of a nematode is shown in Figure 1. What appears to be a rich and confusing diversity of life histories among various orders of nematodes can all be related and rationalized according to this basic pattern.

![Figure 1: Stages and transitions in the ontogenetic development of a nematode.](image)

In general, whether or not a nematode requires an intermediate host is determined by two factors. The first factor is whether the nematode is located in the gastrointestinal tract. Because the gastrointestinal tract provides direct access to the outside world for the nematode's eggs or larvae by way of the feces, these parasites do not require an intermediate host (unless they are members of the order Spirurida). In contrast, nematodes whose adults are found in locations other than the gastrointestinal tract generally do require intermediate hosts.

The second factor is the taxonomic order to which the parasite belongs. If the parasite is a member of the order Spirurida or the superfamily Metastrongylidea, then it requires an intermediate host. An exception to this rule is the metastrongylid *Filaroides*.

**Order Strongylida**

The order Strongylida is composed of four superfamilies: (1) Strongylidea, the large bowel "strongyle" of horses and the nodular worms of ruminants, swine, and primates; (2) Trichostrongylidea, the abomasal and small intestinal "hairworms" of ruminants; (3) Ancylostomatidea, the "hookworms" of diverse mammals; and (4) Metastrongylidea, the "lungworms." One of the most important genera of lungworms falls within the Trichostrongylidea rather than the Metastrongylidea, but there are always exceptions to be resolved.

The life histories of superfamilies Strongylidea, Trichostrongylidea, and Ancylostomatidea are typically direct, with free-living microbivorous first and second larval stages and an infective third larval stage (Figure 2). Females of all three superfamilies lay typical "strongyle eggs" (i.e., eggs with smooth-surfaced, ellipsoidal shells that contain an embryo in the morula stage of development when laid and passed out with the feces). Such eggs are produced by all members of the order Strongylida, except certain genera in the superfamily Metastrongylidea. The morula develops into a first-stage larva that hatches from the egg within a day or two. After feeding, this larva undergoes its first molt to become a second-stage larva. Both first- and second-stage larvae remain in the feces, where they feed on bacteria. In the second molt, the cuticle of the second stage is temporarily retained as a protective "sheath" about the infective third-stage larva and will not be shed until this larva enters a suitable host. In about a week, these "sheathed" third-stage larvae begin to migrate out of the fecal mass and into the water film covering the surrounding soil particles and vegetation. Infection occurs when these "sheathed larvae" are ingested by grazing animals.

Metastrongylids typically require a molluscan or annelid intermediate host for development from the first stage to the infective third stage, and infection of the definitive host occurs through ingestion of smalls: slugs, or earthworms containing...
infective third-stage larvae. _Filaroides oxleri_ and _Filaroides kirti_, both directly infective to the dog in the first larval stage, form important exceptions to this rule.

![Diagram of parasitic stages](image)

**FIGURE 2** A typical strongyloïd life history.

1. Eggs are shed in the feces in the morula stage of development.
2. First-stage larvae develop and hatch in a day or two to feed on microorganisms in the feces. After a molt, the resulting second-stage larva also feeds on microorganisms.
3. The infective third-stage larva remains encased in the cuticle of the second stage until it is ingested.
4. The sheath is cast off in the abomasum of the sheep and the now parasitic third-stage larva undergoes a molt to the fourth stage. The fourth stage sooner or later molts to the fifth or adult stage, depending on whether it enters a period of arrested development.

**Superfamily Trichostrongyliidae**

Trichostrongyloid nematodes are especially common and pathogenic in grazing ruminants, but swine, horses, cats, and birds also host important species. The abomasum and small intestine are the usual locations in ruminants, but one aberrant genus, _Dictyocaulus_, reaches maturity in the air passages.

**Trichostrongylius**  
Stomach, abomasum, small intestine  
No intermediate host

*Trichostrongylius axei* parasitizes the simple stomach or abomasum of a wide range of hosts including ruminants and horses. Other species are parasites of the small intestine of ruminants and display a higher order of host specificity. *Trichostrongylius* spp. infective third-stage larvae survive the winter on pasture, and ruminants are exposed to infection when they are turned to pasture in spring. As the weather becomes warmer, the infective larvae die off, and by summer the overwintering generation is essentially gone. However, egg production from now infections rapidly recontaminates the pasture and continues well into fall to produce the next season's overwintering population of _Trichostrongylius_ spp.

**Ostertagia**  
Abomasum  
No intermediate host

*Ostertagia* spp. are found in the abomasum of ruminants. The eggs are typical strongyloid eggs. Infective third-stage larvae resemble those of _Trichostrongylius_ spp. in overwintering on northern pastures and in thus infecting ruminants during the early grazing season. However, arrested development of parasitic larvae is also very well developed in *Ostertagia* spp. *O. ostertagi* causes chronic abomasitis in young cattle, a disease marked by profuse watery diarrhea, anemia, and hypoproteinemia manifested clinically as submaxillary edema.

**Haemonchus**  
Abomasum  
No intermediate host

*Haemonchus* are parasites of the abomasum of ruminants. The white, egg-filled uterine of the female spirals around the blood-filled gut, giving rise to the so-called barber pole appearance.

At peak infection, naturally acquired populations of *Haemonchus contortus* may remove one fifth of the circulating erythrocyte volume per day from lambs and may remove an average of one tenth of the circulating erythrocyte volume per day over the course of nonfatal infections lasting two months. The pathogenic effects of _H. contortus_ result from the inability of the host to compensate for blood loss. The cardinal sign of haemorrhage is pallor of the skin and mucous membranes. Individual older ewes may succumb in late spring to the overwhelming challenge imposed by hordes of larvae simultaneously emerging from developmental arrest.
Appendix J: Experiment 1: Intervention 4 (Proximity + Explicitness)

**Nematodirus**  Intestine  No intermediate host
The life history and epidemiology of *Nematodirus* species infecting domestic ruminants are distinctly different from those of most other trichostongyloids. The larva develops to the infective third stage within the eggshell, and hatching depends on extrinsic stimuli, at least in certain species. For example, the infective larva of *Nematodirus battus* must usually be subjected to freezing followed by warmer weather before it will hatch. This property tends to concentrate hatching of infective larvae in the spring, to limit reproduction to one generation per year, and to generate a single wave of infection and disease in late spring.

**Dictyocaulus**  Bronchial tree  No intermediate host
Adult *Dictyocaulus* worms are found in the respiratory passages of ruminants and horses. The egg contains a first-stage larva when laid. Adult *Dictyocaulus* spp. live in the lumen of the bronchial tree, where they cause chronic bronchitis and localized occlusion of the bronchial tree with abscessation. *Dictyocaulus viviparum* is the only nematode that reaches maturity in the lungs of cattle. The freshly laid egg contains a verminiform embryo that usually hatches before being eliminated in the feces. When ingested, the infective larva migrate by way of the mesenteric lymph nodes and thoracic duct.

**Superfamily Strongyloidea**

Strongyloid life histories are typical of the order, but significant variations occur in certain groups. For example, *Syngamus* sp., the "gape worm" of domestic and wild birds, and *Stephanurus* sp., the "kidney worm" of swine, use earthworms as paratenic hosts.

**Strongylus**  Cecum, colon  No intermediate host
*Strongylus vulgaris* is a parasite of the horse. The adult worms are found in the cecum and colon.

The extrahost development of *S. vulgaris* is typical of strongylids in general (see Figure 2). When ingested by a horse, the infective third-stage larvae of *S. vulgaris* enter the wall of the cecum and ventral colon. The larvae penetrate nearby small arterioles and wander in these vessels and progressively larger branches of the cranial mesenteric artery. The rapidly migrating larvae reach the colic and cecal arteries and the cranial mesenteric artery. Some of the larvae push on into the aorta and its branches, where they may cause important pathological changes.

The migrations of fourth-stage *S. vulgaris* larvae cause arteritis, thrombosis, and embolism of the cranial mesenteric artery and its branches.

**Stephanurus**  Hepatic, renal, perirenal tissue  No intermediate host or earthworms
*Stephanurus demersus*, the kidney worm of swine, is a stout parasite of the hepatic, renal, and perirenal tissues, axial musculature, and spinal canal of swine and sometimes of cattle.

Earthworms serve as intermediate hosts. The life history may be direct or could involve earthworms as facultative intermediate hosts, infection occurring by ingestion of third-stage larvae or by ingestion of infected earthworms. Once in the body of the pig, the larvae enter the liver and wander destructively there. Some are trapped by an encapsulating tissue reaction, but the rest migrate to the retroperitoneal tissue surrounding the kidneys and ureters. Eggs appear in the urine. Piglets may become infected in utero.

**Syngamus**  Trachea  Earthworm
The genus *Syngamus* are parasites of the upper respiratory tract in birds. Males and females of *Syngamus* spp. are fused permanently in copula. *Syngamus* trachea infections have caused the deaths of farmed rhesus. Earthworms serve as intermediate hosts.

**Superfamily Metastrongyloidea**

Metastrongyloids are parasites of the respiratory, vascular, and nervous systems of mammals. Most species require a snail or slug intermediate host. However, *Metastrongyles* spp. develop to the infective stage in earthworms, and *F. heirtzi* and *F. hirshli* infect their definitive hosts directly.

**Metastrongyles**  Bronchi  Earthworm
These are large white parasites of the bronchi and bronchioles of swine. Oviparous females lay eggs containing first-stage larvae. These eggs do not hatch or develop into infective larvae unless they are ingested by an earthworm.
Family Protostrongylidae
Females deposit unsegmented eggs in the surrounding lung, vascular, or neural tissues. These eggs develop into first-stage larvae before they appear in the feces. If these first-stage larvae are ingested by any of a wide range of snails and slugs, they develop in these intermediate hosts into doubly sheathed third-stage infective larvae.

*Parelaphostrongylus* Meninges Snails, slugs

*Parelaphostrongylus tenuis* is normally a parasite of the meninges of the white-tailed deer, in which species it rarely if ever causes disease. However, in abnormal hosts such as sheep, goats, llamas, camel, moose, caribou, reindeer, wapiti, fallow deer, and mule deer, *P. tenuis* tends to invade the nervous tissue proper, causing serious or fatal neurological disease. Because *P. tenuis* rarely matures in these hosts, larvae are not shed in the feces. Therefore diagnosis is presumptive and based on the appearance of neurological signs in ruminants that share their pastures with whitetailed deer.

Family Filaroididae

*Filaroides* Lung No intermediate host

Do not confuse the family Filaroididae with the very distantly related superfamily Filaroididea. The canine parasites, *F. oxyuris* and *F. heinzii* occur in nodules within the epithelium of the trachea and bronchi or within the lung parenchyma, respectively.

The ooviviparous females deposit delicate, thin-shelled eggs containing first-stage larvae that hatch before being voided in the host's feces. Unlike other metastrongyloids, most or all of which require a mollusca or annelid intermediate host to develop into the infective third larval stage, *Filaroides* spp. are directly infective as first-stage larvae, and development through all five stages is completed in the lung tissue of the dog. Because these larvae are released within the host, autoinfection is inevitable and the degree of resulting infection is apparently governed solely by the host's immune reactions. First-stage larvae pass up the trachea and out with the feces, and transmission occurs principally by coprophagy. Cannibalism and regurgitative feeding provide other mechanisms.

Order Oxyurida

*Oxyuris equi* Colon No intermediate host

Adult *O. equi* are found principally in the small colon, although occasional specimens may be found in the large colon. Instead of simply discharging her eggs in the fecal stream, the gravid female *O. equi* migrates down the colon and rectum and out through the anus to cement her eggs in masses to the skin of the anus and its immediate surroundings. The eggs develop to the infective stage in 4 or 5 days. The most common affliction perpetrated by *O. equi* on the horse is pruritus ani caused by the adhesive egg masses deposited on the perianal skin by the female worm. In its efforts to relieve the itching, the horse will persistently rub its tail against posts, mangers, and the like.

*Enterobius vermicularis* Colon No intermediate host

This is the small pinworm of humans and great apes. The gravid *E. vermicularis* female migrates through the anal opening to cement her eggs to the host's perianal skin. The eggs develop to the infective stage within hours and are readily reinfect the host by contamination of the hands, to infect other individuals by contamination of bedclothing or other fomites, or to become airborne on dust particles. Infection may be suspected in children who have pruritus ani and insomnia.

Order Ascaridida

Ascarids are among the largest and most familiar of nematode parasites infecting the intestinal tract of domestic animals.

The single cell develops into an infective larva inside the eggshell within several days or weeks, depending on the species of worm and the ambient temperature. Ascarid eggs are remarkably resistant to chemical and physical insults, especially after they have arrived at the infective stage. The single most important fact to remember in relation to the epidemiology of ascariasis is that the eggs remain infective in soil for many years. The larval stage hatching from the egg of these ascaroids is a third-stage larva. Ascarid eggs are relatively thick walled.

*Ascaris* Intestine No intermediate host

*A. suum* is a parasite of swine. The adult worms are about 30 cm long and white to cream colored.

*Parascaris* Intestine No intermediate host

*Parascaris equorum* is the very large ascarid parasite of the horse.
Appendix J: Experiment 1: Intervention 4 (Proximity + Explicitness)

**Toxascaris**  Intestine  No intermediate host

*Toxascaris leonina* is a parasite of cats and dogs in the cooler climates of the world. Because of the direct life cycle of this parasite, the worm tends to be found in animals older than the hosts of *Toxocara* and *T. cati*.

The restricted mucosal migration of *T. leonina* in dogs and cats precludes the development of somatic larval burdens and the transmission of infection by way of the placenta and mammary gland. Ingestion of infective eggs and paratenic hosts seems to be the only means by which cats and dogs acquire *T. leonina* infection.

**Toxocara**  Intestine  No intermediate host

*Toxocara* is a genus of rather large ascaridoids that as adults are parasites in the small intestine of various mammals. *T. canis* and *T. cati* are two of the most commonly observed parasites of the dog and cat, respectively.

*Toxocara* and *Toxascaris* eggs are very resistant to environmental adversity and remain infective for years, especially in poorly drained clay and silt soils.

**Baylisascaris**  Intestine  No intermediate host

Species of *Baylisascaris* common in North American wildlife include *Baylisascaris procyonis* of the raccoon, *Baylisascaris columnaris* of the skunk, and *Baylisascaris larvis* of the woodchuck.

**Order Spirurida**

Members of the order Spirurida require either an insect or a crustacean intermediate host for development to the infective stage. The definitive host acquires spirurid infection by ingesting infected arthropods or paratenic hosts that have fed on such arthropods. The superfamily Filarioidea requires as its intermediate host a blood-feeding arthropod that becomes infected while taking its blood meal and that vectors the parasite when taking another blood meal.

**Dracunculus**  Subcutaneous tissue  Copepod

*Dracunculus* is a parasite of the subcutaneous tissues of carnivores and man. When the female *Dracunculus* has been fertilized, a shallow ulcer forms in the host’s skin at the location of the anterior end of the worm. When water wets this ulcer, the female projects her body and prolapses a length of uterus, which then bursts to discharge a horde of larvae. Then she returns to await the next wetting.

If they are ingested by a copepod of the genus *Cyclops*, the larvae discharged into the water develop to the infective third larval stage in about 3 weeks. The definitive host becomes infected by ingesting these *Cyclops* in the drinking water. *Dracunculus insignis* is a parasite of raccoons and other carnivores, including the dog and cat in North America. *Dracunculus medinensis* is a parasite of man in the Middle East and India.

**Gnathostoma**  Stomach wall  Copepod

*Gnathostoma* spp. adults are found in cystic nodules in the stomach walls of wild and domestic carnivores. Eggs are passed in the one-to-two-cell stage and develop to the second larval stage in water. These larvae hatch and develop to the infective third stage only if ingested by copepods (*Cyclops*). A variety of amphibians, snakes, and fishes may serve as paratenic hosts to convey the gnathostome from the copepod to the definitive host. The migrations of gnathostome larvae in the liver and other organs of the definitive host are destructive.

**Physaloptera**  Stomach  Beetle

*Physaloptera* spp. are parasites of the stomach of carnivores. The female worm lays thick-walled eggs that develop to the infective stage in various coprophagous beetles. The adult worms tend to live with the anterior end embedded in the mucosa.

**Thelazia**  Conjunctival, lacrimal sacs  Face fly

*Thelazia* spp. are parasites of the conjunctival and lacrimal sacs of cattle and horses. The female *Thelazia* worm deposits thin-shelled eggs containing larvae that develop to the infective stage in the face fly, *Musca autumnalis*.

**Gongylonema**  Esophagus, rumen  Beetle, cockroach

*Gongylonema* spp. can usually be found woven into a remarkably regular sinusoidal tract in the mucous membrane of the host’s esophagus or rumen. Eggs containing first-stage larvae are passed on the host’s feces and, if ingested by a dung beetle or a cockroach, develop to the infective stage in about a month. The definitive host becomes infected by ingesting the infected insect.
Appendix J: Experiment 1: Intervention 4 (Proximity + Explicitness)

**Spirocerca lupi**  
Esophagus, stomach  
Beetle

*Spirocerca lupi* is found in fibrous nodules in the wall of the esophagus or stomach of dogs. The very small egg contains a vermiciform embryo when shed in the feces. If ingested by a cophagous beetle, this vermiciform embryo develops into a larva capable of infecting dogs and a broad range of paratenic hosts. When infective larvae are ingested by a dog, they migrate in the adventitia of the visceral arteries and aorta to the walls of the esophagus and stomach. Reproductive adults are normally found in cystic nodules that communicate with the lumen of the esophagus or stomach through fistulas. Dysphagia and vomiting, esophageal neoplasia, aortic aneurysm or rupture, and secondary pulmonary osteoartropathy may be associated with chronic *S. lupi* infection.

**Dracchia and Habronema**  
Stomach and Fly

*Dracchia megastoma, Habronema muscae,* and *Habronema microstoma* are parasites of the equine stomach. Larvae hatch from the eggs soon after they are laid. If ingested by maggots (*Musca domestica* for *D. megastoma* and *H. muscae; Stomoxys calcitrans* for *H. microstoma*), these develop to the infective third-stage larvae in a little more than a week.

The infective larvae migrate to the head of the fly and collect in the labium. When a fly alights on a warm, moist surface such as the muzzle, ocular conjunctiva, or cutaneous wounds of a horse, the larvae change hosts. Those larvae that are swallowed presumably complete their life histories, whereas those that enter wounds have probably reached an impasse. However, these aberrant larvae are extremely important because of the granulomas they induce. Typical cutaneous habronemiasis lesions are characterized by an initial rapid production of granulation tissue that sluggishly refuses to resolve during fly season, by the subsequent appearance of caseo-calcareous nodules in this granulation tissue, and by the presence of *Dracchia* or *Habronema* larvae.

**Superfamily Filarioidea**

Filarioidea tend to be rather long and thin white- to cream-colored worms. They are found typically in tissue spaces and body cavities, or sometimes within the vascular or lymphatic system. All filarioidea are transmitted by bloodsucking insects in which vermiciform embryos called microfilariae develop into infective third-stage larvae. The microfilariae either circulate in the blood of the definitive host (e.g., *Draccharia* and *Setaria* spp.) or accumulate in the dermal connective tissues (e.g., *Onchocerca* spp.). In either case, the microfilariae are ingested and the infective larvae deposited when the insect feeds on the definitive host.

**Dirofilaria**  
Pulmonary arteries, heart  
Mosquito

*D. immitis* is the canine heartworm. The dog and its close relatives are the natural hosts, but infection also occurs in cats and ferrets. Adult heartworms normally are found in the pulmonary arteries. In heavy infections worms may be found in the right heart. When defunct, the worms are carried deeper into the lungs where they occlude the pulmonary arterial branches and produce infarcts. Endemic areas exist in all parts of the United States. The life history may involve several species of mosquitoes as intermediate hosts. Only when mosquito populations are sufficiently reduced will heartworm disappear.

The life cycle of *D. immitis* is initiated when the dog is bitten by an infected mosquito. Fertilized females contain fully developed microfilariae within the sixth month after infection. Microfilariae typically are not found in the peripheral blood for several more weeks. Mosquitoes are infected when they bite an infected dog.

**Setaria**  
Serous membranes  
Mosquito

*Setaria latipapillosa* and *Setaria equina* are large white parasites of the serous membranes of cattle and horses, respectively. Microfilariae of *Setaria* spp. show up on blood smears, and the adult parasites are likely to be encountered during abdominal surgery or on the killing floor or necropsy table. Migrating *Setaria* larvae occasionally invade the central nervous system and cause serious neurological disease, especially in species other than their normal host.

**Onchocerca**  
Connective tissue  
Fly

*Onchocerca* spp. adults, although large, are intricately woven into the deep connective tissues. *Onchocerca cervicalis* adults are found in the nuchal ligament of the horse, and the microfilariae are widely distributed in the dermis and other connective tissues including those of the ocular conjunctivae.

In North American cattle, *Onchocerca gutersoni* adults are found in connective tissues about the nuchal ligament, and *Onchocerca lienalis* are found in the connective tissue between the spleen and rumen. Microfilariae of both species are found in the dermis. The intermediate hosts of bovine *Onchocerca* species may involve simulid or heleid (ceratopogonid) flies.
Appendix J: Experiment 1: Intervention 4 (Proximity + Explicitness)

*Parafilaria* Connective tissue  *Fly*
*Parafilaria* spp. of horses and cattle live in the subcutaneous and intermuscular connective tissues and when sexually mature, produce crops of pinhead nodules that bleed through a tiny pore. The blood escapes in fine drops, runs off in streaks along the hairs, and dries in brown crusts. Eggs and microfilariae of *Parafilaria* spp. may be demonstrated in this material but never in samples from the circulation. Active bleeding occurs only during daylight hours and especially when horses are exposed to direct sunshine. The activity of the lesions suggests an adaptation on the part of *Parafilaria* spp. to the habits of flies that feed on blood.

*Dipetalonema* Connective tissue  *Flea, louse*
The canine parasite *Dipetalonema reconditum* is small, usually few in number, and lies inconspicuously in the connective tissues. The microfilariae, on the other hand, are rather commonly seen and easy to confuse with those of *D. immitis*. *D. reconditum* develops to the infective stage in the flea *Ctenocephalides felis* and in the ambly Gunn louse *Heterodoxus spiniger*.

About 90% of the adults are located in subcutaneous tissues, but a small percentage can be found in the peritoneal cavity. The microfilariae circulate in the blood, usually at low densities.

### Order Enopla
down

*Dictyocaulus* Kidney  *Oligochaete annelid worm*
*Dictyocaulus renale*, the "giant kidney worm" of carnivores, swine, and sometimes man, is one of the largest species of nematodes. Mink are the principal definitive hosts. The female *D. renale* produces brownish, thick-shelled eggs with bipolar plugs. The eggs are passed in the urine in the one- or two-cell stage and develop, in water, to the first larval stage in a month or longer. Larvated eggs are infective to oligochaete annelid worms in which they develop to the infective third larval stage. If infected oligochaetes are ingested by fish or frogs, the larvae invade the tissues of these paratenic hosts but do not undergo development. However, if the infected oligochaete (or paratenic host) is ingested by a dog, the *D. renale* larvae mature and complete the cycle. In the dog, *D. renale* may be found in the pelvis of the right kidney or free in the abdominal cavity.

*Trichinella* Intestine  No intermediate host
The tiny adults of *Trichinella spiralis* are found embedded in the mucosa of the small intestine of swine, carnivores, and man.

Predation has provided an efficient channel for the evolutionary development of many parasites. In most instances, the larval parasite lies encysted in the tissues of the prey, and the reproductive adults inhabit the alimentary tract of the predator. Thus, in most systems, the predator becomes infected by eating the prey, and the prey becomes infected by ingesting eggs passed in the feces of the predator. However, in the unique life history of *Trichinella spiralis*, both adult and larval stages occur in sequence in the same host, the tiny adults lying among the villi of the small intestine and the larvae curled up in cysts in the striated muscle.

First-stage larva of *T. spiralis*, liberated from their cysts by digestive enzymes of the host, invade the intestinal mucosa. Both sexes reach maturity about 2 days after the infected meat is eaten. The viviparous females give birth to prelarvae, which enter the lymphatics and later the bloodstream to be transported to the muscles. These prelarvae invade striated muscle cells. After 2 or 3 weeks they have developed into first-stage larvae and roll up in spirals, or like pretzels become enveloped in cysts and are then infective.

Almost all mammals can be experimentally infected with *T. spiralis*, but carnivores and omnivores are more likely to become naturally infected. Infection occurs through predation, cannibalism, and carrion feeding. The larvae encysted in muscles are exceptionally resistant to external conditions, including extreme purretfication. Human trichinosis usually results from eating raw or undercooked pork, bear, or seal.

*Trichurus* Intestine  No intermediate host
The adult is embedded in the wall of the large intestine, with the posterior end lying free in the lumen. The egg is lemon-shaped with a distinct plug at each pole and contains a single cell when passed in the feces. An infective first-stage larva develops inside the egg but does not hatch unless swallowed by a suitable host. Once eggs are ingested, all development occurs within the epithelium of the intestine (i.e., there is no extraintestinal migration).

Infective *T. vulpis* eggs survive in soil for a long time, and dogs kept in contact with contaminated soils tend to become reinfected after treatment.
### Summary, sorted by Order

In general, whether or not a nematode requires an intermediate host is determined by two factors. The first factor is whether the nematode is located in the gastrointestinal tract. Because the gastrointestinal tract provides direct access to the outside world for the nematode's eggs or larvae by way of the feces, these parasites do not require an intermediate host (unless they are members of the order Spirurida). In contrast, nematodes whose adults are found in locations other than the gastrointestinal tract generally do require intermediate hosts. The second factor is the taxonomic order to which the parasite belongs. If the parasite is a member of the order Spirurida or the superfamily Metastrongyloidea, then it requires an intermediate host. An exception to this rule is the metastrongylid *Filaroides*.

#### Order Strongylida

<table>
<thead>
<tr>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trichostongylus</strong></td>
<td>Stomach, abomasum, small intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Ostertagia</strong></td>
<td>Abomasum</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Haemonchus</strong></td>
<td>Abomasum</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Nematodirius</strong></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Dictyocaulus</strong></td>
<td>Bronchial tree</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Strongylus</strong></td>
<td>Cecum, colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Stephanurus</strong></td>
<td>Hepatic, renal, perirenal tissue</td>
<td>No intermediate host, or Earthworm</td>
</tr>
<tr>
<td><strong>Syngamus</strong></td>
<td>Trachea</td>
<td>Earthworm</td>
</tr>
</tbody>
</table>

#### Superfamily Metastrongyloidea

<table>
<thead>
<tr>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metastrongylus</strong></td>
<td>Bronchial tree</td>
<td>Earthworm</td>
</tr>
<tr>
<td><strong>Paraspirorchis</strong></td>
<td>Meninges</td>
<td>Snails, slugs</td>
</tr>
<tr>
<td><strong>Filaroides</strong></td>
<td>Lung</td>
<td>No intermediate host</td>
</tr>
</tbody>
</table>

#### Order Oxyurida

<table>
<thead>
<tr>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxyuris equi</strong></td>
<td>Colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Enterobius vermicularis</strong></td>
<td>Colon</td>
<td>No intermediate host</td>
</tr>
</tbody>
</table>

#### Order Ascaridida

<table>
<thead>
<tr>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ascaris</strong></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Parascaris</strong></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Trichuris</strong></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Baylisascaris</strong></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
</tbody>
</table>

#### Order Spirurida

<table>
<thead>
<tr>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dracunculus</strong></td>
<td>Subcutaneous tissue</td>
<td>Cepepod</td>
</tr>
<tr>
<td><strong>Gnathostoma</strong></td>
<td>Stomach wall</td>
<td>Cepepod</td>
</tr>
<tr>
<td><strong>Physaloptera</strong></td>
<td>Stomach</td>
<td>Beetles</td>
</tr>
<tr>
<td><strong>Tsetse</strong></td>
<td>Conjunctival, lacrimal sacs</td>
<td>Face fly</td>
</tr>
<tr>
<td><strong>Gorgolaima</strong></td>
<td>Esophagus, rumen</td>
<td>Beetle, cockroach</td>
</tr>
<tr>
<td><strong>Spirocerca</strong></td>
<td>Esophagus, stomach</td>
<td>Beetle</td>
</tr>
<tr>
<td><strong>Dracunculus</strong></td>
<td>Stomach</td>
<td>Fly</td>
</tr>
<tr>
<td><strong>Habronema</strong></td>
<td>Stomach</td>
<td>Fly</td>
</tr>
<tr>
<td><strong>Dirofilaria</strong></td>
<td>Pulmonary arteries, heart</td>
<td>Mosquito</td>
</tr>
<tr>
<td><strong>Setaria</strong></td>
<td>Serous membranes</td>
<td>Mosquito</td>
</tr>
<tr>
<td><strong>Onchocerca</strong></td>
<td>Connective tissue</td>
<td>Fly</td>
</tr>
<tr>
<td><strong>Parafilaria</strong></td>
<td>Connective tissue</td>
<td>Fly</td>
</tr>
<tr>
<td><strong>Diplotomina</strong></td>
<td>Connective tissue</td>
<td>Flea, louse</td>
</tr>
</tbody>
</table>

#### Order Enoplida

<table>
<thead>
<tr>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dictyophyme</strong></td>
<td>Kidney</td>
<td>Oligochaete annelid worms</td>
</tr>
<tr>
<td><strong>Trichinella</strong></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td><strong>Trichuris</strong></td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
</tbody>
</table>
## Summary, sorted by Intermediate Host

<table>
<thead>
<tr>
<th>Order</th>
<th>Genus</th>
<th>Location</th>
<th>Intermediate Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spirurida</td>
<td>Spirocerca</td>
<td>Esophagus, stomach</td>
<td>Beetle</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Physostomum</td>
<td>Stomach</td>
<td>Beetle</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Gongyloides</td>
<td>Esophagus, rumen</td>
<td>Beetle, cockroach</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Gnathostoma</td>
<td>Stomach wall</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Dracunculus</td>
<td>Subcutaneous tissue</td>
<td>Cephalopod</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Syngamus</td>
<td>Trachea</td>
<td>Earthworm</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Metastrongylus</td>
<td>Bronchi</td>
<td>Earthworm</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Dipetalonema</td>
<td>Connective tissue</td>
<td>Flea, louse</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Thelazia</td>
<td>Conjunctival, lacrimal sacs</td>
<td>Fly</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Onchocerca</td>
<td>Connective tissue</td>
<td>Fly</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Parafilaria</td>
<td>Connective tissue</td>
<td>Fly</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Dracunculus</td>
<td>Stomach</td>
<td>Fly</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Habronema</td>
<td>Stomach</td>
<td>Fly</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Dirofilaria</td>
<td>Pulmonary arteries, heart</td>
<td>Mosquito</td>
</tr>
<tr>
<td>Spirurida</td>
<td>Setaria</td>
<td>Serous membranes</td>
<td>Mosquito</td>
</tr>
<tr>
<td>Ascaridida</td>
<td>Ascaris</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Ascaridida</td>
<td>Baflfasaris</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Ascaridida</td>
<td>Parascaris</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Ascaridida</td>
<td>Toxascariis</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Ascaridida</td>
<td>Toxascariis</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Enoplida</td>
<td>Trichonella</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Enoplida</td>
<td>Trichuirus</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Oxyurida</td>
<td>Enterobius</td>
<td>Colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Oxyurida</td>
<td>Oxyuris equi</td>
<td>Colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Haemonchus</td>
<td>Abomasum</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Ostertagia</td>
<td>Abomasum</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Dictyocaulus</td>
<td>Bronchial tree</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Strongyloius</td>
<td>Cecum, colon</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Nomastodes</td>
<td>Intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Filarioides</td>
<td>Lung</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Trichostrongylus</td>
<td>Stomach, abomasum, small intestine</td>
<td>No intermediate host</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Stephanurus</td>
<td>Hepatic, renal, periportal tissue</td>
<td>No intermediate host, or earthworm</td>
</tr>
<tr>
<td>Enoplida</td>
<td>Diectophyme</td>
<td>Kidney</td>
<td>Oligochaete annelid worms</td>
</tr>
<tr>
<td>Strongylida</td>
<td>Paratrichostongylus</td>
<td>Meninges</td>
<td>Snails, slugs</td>
</tr>
</tbody>
</table>
Appendix K: Experiment 1: Pretest

Pre-Test

1. Choose the factor(s) that most influence whether a nematode has an intermediate host. Indicate your answers with an X in the appropriate blank(s).

   — Size of adult parasite
   — Type of reproductive product (eggs, larvae, microfilariae)
   — Size of the parasite’s reproductive product (eggs, larvae, microfilariae)
   — Clinical signs that the parasite produces in its host
   — Influence of estrogens / prolactin
   — Climactic conditions such as temperature / moisture
   — Taxonomic group to which the parasite belongs
   — Organ in which the adult parasite is located in the host
   — All of the above
   — None of the above

2. For each parasite in the left column, indicate whether or not it requires an intermediate host by marking the appropriate "yes" or "no" blank in the right column.

<table>
<thead>
<tr>
<th>Parasite</th>
<th>Intermediate host required?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ostertagia</td>
<td>yes</td>
</tr>
<tr>
<td>Syngamus</td>
<td>yes</td>
</tr>
<tr>
<td>Paraphaenostrogylus</td>
<td>yes</td>
</tr>
<tr>
<td>Dictyocaulus</td>
<td>yes</td>
</tr>
<tr>
<td>Enterobius</td>
<td>yes</td>
</tr>
<tr>
<td>Baylisascaris</td>
<td>yes</td>
</tr>
<tr>
<td>Gnathostoma</td>
<td>yes</td>
</tr>
<tr>
<td>Thelazia</td>
<td>yes</td>
</tr>
<tr>
<td>Habronema</td>
<td>yes</td>
</tr>
<tr>
<td>Onchocerca</td>
<td>yes</td>
</tr>
</tbody>
</table>

3. Which of the following do not require an intermediate host? Indicate your answers with an X in the appropriate blank(s).

   — Ascaridida
   — Enoplida
   — Oxyurida
   — Spirura
   — Strongylida
Appendix K: Experiment 1: Pretest

4. Match each parasite to its usual location in the host by writing the number of the location in the answer blank. Answers may be used more than once or not at all.

<table>
<thead>
<tr>
<th>Answer</th>
<th>Parasite</th>
<th>Location in host</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trichostrongylus</td>
<td>1. Esophagus, rumen, stomach, or abomasum</td>
</tr>
<tr>
<td></td>
<td>Filaroides</td>
<td>2. Intestine, cecum, or colon</td>
</tr>
<tr>
<td></td>
<td>Oxyuris</td>
<td>3. Lungs, bronchi, or trachea</td>
</tr>
<tr>
<td></td>
<td>Parascaris</td>
<td>4. Skin, connective tissue, or muscle</td>
</tr>
<tr>
<td></td>
<td>Physaloptera</td>
<td>5. Kidney or bladder</td>
</tr>
<tr>
<td></td>
<td>Dracunculus</td>
<td>6. Heart or pulmonary arteries</td>
</tr>
<tr>
<td></td>
<td>Thelazia</td>
<td>7. Conjunctiva or lacrimal sacs</td>
</tr>
<tr>
<td></td>
<td>Dracisia</td>
<td>8. Nervous system</td>
</tr>
<tr>
<td></td>
<td>Setaria</td>
<td>9. Serous membranes</td>
</tr>
<tr>
<td></td>
<td>Dioctophyme</td>
<td></td>
</tr>
</tbody>
</table>

5. For each body location in the left column, indicate whether nematodes found in that location require an intermediate host by marking the appropriate "yes" or "no" blank in the right column. If some nematodes in a given body location do require an intermediate host while others do not, mark the "both yes and no" column and give an explanation.

<table>
<thead>
<tr>
<th>Body Location</th>
<th>Intermediate host required?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrointestinal tract</td>
<td>yes no both and no (explain)</td>
</tr>
<tr>
<td>Explanation:</td>
<td></td>
</tr>
<tr>
<td>Respiratory tract</td>
<td>yes no both and no (explain)</td>
</tr>
<tr>
<td>Explanation:</td>
<td></td>
</tr>
<tr>
<td>Serous mucous membranes</td>
<td>yes no both and no (explain)</td>
</tr>
<tr>
<td>Explanation:</td>
<td></td>
</tr>
<tr>
<td>Skin, connective tissue, or muscle</td>
<td>yes no both and no (explain)</td>
</tr>
<tr>
<td>Explanation:</td>
<td></td>
</tr>
</tbody>
</table>
Appendix K: Experiment 1: Pretest

6. For nematodes that have an intermediate host, effective control of the parasite usually depends on control of that intermediate host, not the parasite itself. For each of the following clinical observations, predict whether the parasite in question requires an intermediate host by marking either "yes" or "no" in the Intermediate host required column. If there is not enough information to determine whether the parasite requires an intermediate host, mark "need more information".

<table>
<thead>
<tr>
<th>Observation</th>
<th>Intermediate host required</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. You observe nematode eggs in the feces of a goat.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>b. You observe larvae in tissue from a horse's cheek.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>c. You are asked to examine a wound on the leg of a raccoon. You see the tail of a nematode protruding from the wound.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>d. You observe large white nematodes in the intestine of a horse.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>e. You are a pathologist examining a muscle biopsy, and you observe coiled nematode larvae.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>f. You are performing a field necropsy on a cow that died a few hours ago, and you observe nematodes swimming in some ascitic fluid in the abdominal cavity.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>g. On this same cow, you observe small nematodes in the abomasum.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>h. On this same cow, you observe serpentine lesions in the mucosa of the rumen.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>i. You observe microfilaria in a skin biopsy from a cow.</td>
<td>yes ___ no ___ need more information</td>
</tr>
<tr>
<td>j. A family has slaughtered a hog, but want you to examine it before they consume the meat. You observe large nematodes in the hepatic and renal tissues.</td>
<td>yes ___ no ___ need more information</td>
</tr>
</tbody>
</table>
Appendix L: Experiment 1: Posttest

Post-Test

1. Choose the factor(s) that most influence whether a nematode has an intermediate host. Indicate your answers with an X in the appropriate blank(s).

- Size of adult parasite
- Type of reproductive product (eggs, larvae, microfilariae)
- Size of the parasite's reproductive product (eggs, larvae, microfilariae)
- Clinical signs that the parasite produces in its host
- Influence of estrogens / prolactin
- Climactic conditions such as temperature / moisture
- Taxonomic group to which the parasite belongs
- Organ in which the adult parasite is located in the host
- All of the above
- None of the above

2. For each parasite in the left column, indicate whether or not it requires an intermediate host by marking the appropriate "yes" or "no" blank in the right column.

<table>
<thead>
<tr>
<th>Parasite</th>
<th>Intermediate host required?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichostrongylus</td>
<td>yes</td>
</tr>
<tr>
<td>Filarioides</td>
<td>yes</td>
</tr>
<tr>
<td>Onyuris</td>
<td>yes</td>
</tr>
<tr>
<td>Parascaris</td>
<td>yes</td>
</tr>
<tr>
<td>Physaloptera</td>
<td>yes</td>
</tr>
<tr>
<td>Dracunculus</td>
<td>yes</td>
</tr>
<tr>
<td>Thelazia</td>
<td>yes</td>
</tr>
<tr>
<td>Draschia</td>
<td>yes</td>
</tr>
<tr>
<td>Setaria</td>
<td>yes</td>
</tr>
<tr>
<td>Diectophyma</td>
<td>yes</td>
</tr>
</tbody>
</table>

3. Which of the following do require an intermediate host? Indicate your answers with an X in the appropriate blank(s).

- Ascaridida
- Enoploida
- Onyurida
- Spirurida
- Strongylida
4. Match each parasite to its usual location in the host by writing the number of the location in the answer blank. Answers may be used more than once or not at all.

<table>
<thead>
<tr>
<th>Answer</th>
<th>Parasite</th>
<th>Body Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Osteotagia</td>
<td>1. Esophagus, rumen, stomach, or abomasum</td>
</tr>
<tr>
<td></td>
<td>Syngamus</td>
<td>2. Intestine, cecum, or colon</td>
</tr>
<tr>
<td></td>
<td>Parelaphostrongylus</td>
<td>3. Lungs, bronchi, or trachea</td>
</tr>
<tr>
<td></td>
<td>Dictyocaulus</td>
<td>4. Skin, connective tissue, or muscle</td>
</tr>
<tr>
<td></td>
<td>Enterobius</td>
<td>5. Kidney or bladder</td>
</tr>
<tr>
<td></td>
<td>Baylisascaris</td>
<td>6. Heart or pulmonary arteries</td>
</tr>
<tr>
<td></td>
<td>Gnathostoma</td>
<td>7. Conjunctiva or lacrimal sacs</td>
</tr>
<tr>
<td></td>
<td>Thelazia</td>
<td>8. Nervous system</td>
</tr>
<tr>
<td></td>
<td>Habronema</td>
<td>9. Serous membranes</td>
</tr>
<tr>
<td></td>
<td>Onchocerca</td>
<td></td>
</tr>
</tbody>
</table>

5. For each body location in the left column, indicate whether nematodes found in that location require an intermediate host by marking the appropriate "yes" or "no" blank in the right column. If some nematodes in a given body location do require an intermediate host while others do not, mark the "both yes and no" column and give an explanation.

<table>
<thead>
<tr>
<th>Body Location</th>
<th>Intermediate host required?</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gastrointestinal tract</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>2. Kidney or bladder</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>3. Conjunctiva or lacrimal sacs</td>
<td>both yes and no</td>
<td></td>
</tr>
<tr>
<td>4. Nervous system</td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>
6. For nematodes that have an intermediate host, effective control of the parasite usually depends on control of that intermediate host, not the parasite itself. For each of the following clinical observations, predict whether the parasite in question requires an intermediate host by marking either “yes” or “no” in the Intermediate host required column. If there is not enough information to determine whether the parasite requires an intermediate host, mark “need more information”.

<table>
<thead>
<tr>
<th>Observation</th>
<th>Intermediate host required?</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. You observe a nematode in the conjunctiva of a cow.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>b. You are performing a gastroscopy on a cat with a history of vomiting, and observe nematodes in the wall of the stomach.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>c. You are performing a necropsy on an alpaca that died after showing neurological signs, you observe nematodes in the meninges.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>d. You observe nematode eggs in the feces of a dog.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>e. While performing an exploratory thoracic surgery on a cat, you observe small, subpleural nodules.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>f. You observe filariform larvae in the stool of a dog.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>g. You observe nodules in the trachea of a dog.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>h. You observe your two-year-old repeatedly scratching his bottom.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>i. You are performing a necropsy on a dog, and you observe nodules in the walls of the esophagus and stomach.</td>
<td>yes      no      need more information</td>
</tr>
<tr>
<td>j. You observe filariform larvae in the blood of a coyote.</td>
<td>yes      no      need more information</td>
</tr>
</tbody>
</table>

7. On a scale of 1-9, with 1 corresponding to very, very low mental effort and 9 corresponding to very, very high mental effort, how much mental effort did it take you to study the material to answer these questions? Please circle your answer below.

<table>
<thead>
<tr>
<th>Very, very low mental effort</th>
<th>Very, very high mental effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5</td>
<td>6  7  8  9</td>
</tr>
</tbody>
</table>

Page 3 of 3
Appendix M: Experiment 2: Intervention 1 (Control – Table only, no details)

Material for
The Effect of Proximity and Explicitness in Learning Materials on Student Ability to Utilize Basic Science Knowledge in Clinical Problem-Solving

Experiment 2: Representation Type

Variation 1

Texas A&M University
October 29-30, 2008
Appendix M: Experiment 2: Intervention 1 (Control – Table only, no details)

CLASS CESTODA

Tapeworms belong to the class Cestoda of the phylum Platyhelminthes. An adult tapeworm is essentially a chain (strobila) of independent, progressively maturing reproductive units, one end of which is capable of attachment to the wall of the host's intestine by a holdfast organ or scolex. In a fully developed adult tapeworm, all stages of development are displayed in a linear array starting at the scolex and terminating at the distal end. There are no organs of predation or digestion; all nutrients are absorbed through the tapeworm's specialized integument. The body of an adult tapeworm is so flattened that for the purposes of argument it can be said to have two surfaces and two edges. This shape affords maximum surface area per unit volume, a distinct asset for an animal that absorbs all of its nourishment through its skin.

Two orders of the class Cestoda are of greatest interest to veterinarians: Pseudophyllidea and Cyclophyllidea. The order Pseudophyllidea is represented by only two genera of importance to most veterinarians: Diphylllobothrium and Spirometra. Both use copepods as the first intermediate host in which the oncosphere develops into a second-stage larva called a procercoid. The second intermediate host may be a fish, amphibian, or reptile and supports development of the procercoid into a third-stage larva called a plocercoid. The definitive host becomes infected when it ingests a second intermediate host containing plocercoids. Pseudophyllideans are associated with aquatic food chains. The order Cyclophyllidea contains five families of veterinary importance: Taeniidae, Mesocestoidae, Anoplocephalidae, Dipylidiidae, and Hymenolepididae. Most cyclophyllideans require only one intermediate host. Depending on the family of tapeworm, the intermediate host may be a mammal (Taeniidae) or an arthropod (Anoplocephalidae, Dipylidiidae, Hymenolepididae). Members of the Mesocestoidae are thought to require two intermediate hosts, the second of which may be a mammal, bird, or reptile. Cyclophyllideans are associated with terrestrial food chains.

Almost all tapeworms require at least two and some require three hosts to complete their life histories. Vampirolepis nana, a cyclophyllidean parasite of mice and sometimes of humans, is exceptional in being able to complete its life history within the confines of a single individual.

Cestodes produce eggs that when fully developed contain a first-stage larva called an oncosphere. Oncospheres develop into second-stage larvae in the body cavities or tissues of an intermediate host. Usually, the second-stage larva is infective for the definitive host on ingestion. However, in certain cases, the second-stage larva must first develop into a third-stage larva in a second intermediate host before it is ready to infect the definitive host. The oncosphere is the first-stage larva and is infective for the first (or only) intermediate host. The first-stage larva develops in this host into a second-stage larva. In most cyclophyllideans, there is only one intermediate host, and the second-stage larva is the stage infective to the definitive host in which it matures. In the Mesocestoidae and in the Pseudophyllidea, the second-stage larvae are infective to the second intermediate host in which it develops into a third-stage larva. The third-stage larvae of mesocestoids and pseudophyllideans are the form infective for the definitive host. The second and third larval stages of these various tapeworms have their own names that are presented later in the discussion of their respective life histories. The objective of larval development is to form a scolex in a kind of intermediate host that is likely, for one reason or another, to be ingested by a suitable definitive host.

Depending on the kind of tapeworm, fertilized eggs either are discharged through a uterine pore or accumulate in the segment. Therefore the terminal segments of a mature tapeworm are found to be empty in the former case and packed full of eggs like ripe seedpods in the latter.

A reliable identification usually can be made on the basis of host identity and somewhat more accessible morphological features as outlined later. However, differences do exist between cyclophyllideans and pseudophyllideans that are important in diagnosis and in understanding their particular life histories.
Pseudophyllidean Tapeworms

The holdfast of pseudophyllideans has only two shallow, longitudinally grooved bothria for locomotion and attachment. The two most important genera, Diphyllobothrium and Spirometra, have no hooks to assist the weak grip of the bothria.

Pseudophyllidean segments have a uterine pore that permits the escape of eggs. Segments discharge their eggs until their supply is exhausted. The terminal segments of pseudophyllidean tapeworms become senile rather than gravid and are usually detached in short chains rather than individually. Thus the diagnosis of pseudophyllidean infection depends on distinguishing the operculate eggs in fecal sediments from those of trematodes, which sometimes is not an easy matter.

The pseudophyllidean oncosphere is surrounded by an operculate shell. The oncosphere pops open the operculum of the shell and swims away. The ciliated pseudophyllidean oncosphere is called a coracidium.

Family Diphyllobothriidae

The scolex of Diphyllobothrium latum and Spirometra mansonioides has two slitlike grooves. The uterus consists of a spiral tube and opens to the outside through a midventral uterine pore behind the genital pore. Operculated eggs are discharged through the uterine pore.

Diphyllobothrium latum    IH 1: copepod    IH 2: fish    DH: dog, human, etc
Whereas cyclophyllidean development involves only one intermediate host, pseudophyllideans require at least two, of which the first is a copepod and the second is a vertebrate. When ingested by a copepod, the coracidium develops into a solid wormlike proceroid within the body cavity. When the infected copepod is ingested by a second intermediate host, the proceroid enters its musculature or connective tissues and develops into a plerocercid. The plerocercid is notable for its ability to parasitize a series of preditory parasitic hosts until a suitable definitive host is found. When a pig eats a minnow infected with the plerocercoids of D. latum, these merely invade the flesh of the pig and remain plerocercoids. However, when a human, a dog, or a cat eats either the minnow or the pig, the plerocercid matures into an adult tapeworm. D. latum plerocercoids develop in copepods, and its plerocercoids develop in fish. Definitive hosts of D. latum include humans, dogs, mongooses, walruses, seals, sea lions, bears, foxes, and mink. Diphyllobothrium infection is acquired by eating uncooked predatory freshwater fish.

Spirometra mansonioides    IH 1: copepod    IH 2: any vertebrate except fish    DH: cat
S. mansonioides plerocercoids develop in copepods of the genus Cyclops. The natural intermediate host is probably the water snake Natrix, and the natural definitive host is probably the bobcat Lynx rufus. Other definitive hosts of S. mansonioides include the domestic cat and dog and the raccoon. Coracidia develop and hatch from eggs deposited in water and swim about until they are ingested by copepods of the genus Cyclops. Shedding its ciliated coat, the hexacanth embryo develops into a proceroid larva in the body cavity of the copepod. If an infected copepod is swallowed by any vertebrate except a fish, the proceroids develop into plerocercoids, which tend to locate in the subcutaneous tissues and flat muscles of the body wall. Plerocercoids survive predation of their hosts and remain plerocercoids in their new hosts unless the new host happens to be a cat. Plerocercoids develop into adult S. mansonioides tapeworms in the small intestine of the domestic cat and bobcat.

D. latum and S. mansonioides are less obtrusive than other tapeworm parasites of dogs and cats because they do not detach segments but release their eggs more or less continuously through the uterine pores of their mature segments. Therefore the client usually is unaware of Diphyllobothrium and Spirometra infection unless a whole tapeworm or a long chain of senile segments is discharged at once.
Cyclophyllidean Tapeworms

Segments of cyclophyllidean strobila have genital pores for fertilization but no opening to allow the eggs to escape from the uterus. Thus the eggs accumulate until the segment becomes packed full like a ripe seedpod. As they reach the end of the chain, these gravid segments are detached and pass out with the feces or crawl out the anus onto the perianal skin. Therefore cyclophyllidean infections are usually diagnosed by identifying gravid segments on the host or in its environment. Cyclophyllidean oncospheres are fully developed when passed in the feces of the definitive host and are immediately infective for the intermediate host.

Family Taeniidae

Taenia

Adult tapeworms of the genus *Taenia* measure from tens to hundreds of centimeters in length, depending on the species in question and degree of maturity of the specimen.

Gravid taeniid segments are shed and exit from the carnivorous definitive host through the anus. The segments crawl about on the pelage of the host or surface of the fecal mass, emptying themselves of their eggs (oncospheres) in the process. Therefore any segment collected after it has been out for more than a few minutes may contain few if any eggs. If ingested by a suitable vertebrate intermediate host (usually a species normally taken as prey by the definitive host), the egg hatches and the hexacanth embryo enters the wall of the intestine and migrates to its organ of predilection, usually the liver and peritoneal membranes or the skeletal and cardiac muscles. Here the hexacanth embryo grows, cavitates, and differentiates to form the second-stage larva, which is infective to the definitive host. The fully developed second-stage larva of the family Taeniidae consists of a fluid-filled bladder with one or more scolecis (often called a bladderworm) and is surrounded by a connective tissue capsule formed by the vertebrate intermediate host.

When a second-stage larva is ingested by a suitable definitive host, the bladder is digested away, the scolex embeds itself in the mucosa of the small intestine, and the neck begins to bud off segments to form the strobila.

There are four basic kinds of taeniid second-stage larvae: the cysticercus, strobilocercus, coenurus, and hydatid. Members of the genus *Taenia* typically form cysticerci, strobilocerci, and coenuri, depending on the species in question. A cysticercus consists of a single bladder with one scolex. A strobilocercus is a cysticercus that has already begun to elongate and segment while still in the intermediate host, and a coenurus consists of a single bladder with many scolecis, each with the potential of developing into a mature tapeworm. Hydatids are formed by members of the genus *Echinococcus* and are of two kinds, unilocular hydatid cysts and alveolar hydatids, both of which often contain thousands of scolecis.

*Taenia hydatigena*  
IH: cattle, sheep, swine  
DH: dog

The cysticercus of the canine taeniid tapeworm *T. hydatigena* migrates through the liver tissue and encysts on the peritoneal membranes of cattle, sheep, swine, and certain wild ungulates. Massive invasions, such as when entire tapeworm segments are ingested, result in acute traumatic hepaticis, and even small numbers of migrating *T. hydatigena* larvae are capable of precipitating "black disease" in the presence of *C. novyi*. However, frank disease is rarely caused by this larval tapeworm, and the principal economic loss results from condemnation of infected livers by meat inspection authorities.

*Taenia ovis*  
IH: sheep  
DH: dog

The cysticercus of a second canine taeniid tapeworm, *Taenia ovis*, infects the cardiac and skeletal muscles of sheep and represents the most important pathological lesion found by United States inspectors in imported Australian mutton.
Appendix M: Experiment 1 (Control – Table only, no details)

**Taenia pisiformis**  
**IH:** rabbit  
**DH:** dog  
The cysticercus of a third canine taenid tapeworm, *Taenia pisiformis*, is found in the liver and peritoneal cavity of rabbits. This tapeworm is the most common taenid tapeworm of dogs in the United States. Every dog that is so infected must have eaten a rabbit or parts of a rabbit and this means that many rabbits are infected by grazing near where *Taenia pisiformis* segments have been shed.

**Taenia saginata**  
**IH:** cattle  
**DH:** human  
The cysticercus of the human tapeworm *T. saginata* encysts in the striated muscles of cattle, especially the heart and muscles of mastication. Taenid eggs survive the rigors of the septic tank, as well as many contemporary municipal sewage treatment processes, and because defecating out-of-doors is unavoidable when hunting or camping out (and because the segments can leave the host by crawling out through the anal opening), it is easy to see how cattle pastures become contaminated with *T. saginata* eggs. The cysticerci that develop when these eggs are ingested by cattle are relatively inconspicuous and easily overlooked by the lover of rare or raw beef. Consequently, *T. saginata* is a common parasite in the United States.

**Taenia solium**  
**IH:** swine, human  
**DH:** human  
The cysticercus of the human tapeworm *T. solium* represents a significant hazard to human health. People become infected with *T. solium* by ingesting the cysticerci in undercooked pork. After the tapeworm matures, the person's feces contain a steady supply of eggs, which may be conveyed to the mouth at any time by a lapse in personal hygiene. When the eggs reach the stomach, the oncospheres hatch out, enter the gut wall, and wander far and wide in the body, slowly developing into cysticerci. Apparently the milieu interior of humans resembles that of swine closely enough to satisfy the development requirements of the cysticerci. In humans, the signs depend on where the cysticerci localize, and sites may include the eye, brain, or spinal cord.

**Taenia taeniaeformis**  
**IH:** meadow vole  
**DH:** cat  
The larva of the cat tapeworm *T. taeniaeformis* is a strobilocercus. This larva is a very common parasite of meadow voles. Meadow voles are relished by cats, which serve as definitive hosts of *T. taeniaeformis*.

**Taenia multiceps**  
**IH:** sheep, goats, cattle  
**DH:** dog  
The coenurus of the canine taenid tapeworm *T. multiceps* invades the cranial cavity of sheep, goats, and sometimes cattle. As the cyst grows over a period of 6 or 8 months, neurological signs of progressive space occupation slowly develop. There may be blindness, incoordination, walking in circles, and pressing the head against walls, tree trunks, and the like. Finally, the animal lies down and dies. The most common diseases that might be confused with cerebral coenurosis are bacterial encephalitis (listeriosis) and paralophostrongylosis. Intracranial surgery is the only cure for cerebral coenurosis. As in the case of *T. hydatigena* and *T. ovis*, control can be based only on excluding dogs and other canids from sheep pastures.

**Echinococcus granulosus, E. multilocularis**  
**IH:** sheep, human  
**DH:** dog  
The genus *Echinococcus* contains two species of special importance to veterinary medicine, *Echinococcus granulosus* and *Echinococcus multilocularis*, which are very small (2 to 8 mm long) adult tapeworms having only four or five segments.

*E. granulosus* is a parasite of the dog, coyote, wolf, and dingo. Its larva is a hydatid cyst in sheep, swine, cattle, humans, moose, caribou, kangaroos, and others. The hydatid membrane may bud off daughter cysts either internally or externally. The whole structure occupies progressively more space as it grows, but hydatid cysts do not infiltrate, in contrast to alveolar hydatids. Pathogenic effects of hydatid cysts include pressure atrophy of surrounding organs and allergic reactions to hydatid fluid leaks. Rupture of a fertile hydatid cyst may scatter bits of germinative membrane, scolices, and brood capsules throughout the pleural or peritoneal cavity and result in multiple hydatidosis.

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Page 5 of 8
HYDATID DISEASE

The unilocular hydatid cyst is the second-stage larva of *E. granulosus* and is infective to dogs and other canids that serve as definitive hosts. Starting as an oncosphere less than 30 µm in diameter, the larva grows very slowly and infrequently exceeds more than a few centimeters in diameter in slaughtered sheep and cattle. Because humans live longer, a fertile hydatid infecting man may grow very large and interfere with the function of neighboring organs by pressing against them. The hydatid membrane is surrounded by an inflammatory connective tissue capsule. Brood capsules, each containing many scoleces, develop from the germinal epithelium lining the laminated hydatid membrane. Some of these rupture, releasing scolecites to form a sediment of so-called hydatid sand in the hydatid fluid.

Alveolar hydatid cysts are second-stage larvae of *E. multilocularis* and are infective to dogs, foxes, and cats, which serve as definitive hosts. Alveolar hydatids develop in voles, lemmings, cattle, horses, swine, and humans. They are characterized by exogenous budding that does not remain contained within the reactive connective tissue capsule but continuously proliferates and infiltrates surrounding tissue like a malignant neoplasm. Alveolar hydatid infection proves invariably fatal in a few years.

Both *E. granulosus* and *E. multilocularis* tend to establish sylvatic cycles when suitable predator-prey relationships exist in the wildlife population of a region. Therefore *E. granulosus* cycles are maintained among wild ruminants and wolves in the Canadian north woods and among wallabies and dingoes in Australia. Natural nidi of *E. multilocularis* are maintained in various rodents and foxes. The sylvatic cycle reaches humans through their domesticated animals. Dogs that scavenge the entrails of wild game infected with *Echinococcus* spp. become direct sources of hydatid infection to humans and their domestic animals. Contamination of pastures with the feces of infected wild carnivores also results in hydatid infection of domestic ruminants and swine. The establishment of a pastoral cycle may then result from the feeding of uncooked offals from these domestic animals to dogs and, in the case of *E. multilocularis*, to cats. The direct source of human infection is, in most instances, the domestic dog or cat, and scrupulous hygiene is the first line of defense.

Other Cyclophyllidean Tapeworms

The second-stage larvae of all of the following cyclophyllidean families are cysticercoids of one kind or another. A cysticercoid may be thought of as a cysticercus small enough to fit into the body of an arthropod.

**Family Anoplocephalidae**

The tapeworms of cattle, sheep, and goats all belong to the family Anoplocephalidae. The life histories involve an arthropod intermediate host in which the infective cysticercoid develops. Infection results from the incidental ingestion of these infected arthropods by the grazing animal. Adult tapeworms are relatively nonpathogenic.

*Moniezia*  
IH: mites  
DH: cattle, sheep, goats
*Moniezia* spp. are found in the small intestine of cattle, sheep, and goats (*Moniezia benedeni*, *Moniezia expansa*, and *Moniezia capræ*). The egg of *Moniezia* sp. found in cattle feces is one of the few eggs that appears square. Free-living oribatid mites serve as hosts for cysticercoids of *Moniezia* spp. of sheep and cattle.

*Thysanosoma actinoides*  
IH: booklice  
DH: ruminants except cattle
*Thysanosoma actinoides*, the "fringed tapeworm," is found in the common bile duct and duodenum of virtually all ruminant species except cattle. *Thysanosoma actinoides* is apparently transmitted by
"booklice" or "barklice" of the family Psocidae, order Pscoptera. Pscopterans resemble mallophagan lice but are entirely free living and have no other known relationship to parasite life histories.

*Anaplocephala*

*IH*: mites  
*DH*: horse

*Anaplocephala magna* is a relatively harmless parasite in the small intestine of horses. *Anaplocephala perfoliata* is found mainly in the cecum but also tends to cluster in the ileum near the ileocecal valve. This clustering results in ulceration of the mucous membrane and inflammation with thickening and induration of the deeper layers of the intestinal wall. These pathological changes probably account for some cases of persistent diarrhea and may predispose to intussusception of the ileum into the cecum or rupture of the bowel wall in the vicinity of the ileocecal valve.

**Family Dipyldidiidae**

*Dipyldium caninum*

*IH*: flea  
*DH*: dog, human

*Dipyldium caninum* segments are shaped like cucumber seeds and have bilateral genital pores. Each egg capsule may contain from 5 to 30 eggs.

Gravid segments discharge their egg packets as they move about. Larvae of *Ctenocephalides* chew their way into egg packets and ingest the oncospheres of the tapeworm. The hexacanth embryo enters the body cavity of the flea larva and remains there through its metamorphosis. After the adult flea emerges from the cocoon, the hexacanth develops into a cysticercoid in 2 or 3 days. If such a flea is ingested by the definitive host as during self-grooming, the cysticercoids develop into adult tapeworms in the small intestine.

Cysticercoids of *D. caninum* develop in fleas (*Ctenocephalides* spp.) and biting lice (*Trichodectes canis*), and the dog acquires this tapeworm while nipping its insects. Children also may become infected in this way. *D. caninum* requires only 2 to 3 weeks to develop from a cysticercoid into a segment-shedding tapeworm. Thus the benefits of anthelmintic therapy are particularly short-lived unless fleas and biting lice also are brought under control.

**Family Hymenolepididae**

*Hymenolepis diminuta*

*IH*: fleas, beetles  
*DH*: rodent, human

*Hymenolepis diminuta* is a parasite of the small intestine principally of rodents but occasionally also of dogs and even humans. The cysticercoid of *H. diminuta* develops in fleas, flour beetles, and a rather wide range of other insects.

*Vampirolepis nana*

*IH*: fleas, beetles  
*DH*: rodent, human

*Vampirolepis nana* is also a parasite of rodents and humans, and its second-stage larva is a cysticercoid in fleas and flour beetles or in the intestinal mucosa of its definitive host. *V. nana* can complete its life history within the intestinal tract of a mouse or a human. Some of the eggs hatch within the intestine, and the hexacanth embryos burrow into the mucous membrane to form cysticercoids that later reenter the lumen to complete their development as mature tapeworms. The rest of the eggs pass out with the feces to await ingestion by flour beetles or fleas, in which the cysticercoids develop. Thus *H. diminuta* requires fleas, flour beetles, or other insects as intermediate hosts, whereas *V. nana* may or may not.

**Family Mesostostoididae**

*Mesostoides*

*IH 1*: arthropod  
*IH 2*: vertebrates  
*DH*: dog, cat

The complete life history of the genus *Mesostoides* has yet to be worked out. The larval form infective for the definitive host is a third-stage larva found in the peritoneal cavity of mammals and reptiles and in the lungs of birds.
Mesocestoides infection of dogs and cats results from predation on snakes, birds, and small mammals. *M. corti* tapeworms multiply asexually in the intestines of dogs. If this species is not totally eliminated by anthelmintic medication, it will repopulate the intestine even without further exposure.

### Summary of Class Cestoda

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Intermediate Host(s)</th>
<th>Definitive Host(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudophyllidea</td>
<td>Diaphyllabothriidae</td>
<td>Diphyllobothrium latum</td>
<td>1st: copepod</td>
</tr>
<tr>
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<td>Dipylidium caninum</td>
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<tr>
<td>Hymenolepididae</td>
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<td>Mesocestoididae</td>
<td>Mesocestoides</td>
<td>arthropod and vertebrates</td>
<td>dog, cat</td>
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</table>
Appendix N: Experiment 2: Variation 2 (Table with details)

Material for
The Effect of Proximity and Explicitness in Learning Materials on Student Ability to Utilize Basic Science Knowledge in Clinical Problem-Solving

Experiment 2: Representation Type

Variation 2

Texas A&M University
October 29-30, 2008
CLASS CESTODA

Tapeworms belong to the class Cestoda of the phylum Platyhelminthes. An adult tapeworm is essentially a chain (strobila) of independent, progressively maturing reproductive units, one end of which is capable of attachment to the wall of the host's intestine by a holdfast organ or scolex. In a fully developed adult tapeworm, all stages of development are displayed in a linear array starting at the scolex and terminating at the distal end. There are no organs of pretension or digestion; all nutrients are absorbed through the tapeworm's specialized integument. The body of an adult tapeworm is so flattened that for the purposes of argument it can be said to have two surfaces and two edges. This shape affords maximum surface area per unit volume, a distinct asset for an animal that absorbs all of its nourishment through its skin.

Two orders of the class Cestoda are of greatest interest to veterinarians: Pseudophyllidea and Cyclophyllidea. The order Pseudophyllidea is represented by only two genera of importance to most veterinarians: Diphyllolothrium and Spionometra. Both use copepods as the first intermediate host in which the oncosphere develops into a second-stage larva called a procercoid. The second intermediate host may be a fish, amphibian, or reptile and supports development of the procercoid into a third-stage larva called a plerocercoid. The definitive host becomes infected when it ingests a second intermediate host containing plerocercoids. Pseudophyllideans are associated with aquatic food chains. The order Cyclophyllidea contains five families of veterinary importance: Taeiniidae, Mesocestoidae, Anoplocephalidae, Dipyllidae, and Hymenolepidae. Most cyclophyllideans require only one intermediate host. Depending on the family of tapeworm, the intermediate host may be a mammal (Taeiniidae) or an arthropod (Anoplocephalidae, Dipyllidae, Hymenolepidae). Members of the Mesocestoidae are thought to require two intermediate hosts, the second of which may be a mammal, bird, or reptile. Cyclophyllideans are associated with terrestrial food chains.

Almost all tapeworms require at least two and some require three hosts to complete their life histories. Vampirolopides nana, a cyclophyllidean parasite of mice and sometimes of humans, is exceptional in being able to complete its life history within the confines of a single individual.

Cestodes produce eggs that when fully developed contain a first-stage larva called an oncosphere. Oncospheres develop into second-stage larvae in the body cavities or tissues of an intermediate host. Usually, the second-stage larva is infective for the definitive host on ingestion. However, in certain cases, the second-stage larva must first develop into a third-stage larva in a second intermediate host before it is ready to infect the definitive host. The oncosphere is the first-stage larva and is infective for the first (or only) intermediate host. The first-stage larva develops in this host into a second-stage larva. In most cyclophyllideans, there is only one intermediate host, and the second-stage larva is the stage infective to the definitive host in which it matures. In the Mesocestoidae and in the Pseudophyllidea, the second-stage larvae are infective to the second intermediate host in which they develop into a third-stage larva. The third-stage larvae of mesocestoids and pseudophyllideans are the form infective for the definitive host. The second and third larval stages of these various tapeworms have their own names that are presented later in the discussion of their respective life histories. The objective of larval development is to form a scolex in a kind of intermediate host that is likely, for one reason or another, to be ingested by a suitable definitive host.

Depending on the kind of tapeworm, fertilized eggs either are discharged through a uterine pore or accumulate in the segment. Therefore the terminal segments of a mature tapeworm are found to be empty in the former case and packed full of eggs like ripe seedpods in the latter.

A reliable identification usually can be made on the basis of host identity and somewhat more accessible morphological features as outlined later. However, differences do exist between cyclophyllideans and pseudophyllideans that are important in diagnosis and in understanding their particular life histories.
Pseudophyllidean Tapeworms

The holdfast of pseudophyllideans has only two shallow, longitudinally grooved bothria for locomotion and attachment. The two most important genera, *Diphyllobothrium* and *Spirometra*, have no hooks to assist the weak grip of the bothria.

Pseudophyllidean segments have a uterine pore that permits the escape of eggs. Segments discharge their eggs until their supply is exhausted. The terminal segments of pseudophyllidean tapeworms become senile rather than gravid and are usually detached in short chains rather than individually. Thus the diagnosis of pseudophyllidean infection depends on distinguishing the operculate eggs in fecal sediments from those of trematodes, which sometimes is not an easy matter.

The pseudophyllidean oncosphere is surrounded by an operculate shell. The oncosphere pops open the operculum of the shell and swims away. The ciliated pseudophyllidean oncosphere is called a coracidium.

Family Diphyllobothriidae

The scolex of *Diphyllobothrium latum* and *Spirometra mansonioides* has two slitlike grooves. The uterus consists of a spiral tube and opens to the outside through a midventral uterine pore behind the genital pore. Operculated eggs are discharged through the uterine pore.

*Diphyllobothrium latum*  IH 1: copepod IH 2: fish DH: dog, human, etc

Whereas cyclophyllidean development involves only one intermediate host, pseudophyllideans require at least two, of which the first is a copepod and the second is a vertebrate. When ingested by a copepod, the coracidium develops into a solid wormlike procerocid within the body cavity. When the infected copepod is ingested by a second intermediate host, the procerocid enters its musculature or connective tissues and develops into a procerocid. The procerocid is notable for its ability to parasitize a series of predatory parasitic hosts until a suitable definitive host is found. When a pike eats a minnow infected with the procerocids of *D. latum*, these merely invade the flesh of the pike and remain procerocids. However, when a human, a dog, or a cat eats either the minnow or the pike, the procerocid matures into an adult tapeworm. *D. latum* procerocids develop in copepods, and its procerocids develop in fish. Definitive hosts of *D. latum* include humans, dogs, mongooses, walruses, seals, sea lions, bears, foxes, and mink. *Diphyllobothrium* infection is acquired by eating uncooked predatory freshwater fish.

* Spirometra mansonioides  IH 1: copepod IH2: any vertebrate except fish DH: cat

*S. mansonioides* procerocids develop in copepods of the genus *Cyclops*. The natural intermediate host is probably the water snake *Natric*, and the natural definitive host is probably the bobcat *Lynx rufus*. Other definitive hosts of *S. mansonioides* include the domestic cat and dog and the raccoon. Coracidia develop and hatch from eggs deposited in water and swim about until they are ingested by copepods of the genus *Cyclops*. Shedding its ciliated coat, the hexacanth embryo develops into a procerocid larva in the body cavity of the copepod. If an infected copepod is swallowed by any vertebrate except a fish, the procerocids develop into procerocids, which tend to locate in the subcutaneous tissues and flat muscles of the body wall. Procerocids survive predation of their hosts and remain procerocids in their new hosts unless the new host happens to be a cat. Procerocids develop into adult *S. mansonioides* tapeworms in the small intestine of the domestic cat and bobcat.

*D. latum* and *S. mansonioides* are less obstructive than other tapeworm parasites of dogs and cats because they do not detach segments but release their eggs more or less continuously through the uterine pores of their mature segments. Therefore the client usually is unaware of *Diphyllobothrium* and *Spirometra* infection unless a whole tapeworm or a long chain of senile segments is discharged at once.
Appendix N: Experiment 2: Variation 2 (Table with details)

Cyclophyllidean Tapeworms

Segments of cyclophyllidean strobila have genital pores for fertilization but no opening to allow the eggs to escape from the uterus. Thus the eggs accumulate until the segment becomes packed full like a ripe seedpod. As they reach the end of the chain, these gravid segments are detached and pass out with the feces or crawl out the anus onto the perianal skin. Therefore cyclophyllidean infections are usually diagnosed by identifying gravid segments on the host or in its environment. Cyclophyllidean oncospheres are fully developed when passed in the feces of the definitive host and are immediately infective for the intermediate host.

Family Taeniidae

*Taenia*

Adult tapeworms of the genus *Taenia* measure from tens to hundreds of centimeters in length, depending on the species in question and degree of maturity of the specimen.

Gravid taenid segments are shed and exit from the carnivorous definitive host through the anus. The segments crawl about on the pelage of the host or surface of the fecal mass, emptying themselves of their eggs (oncospheres) in the process. Therefore any segment collected after it has been out for more than a few minutes may contain few if any eggs. If ingested by a suitable vertebrate intermediate host (usually a species normally taken as prey by the definitive host), the egg hatches and the hexacanth embryo enters the wall of the intestine and migrates to its organ of predilection, usually the liver and peritoneal membranes or the skeletal and cardiac muscles. Here the hexacanth embryo grows, cavitates, and differentiates to form the second-stage larva, which is infective to the definitive host. The fully developed second-stage larva of the family *Taeniidae* consists of a fluid-filled bladder with one or more scoleces (often called a bladderworm) and is surrounded by a connective tissue capsule formed by the vertebrate intermediate host.

When a second-stage larva is ingested by a suitable definitive host, the bladder is digested away, the scolex embeds itself in the mucosa of the small intestine, and the neck begins to bud off segments to form the strobila.

There are four basic kinds of taenid second-stage larvae: the cysticerus, strobilocercus, coenurus, and hydatid. Members of the genus *Taenia* typically form cysticeri, strobilocerci, and coenuri, depending on the species in question. A cysticerus consists of a single bladder with one scolex. A strobilocercus is a cysticerus that has already begun to elongate and segment while still in the intermediate host, and a coenurus consists of a single bladder with many scoleces, each with the potential of developing into a mature tapeworm. Hydatids are formed by members of the genus *Echinococcus* and are of two kinds, unilocular hydatid cysts and alveolar hydatids, both of which often contain thousands of scoleces.

*Taenia hydatigena*  
IH: cattle, sheep, swine  
DH: dog

The cysticerus of the canine taenid tapeworm *T. hydatigena* migrates through the liver tissue and encysts on the peritoneal membranes of cattle, sheep, swine, and certain wild ungulates. Massive invasions, such as when entire tapeworm segments are ingested, result in acute traumatic hepatitis, and even small numbers of migrating *T. hydatigena* larvae are capable of precipitating "black disease" in the presence of *C. novyi*. However, frank disease is rarely caused by this larval tapeworm, and the principal economic loss results from condemnation of infected livers by meat inspection authorities.

*Taenia ovis*  
IH: sheep  
DH: dog

The cysticerus of a second canine taenid tapeworm, *Taenia ovis*, infects the cardiac and skeletal muscles of sheep and represents the most important pathological lesion found by United States inspectors in imported Australian mutton.
**Taenia pisiformis**  
IH: rabbit  
DH: dog  
The cysticercus of a third canine taeniid tapeworm, *Taenia pisiformis*, is found in the liver and peritoneal cavity of rabbits. This tapeworm is the most common taeniid tapeworm of dogs in the United States. Every dog that is so infected must have eaten a rabbit or parts of a rabbit and this means that many rabbits are infected by grazing near where *Taenia pisiformis* segments have been shed.

**Taenia saginata**  
IH: cattle  
DH: human  
The cysticercus of the human tapeworm *T. saginata* encysts in the striated muscles of cattle, especially the heart and muscles of mastication. Taenid eggs survive the rigors of the septic tank, as well as many contemporary municipal sewage treatment processes, and because defecating out-of-doors is unavoidable when hunting or camping out (and because the segments can leave the host by crawling out through the anal opening), it is easy to see how cattle pastures become contaminated with *T. saginata* eggs. The cysticerci that develop when these eggs are ingested by cattle are relatively inconspicuous and easily overlooked by the breeder of rare or raw beef. Consequently, *T. saginata* is a common parasite in the United States.

**Taenia solium**  
IH: swine, human  
DH: human  
The cysticercus of the human tapeworm *T. solium* represents a significant hazard to human health. People become infected with *T. solium* by ingesting the cysticerci in undercooked pork. After the tapeworm matures, the person’s feces contain a steady supply of eggs, which may be conveyed to the mouth at any time by a lapse in personal hygiene. When the eggs reach the stomach, the oncospheres hatch out, enter the gut wall, and wander far and wide in the body, slowly developing into cysticerci. Apparently the milieu interieur of humans resembles that of swine closely enough to satisfy the development requirements of the cysticerci. In humans, the signs depend on where the cysticerci localize, and sites may include the eye, brain, or spinal cord.

**Taenia taeniacformis**  
IH: meadow vole  
DH: cat  
The larva of the cat tapeworm *T. taeniacformis* is a strobilocercus. This larva is a very common parasite of meadow voles. Meadow voles are relished by cats, which serve as definitive hosts of *T. taeniacformis*.

**Taenia multiceps**  
IH: sheep, goats, cattle  
DH: dog  
The coenurus of the canine taeniid tapeworm *T. multiceps* invades the cranial cavity of sheep, goats, and sometimes cattle. As the cyst grows over a period of 6 or 8 months, neurological signs of progressive space occupation slowly develop. There may be blindness, incoordination, walking in circles, and pressing the head against walls, tree trunks, and the like. Finally, the animal lies down and dies. The most common diseases that might be confused with cerebral coenurusis are bacterial encephalitis (listeriosis) and parechymatous meningitis. Intracranial surgery is the only cure for cerebral coenurusis. As in the case of *T. hydatigena* and *T. ovis*, control can be based only on excluding dogs and other canids from sheep pastures.

**Echinococcus granulosus, E. multilocularis**  
IH: sheep, human  
DH: dog  
The genus *Echinococcus* contains two species of special importance to veterinary medicine, *Echinococcus granulosus* and *Echinococcus multilocularis*, which are very small (2 to 8 mm long) adult tapeworms having only four or five segments.

*E. granulosus* is a parasite of the dog, coyote, wolf, and dingo. Its larva is a hydatid cyst in sheep, swine, cattle, humans, moose, caribou, kangaroos, and others. The hydatid membrane may bud off daughter cysts either internally or externally. The whole structure occupies progressively more space as it grows, but hydatid cysts do not infiltrate, in contrast to alveolar hydatids. Pathogenic effects of hydatid cysts include pressure atrophy of surrounding organs and allergic reactions to hydatid fluid leaks. Rupture of a fertile hydatid cyst may scatter bits of germinal membrane, scolexes, and brood capsules throughout the pleural or peritoneal cavity and result in multiple hydatidosis.
HYDATID DISEASE

The unilocular hydatid cyst is the second-stage larva of *E. granulosus* and is infective to dogs and other canids that serve as definitive hosts. Starting as an oncosphere less than 30 μm in diameter, the larva grows very slowly and infrequently exceeds more than a few centimeters in diameter in slaughtered sheep and cattle. Because humans live longer, a fertile hydatid infecting man may grow very large and interfere with the function of neighboring organs by pressing against them. The hydatid membrane is surrounded by an inflammatory connective tissue capsule. Brood capsules, each containing many scolices, develop from the germinal epithelium lining the laminated hydatid membrane. Some of these rupture, releasing scolices to form a sediment of so-called hydatid sand in the hydatid fluid.

Alveolar hydatid cysts are second-stage larvae of *E. multilocularis* and are infective to dogs, foxes, and cats, which serve as definitive hosts. Alveolar hydatids develop in voles, lemmings, cattle, horses, swine, and humans. They are characterized by exogenous budding that does not remain contained within the reactive connective tissue capsule but continuously proliferates and infiltrates surrounding tissue like a malignant neoplasm. Alveolar hydatid infection proves invariably fatal in a few years.

Both *E. granulosus* and *E. multilocularis* tend to establish sylvatic cycles when suitable predator-prey relationships exist in the wildlife population of a region. Therefore *E. granulosus* cycles are maintained among wild ruminants and wolves in the Canadian north woods and among wallabies and dingoes in Australia. Natural nidi of *E. multilocularis* are maintained in various rodents and foxes. The sylvatic cycle reaches humans through their domesticated animals. Dogs that scavenge the entrails of wild game infected with *Echinococcus* spp. become direct sources of hydatid infection to humans and their domestic animals. Contamination of pastures with the feces of infected wild carnivores also results in hydatid infection of domestic ruminants and swine. The establishment of a pastoral cycle may then result from the feeding of uncooked offal from these domestic animals to dogs and, in the case of *E. multilocularis*, to cats. The direct source of human infection is, in most instances, the domestic dog or cat, and scrupulous hygiene is the first line of defense.

**Other Cyclophyllidean Tapeworms**

The second-stage larvae of all of the following cyclophyllidean families are cisticercoids of one kind or another. A cisticercoid may be thought of as a cysticerus small enough to fit into the body of an arthropod.

**Family Anoplocephalidae**

The tapeworms of cattle, sheep, and goats all belong to the family Anoplocephalidae. The life histories involve an arthropod intermediate host in which the infective cisticercoid develops. Infection results from the incidental ingestion of these infected arthropods by the grazing animal. Adult tapeworms are relatively nonpathogenic.

<table>
<thead>
<tr>
<th>Moniezia</th>
<th>IH: mites</th>
<th>DH: cattle, sheep, goats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moniezia spp. are found in the small intestine of cattle, sheep, and goats (<em>Moniezia benedeni, Moniezia expansa, and Moniezia capræ</em>). The egg of <em>Moniezia</em> sp. found in cattle feces is one of the few eggs that appears square. Free-living oribatid mites serve as hosts for cisticercoids of <em>Moniezia</em> spp. of sheep and cattle.</td>
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<table>
<thead>
<tr>
<th>Thysanosoma actinoides</th>
<th>IH: booklice</th>
<th>DH: ruminants except cattle</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Thysanosoma actinoides</em>, the “fringed tapeworm,” is found in the common bile duct and duodenum of virtually all ruminant species except cattle. <em>Thysanosoma actinoides</em> is apparently transmitted by</td>
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</tbody>
</table>
"booklice" or "barklice" of the family Psocidae, order Pscoptera. Pscopterans resemble mallophagan lice but are entirely free living and have no other known relationship to parasite life histories.

**Anoplocephala**  
**Anoplocephala magna** is a relatively harmless parasite in the small intestine of horses. **Anoplocephala perfoliata** is found mainly in the cecum but also tends to cluster in the ileum near the ileocecal valve. This clustering results in ulceration of the mucous membrane and inflammation with thickening and induration of the deeper layers of the intestinal wall. These pathological changes probably account for some cases of persistent diarrhea and may predispose to intussusception of the ileum into the cecum or rupture of the bowel wall in the vicinity of the ileocecal valve.

**Family Dipyldiidae**

**Dipylidium caninum**  
**Dipylidium caninum** segments are shaped like cucumber seeds and have bilateral genital pores. Each egg capsule may contain from 5 to 30 eggs.

Gravid segments discharge their egg packets as they move about. Larvae of *Ctenocephalides* chew their way into egg packets and ingest the oncospheres of the tapeworm. The hexacanth embryo enters the body cavity of the flea larva and remains there through its metamorphosis. After the adult flea emerges from the cocoon, the hexacanth develops into a cysticercoid in 2 or 3 days. If such a flea is ingested by the definitive host as during self-grooming, the cysticercoids develop into adult tapeworms in the small intestine.

Cysticercoids of *D. caninum* develop in fleas (*Ctenocephalides spp.*) and biting lice (*Trichodectes canis*), and the dog acquires this tapeworm while nipping its insects. Children also may become infected in this way. *D. caninum* requires only 2 to 3 weeks to develop from a cysticercoid into a segment-shedding tapeworm. Thus the benefits of anthelmintic therapy are particularly short-lived unless fleas and biting lice also are brought under control.

**Family Hymenolepididae**

**Hymenolepis diminuta**  
**Hymenolepis diminuta** is a parasite of the small intestine principally of rodents but occasionally also of dogs and even humans. The cysticercoid of *H. diminuta* develops in fleas, flour beetles, and a rather wide range of other insects.

**Vampirolepis nana**  
**Vampirolepis nana** is also a parasite of rodents and humans, and its second-stage larva is a cysticercoid in fleas and flour beetles or in the intestinal mucosa of its definitive host. *V. nana* can complete its life history within the intestinal tract of a mouse or a human. Some of the eggs hatch within the intestine, and the hexacanth embryos burrow into the mucous membrane to form cysticercoids that later reenter the lumen to complete their development as mature tapeworms. The rest of the eggs pass out with the feces to await ingestion by flour beetles or fleas, in which the cysticercoids develop. Thus *H. diminuta* requires fleas, flour beetles, or other insects as intermediate hosts, whereas *V. nana* may or may not.

**Family Mesocestoididae**

**Mesocestoides**  
**Mesocestoides** has yet to be worked out. The larval form infective for the definitive host is a third-stage larva found in the peritoneal cavity of mammals and reptiles and in the lungs of birds.
Mesocestoides infection of dogs and cats results from predation on snakes, birds, and small mammals. M. corti tapeworms multiply asexually in the intestines of dogs. If this species is not totally eliminated by anthelmintic medication, it will repopulate the intestine even without further exposure.

### Summary of Class Cestoda

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<thead>
<tr>
<th>Order Pseudophyllidea</th>
<th>Intermediate Host</th>
<th>Definitive Host</th>
</tr>
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<tbody>
<tr>
<td><em>Diphyllolobothriidae</em></td>
<td>- Aquatic food chain - Has uterine pore - Operculated egg</td>
<td>- Requires at least 2 intermediate hosts: 1st: copepod; 2nd: vertebrate</td>
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<td><em>Spirometra mansonioides</em></td>
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<td>cat</td>
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<tr>
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<tr>
<td></td>
<td>2nd: any vertebrate except fish</td>
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</table>
| Order Cyclophyllidea | - Terrestrial food chain | - No uterine pore | - Egg not operculated
| | - Requires intermediate host | | |
| *Taenidae* | - Requires mammal intermediate host | |
| *Taenia hydatigena* | cattle, sheep, swine | dog |
| *Taenia ovis* | sheep | dog |
| *Taenia pisiformis* | rabbit | dog |
| *Taenia saginata* | cattle | human |
| *Taenia solium* | swine, human | human |
| *Taenia taeniaformis* | meadow vole | cat |
| *Taenia multiceps* | sheep, goats, cattle | dog |
| *Echinococcus granulosus* | sheep, human | dog |
| *Echinococcus multilocularis* | sheep, human | dog |

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<tr>
<td><em>Moniezia</em></td>
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<td><em>Dipylidium caninum</em></td>
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Appendix O: Experiment 2: Intervention 3 (Concept map)

Material for

The Effect of Proximity and Explicitness in Learning Materials on Student Ability to Utilize Basic Science Knowledge in Clinical Problem-Solving

Experiment 2: Representation Type

Variation 3

Texas A&M University
October 29-30, 2008
CLASS CESTODA

Tapeworms belong to the class Cestoda of the phylum Platyhelminthes. An adult tapeworm is essentially a chain (strobila) of independent, progressively maturing reproductive units, one end of which is capable of attachment to the wall of the host’s intestine by a holdfast organ or scolex. In a fully developed adult tapeworm, all stages of development are displayed in a linear array starting at the scolex and terminating at the distal end. There are no organs of prehension or digestion; all nutrients are absorbed through the tapeworm’s specialized integument. The body of an adult tapeworm is so flattened that for the purposes of argument it can be said to have two surfaces and two edges. This shape affords maximum surface area per unit volume, a distinct asset for an animal that absorbs all of its nourishment through its skin.

Two orders of the class Cestoda are of greatest interest to veterinarians: Pseudophyllidea and Cycophyllidea. The order Pseudophyllidea is represented by only two genera of importance to most veterinarians: Diphyllolittorina and Sporocysta. Both use copepods as the first intermediate host in which the oncosphere develops into a second-stage larva called a procercoid. The second intermediate host may be a fish, amphibian, or reptile and supports development of the procercoid into a third-stage larva called a plerocercoid. The definitive host becomes infected when it ingests a second intermediate host containing plerocercoids. Pseudophyllidea are associated with aquatic food chains. The order Cycophyllidea contains five families of veterinary importance: Taeniidae, Mesocestoidae, Anoplocephalidae, Dipyldidae, and Hymenolepididae. Most cycophyllidea require only one intermediate host. Depending on the family of tapeworm, the intermediate host may be a mammal (Taeniidae) or an arthropod (Anoplocephalidae, Dipyldidae, Hymenolepididae). Members of the Mesocestoidae are thought to require two intermediate hosts, the second of which may be a mammal, bird, or reptile. Cycophyllidea are associated with terrestrial food chains.

Almost all tapeworms require at least two and some require three hosts to complete their life histories. *Vampyrolepis nana*, a cycophyllidean parasite of mice and sometimes of humans, is exceptional in being able to complete its life history within the confines of a single individual.

Cestodes produce eggs that when fully developed contain a first-stage larva called an oncosphere. Oncospheres develop into second-stage larvae in the body cavities or tissues of an intermediate host. Usually, the second-stage larva is infective for the definitive host on ingestion. However, in certain cases, the second-stage larva must first develop into a third-stage larva in a second intermediate host before it is ready to infect the definitive host. The oncosphere is the first-stage larva and is infective for the first (or only) intermediate host. The first-stage larva develops in this host into a second-stage larva. In most cycophyllidea, there is only one intermediate host, and the second-stage larva is the stage infective to the definitive host in which it matures. In the Mesocestoidae and in the Pseudophyllidea, the second-stage larvae are infective to the second intermediate host in which it develops into a third-stage larva. The third-stage larvae of mesocestoides and pseudophyllidea are the form infective for the definitive host. The second and third larval stages of these various tapeworms have their own names that are presented later in the discussion of their respective life histories. The objective of larval development is to form a scolex in a kind of intermediate host that is likely, for one reason or another, to be ingested by a suitable definitive host.

Depending on the kind of tapeworm, fertilized eggs are discharged through a uterine pore or accumulate in the segment. Therefore the terminal segments of a mature tapeworm are found to be empty in the former case and packed full of eggs like ripe seedpods in the latter.

A reliable identification usually can be made on the basis of host identity and somewhat more accessible morphological features as outlined later. However, differences do exist between cycophyllideans and pseudophyllidea that are important in diagnosis and in understanding their particular life histories.
Pseudophyllidean Tapeworms

The holdfast of pseudophyllideans has only two shallow, longitudinally grooved bothria for locomotion and attachment. The two most important genera, *Diphyllobothrium* and *Spirometra*, have no hooks to assist the weak grip of the bothria.

Pseudophyllidean segments have a uterine pore that permits the escape of eggs. Segments discharge their eggs until their supply is exhausted. The terminal segments of pseudophyllidean tapeworms become senile rather than gravid and are usually detached in short chains rather than individually. Thus the diagnosis of pseudophyllidean infection depends on distinguishing the operculate eggs in fecal sediments from those of trematodes, which sometimes is not an easy matter.

The pseudophyllidean oncosphere is surrounded by an operculate shell. The oncosphere pops open the operculum of the shell and swims away. The ciliated pseudophyllidean oncosphere is called a cercaria.

**Family Diphyllobothriidae**

The scolex of *Diphyllobothrium latum* and *Spirometra mansonioides* has two slitlike grooves. The uterus consists of a spiral tube and opens to the outside through a midventral uterine pore behind the genital pore. Operculated eggs are discharged through the uterine pore.

*Diphyllobothrium latum*  
IH 1: copepod  
IH 2: fish  
DH: dog, human, etc

Whereas cyclophyllidean development involves only one intermediate host, pseudophyllideans require at least two, of which the first is a copepod and the second is a vertebrate. When ingested by a copepod, the cercaria develops into a solid wormlike procercecid within the body cavity. When the infected copepod is ingested by a second intermediate host, the procercecid enters its musculature or connective tissues and develops into a procercecid. The procercecid is notable for its ability to parasitize a series of predatory peritene hosts until a suitable definitive host is found. When a pike eats a minnow infected with the procercecids of *D. latum*, these merely invade the flesh of the pike and remain procercecids. However, when a human, a dog, or a cat eats either the minnow or the pike, the procercecid matures into an adult tapeworm. *D. latum* procercecids develop in copepods, and its procercecids develop in fish. Definitive hosts of *D. latum* include humans, dogs, mongooses, walruses, seals, sea lions, bears, foxes, and mink. *Diphyllobothrium* infection is acquired by eating uncooked predatory freshwater fish.

*SPIROMETRA MANSONOIDES*  
IH 1: copepod  
IH 2: any vertebrate except fish  
DH: cat

*S. mansonioides* procercecids develop in copepods of the genus Cyclops. The natural intermediate host is probably the water snake *Natrix*, and the natural definitive host is probably the bobcat *Lynx rufus*. Other definitive hosts of *S. mansonioides* include the domestic cat and dog and the raccoon. Cercaria develop and hatch from eggs deposited in water and swim about until they are ingested by copepods of the genus *Cyclops*. Shedding its ciliated coat, the hexacanth embryo develops into a procercecid larva in the body cavity of the copepod. If an infected copepod is swallowed by any vertebrate except a fish, the procercecid develops into a procercecid, which tend to locate in the subcutaneous tissues and flat muscles of the body wall. Procercecids survive predation of their hosts and remain procercecids in their new hosts unless the new host happens to be a cat. Procercecids develop into adult *S. mansonioides* tapeworms in the small intestine of the domestic cat and bobcat.

*D. latum* and *S. mansonioides* are less obtrusive than other tapeworm parasites of dogs and cats because they do not detach segments but release their eggs more or less continuously through the uterine pores of their mature segments. Therefore the client usually is unaware of *Diphyllobothrium* and *Spirometra* infection unless a whole tapeworm or a long chain of senile segments is discharged at once.
Cyclophyllidean Tapeworms

Segments of cyclophyllidean strobila have genital pores for fertilization but no opening to allow the eggs to escape from the uterus. Thus the eggs accumulate until the segment becomes packed full like a ripe seedpod. As they reach the end of the chain, these gravid segments are detached and pass out with the feces or crawl out the anus onto the perianal skin. Therefore cyclophyllidean infections are usually diagnosed by identifying gravid segments on the host or in its environment. Cyclophyllidean oncospheres are fully developed when passed in the feces of the definitive host and are immediately infective for the intermediate host.

Family Taeniidae

_Taenia_

Adult tapeworms of the genus *Taenia* measure from tens to hundreds of centimeters in length, depending on the species in question and degree of maturity of the specimen.

Gravid taenid segments are shed and exit from the carnivorous definitive host through the anus. The segments crawl about on the pelage of the host or surface of the fecal mass, emptying themselves of their eggs (oncospheres) in the process. Therefore any segment collected after it has been out for more than a few minutes may contain few if any eggs. If ingested by a suitable vertebrate intermediate host (usually a species normally taken as prey by the definitive host), the egg hatches and the hexacanth embryo enters the wall of the intestine and migrates to its organ of predilection, usually the liver or peritoneal membranes or the skeletal and cardiac muscles. Here the hexacanth embryo grows, cavitates, and differentiates to form the second-stage larva, which is infective to the definitive host. The fully developed second-stage larva of the family Taeniidae consists of a fluid-filled bladder with one or more scoleces (often called a bladderworm) and is surrounded by a connective tissue capsule formed by the vertebrate intermediate host.

When a second-stage larva is ingested by a suitable definitive host, the bladder is digested away, the scolex embeds itself in the mucosa of the small intestine, and the neck begins to bud off segments to form the strobila.

There are four basic kinds of taenid second-stage larvae: the cysticercus, strobilocercus, coenurus, and hydatid. Members of the genus *Taenia* typically form cysticerci, strobilocerci, and coenuris, depending on the species in question. A cysticercus consists of a single bladder with one scolex. A strobilocercus is a cysticercus that has already begun to elongate and segment while still in the intermediate host, and a coenurus consists of a single bladder with many scolecis, each with the potential of developing into a mature tapeworm. Hydatids are formed by members of the genus *Echinococcus* and are of two kinds, unilocular hydatid cysts and alveolar hydatids, both of which often contain thousands of scoleces.

*Taenia hydatigena*  
**III:** cattle, sheep, swine  
**DH:** dog

The cysticercus of the canine taenid tapeworm *T. hydatigena* migrates through the liver tissue and encysts on the peritoneal membranes of cattle, sheep, swine, and certain wild ungulates. Massive invasions, such as when entire tapeworm segments are ingested, result in acute traumatic hepatitis, and even small numbers of migrating *T. hydatigena* larvae are capable of precipitating "black disease" in the presence of *C. novus*. However, frank disease is rarely caused by this larval tapeworm, and the principal economic loss results from condemnation of infected livers by meat inspection authorities.

*Taenia ovis*  
**III:** sheep  
**DH:** dog

The cysticercus of a second canine taenid tapeworm, *Taenia ovis*, infects the cardiac and skeletal muscles of sheep and represents the most important pathological lesion found by United States inspectors in imported Australian mutton.
**Taenia pisiformis**  
IH: rabbit  
DH: dog  
The cysticercus of a third canine taeniid tapeworm, *Taenia pisiformis*, is found in the liver and peritoneal cavity of rabbits. This tapeworm is the most common taeniid tapeworm of dogs in the United States. Every dog that is so infected must have eaten a rabbit or parts of a rabbit, and this means that many rabbits are infected by grazing near where *Taenia pisiformis* segments have been shed.

**Taenia saginata**  
IH: cattle  
DH: human  
The cysticercus of the human tapeworm *T. saginata* encysts in the striated muscles of cattle, especially the heart and muscles of mastication. Taeniid eggs survive the rigors of the septic tank as well as many contemporary municipal sewage treatment processes, and because defecating out-of-doors is unavoidable when hunting or camping out (and because the segments can leave the host by crawling out through the anal opening), it is easy to see how cattle pastures become contaminated with *T. saginata* eggs. The cysticerci that develop when these eggs are ingested by cattle are relatively inconspicuous and easily overlooked by the lover of rare or raw beef. Consequently, *T. saginata* is a common parasite in the United States.

**Taenia solium**  
IH: swine, human  
DH: human  
The cysticercus of the human tapeworm *T. solium* represents a significant hazard to human health. People become infected with *T. solium* by ingesting the cysticerci in undercooked pork. After the tapeworm matures, the person’s feces contain a steady supply of eggs, which may be conveyed to the mouth at any time by a lapse in personal hygiene. When the eggs reach the stomach, the oncospheres hatch out, enter the gut wall, and wander far and wide in the body, slowly developing into cysticerci. Apparently the milieu interieur of humans resembles that of swine closely enough to satisfy the development requirements of the cysticerci. In humans, the signs depend on where the cysticerci localize, and sites may include the eye, brain, or spinal cord.

**Taenia taeniaeformis**  
IH: meadow vole  
DH: cat  
The larva of the cat tapeworm *T. taeniaeformis* is a strobilocercus. This larva is a very common parasite of meadow voles. Meadow voles are relished by cats, which serve as definitive hosts of *T. taeniaeformis*.

**Taenia multiceps**  
IH: sheep, goat, cattle  
DH: dog  
The coenurus of the canine taeniid tapeworm *T. multiceps* invades the cranial cavity of sheep, goats, and sometimes cattle. As the cyst grows over a period of 6 or 8 months, neurological signs of progressive space occupation slowly develop. There may be blindness, incoordination, walking in circles, and pressing the head against walls, tree trunks, and the like. Finally, the animal lies down and dies. The most common diseases that might be confused with cerebral coenurosis are bacterial encephalitis (encephalitis) and paracelphastrengiosis. Intrastral surgery is the only cure for cerebral coenurosis. As in the case of *T. hydatigena* and *T. ovis*, control can be based only on excluding dogs and other canids from sheep pastures.

**Echinococcus granulosus, E. multilocularis**  
IH: sheep, human  
DH: dog  
The genus *Echinococcus* contains two species of special importance to veterinary medicine, *Echinococcus granulosus* and *Echinococcus multilocularis*, which are very small (2 to 8 mm long) adult tapeworms having only four or five segments.

*E. granulosus* is a parasite of the dog, coyote, wolf, and dingo. Its larva is a hydatid cyst in sheep, swine, cattle, humans, moose, caribou, kangaroos, and others. The hydatid membrane may bud off daughter cysts either internally or externally. The whole structure occupies progressively more space as it grows, but hydatid cysts do not infiltrate, in contrast to alveolar hydatids. Pathogenic effects of hydatid cysts include pressure atrophy of surrounding organs and allergic reactions to hydatid fluid leaks. Rupture of a fertile hydatid cyst may scatter bits of germinative membrane, scolexes, and broad capsules throughout the pleural or peritoneal cavity and result in multiple hydatidosis.
Appendix O: Experiment 2: Intervention 3 (Concept map)

HYDATID DISEASE

The unilocular hydatid cyst is the second-stage larva of E. granulosus and is infective to dogs and other canids that serve as definitive hosts. Starting as an oncosphere less than 30 um in diameter, the larva grows very slowly and infrequently exceeds more than a few centimeters in diameter in slaughtered sheep and cattle. Because humans live longer, a fertile hydatid infecting man may grow very large and interfere with the function of neighboring organs by pressing against them. The hydatid membrane is surrounded by an inflammatory connective tissue capsule. Brood capsules, each containing many scolices, develop from the germinal epithelium lining the laminated hydatid membrane. Some of these rupture, releasing scolices to form a sediment of so-called hydatid sand in the hydatid fluid.

Alveolar hydatid cysts are second-stage larvae of E. multilocularis and are infective to dogs, foxes, and cats, which serve as definitive hosts. Alveolar hydatids develop in voles, lemmings, cattle, horses, swine, and humans. They are characterized by exogenous budding that does not remain contained within the reactive connective tissue capsule but continuously proliferates and infiltrates surrounding tissue like a malignant neoplasm. Alveolar hydatid infection proves invariably fatal in a few years.

Both E. granulosus and E. multilocularis tend to establish sylvatic cycles when suitable predator-prey relationships exist in the wildlife population of a region. Therefore E. granulosus cycles are maintained among wild ruminants and wolves in the Canadian north woods and among wallabies and dingoes in Australia. Natural nidi of E. multilocularis are maintained in various rodents and foxes. The sylvatic cycle reaches humans through their domesticated animals. Dogs that scavenge the entrails of wild game infected with Echinococcus spp. become direct sources of hydatid infection to humans and their domestic animals. Contamination of pastures with the feces of infected wild carnivores also results in hydatid infection of domestic ruminants and swine. The establishment of a pastoral cycle may then result from the feeding of uncooked offal from these domestic animals to dogs and, in the case of E. multilocularis, to cats. The direct source of human infection is, in most instances, the domestic dog or cat, and scrupulous hygiene is the first line of defense.

Other Cyclophyllidean Tapeworms

The second-stage larvae of all of the following cyclophyllidean families are cysticercoids of one kind or another. A cysticercoid may be thought of as a cysticercus small enough to fit into the body of an arthropod.

Family Anoplocephalidae

The tapeworms of cattle, sheep, and goats all belong to the family Anoplocephalidae. The life histories involve an arthropod intermediate host in which the infective cysticercoid develops. Infection results from the incidental ingestion of these infected arthropods by the grazing animal. Adult tapeworms are relatively nonpathogenic.

*Moniezia*  
**IH:** mites  
**DH:** cattle, sheep, goats  
*Moniezia* spp. are found in the small intestine of cattle, sheep, and goats (*Moniezia benedeni, Moniezia expansa,* and *Moniezia caprae*). The egg of *Moniezia* sp. found in cattle feces is one of the few eggs that appears square. Free-living onchocercid mites serve as hosts for cysticercoids of *Moniezia* spp. of sheep and cattle.

*Thysanosoma actinoideos*  
**IH:** booklice  
**DH:** ruminants except cattle  
*Thysanosoma actinoideos*, the "fringed tapeworm," is found in the common bile duct and duodenum of virtually all ruminant species except cattle. *Thysanosoma actinoideos* is apparently transmitted by
"booklice" or "barklice" of the family Psocidae, order Pscoptera. Pscopterans resemble mallophagan lice but are entirely free living and have no other known relationship to parasite life histories.

*Anoplodera*  
*Anoplodera magna* is a relatively harmless parasite in the small intestine of horses. *Anoplodera perfoliata* is found mainly in the cecum but also tends to cluster in the ileum near the ileocecal valve. This clustering results in ulceration of the mucous membrane and inflammation with thickening and induration of the deeper layers of the intestinal wall. These pathologial changes probably account for some cases of persistent diarrhea and may predispose to intussusception of the ileum into the cecum or rupture of the bowel wall in the vicinity of the ileocecal valve.

**Family Dipyldiidae**

*Dipylidium caninum*  
*Dipylidium caninum* segments are shaped like cucumber seeds and have bilateral genital pores. Each egg capsule may contain from 5 to 30 eggs.

Gravid segments discharge their egg packets as they move about. Larvae of *Ctenocephalides* chew their way into egg packets and ingest the oncospheres of the tapeworm. The hexacanth embryo enters the body cavity of the flea larva and remains there through its metamorphosis. After the adult flea emerges from the cecum, the hexacanth develops into a cysticercoid in 2 or 3 days. If such a flea is ingested by the definitive host as during self-grooming, the cysticercoids develop into adult tapeworms in the small intestine.

Cysticercoids of *D. caninum* develop in fleas (*Ctenocephalides* spp.) and biting lice (*Trichodectes canis*), and the dog acquires this tapeworm while nipping its insects. Children also may become infected in this way. *D. caninum* requires only 2 to 3 weeks to develop from a cysticercoid into a segment-shedding tapeworm. Thus the benefits of anthelmintic therapy are particularly short-lived unless fleas and biting lice also are brought under control.

**Family Hymenolepididae**

*Hymenolepis diminuta*  
*Hymenolepis diminuta* is a parasite of the small intestine principally of rodents but occasionally also of dogs and even humans. The cysticercoid of *H. diminuta* develops in fleas, flour beetles, and a rather wide range of other insects.

*Vampirolepis nana*  
*Vampirolepis nana* is also a parasite of rodents and humans, and its second-stage larva is a cysticercoid in fleas and flour beetles or in the intestinal mucosa of its definitive host. *V. nana* can complete its life history within the intestinal tract of a mouse or a human. Some of the eggs hatch within the intestine, and the hexacanth embryos burrow into the mucous membrane to form cysticercoids that later reenter the lumen to complete their development as mature tapeworms. The rest of the eggs pass out with the feces to await ingestion by flour beetles or fleas, in which the cysticercoids develop. Thus *H. diminuta* requires fleas, flour beetles, or other insects as intermediate hosts, whereas *V. nana* may or may not.

**Family Mesococestoididae**

*Mesococestoides*  
The complete life history of the genus *Mesococestoides* has yet to be worked out. The larval form infective for the definitive host is a third-stage larva found in the peritoneal cavity of mammals and reptiles and in the lungs of birds.
**Appendix O: Experiment 2: Intervention 3 (Concept map)**

*Mesocestoides* infection of dogs and cats results from predation on snakes, birds, and small mammals. *M. corti* tapeworms multiply asexually in the intestines of dogs. If this species is not totally eliminated by anthelmintic medication, it will repopulate the intestine even without further exposure.

### Summary of Class Cestoda

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<th>Order Pseudophyllidea</th>
<th>Intermediate Host</th>
<th>Definitive Host</th>
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<td>- Aquatic food chain</td>
<td>- Has uterine pore</td>
<td>- Operculated egg</td>
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<td>- Requires at least 2 intermediate hosts: 1st: copepod; 2nd: vertebrate</td>
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Appendix P: Experiment 2: Intervention 4 (Full + partial concept maps)

Material for
The Effect of Proximity and Explicitness in Learning Materials on Student Ability to Utilize Basic Science Knowledge in Clinical Problem-Solving

Experiment 2: Representation Type

Variation 4

Texas A&M University
October 29-30, 2008
Appendix P: Experiment 2: Intervention 4 (full + partial concept maps)

1. Read from left to right, starting at "Class Cestoda" on the left.
2. As you follow the arrows, each box inherits the properties of its parent(s) to the left. For example, Taeniidae has the property that its intermediate host is a mammal, and it also has a terrestrial food chain.

How to Read This Diagram

Class Cestoda

- Aquatic food chain
  - Has uterine pore
  - Operculated eggs
  - Requires at least 2 intermediate hosts:
    1st: copepod; 2nd: vertebrate

Order Pseudophyllidea

Intermediate host is a mammal

Order Cyclophyllidea
- Terrestrial food chain
  - No uterine pore
  - Eggs not operculated
  - Requires an intermediate host

Family Anoplocephalidae
- Moniezia
- Thysanosoma

Intermediate host is an anthropod

Family Dipyldiiidae
- Dipylidium

Family Hymenolepidae
- Hymenolepis

Intermediate host optional
- Vampirolepis

Family Mesocestoidae
- Mesocestoides

Family Taeniidae
- Taenia
- Echinococcus

Family Diphyllolobidae
- Spirometra

Diphyllolobothrium

* Vampirolepis is an exception in that it does not have to have an intermediate host.
CLASS CESTODA

Tapeworms belong to the class Cestoda of the phylum Platyhelminthes. An adult tapeworm is essentially a chain (strobila) of independent, progressively maturing reproductive units, one end of which is capable of attachment to the wall of the host's intestine by aholdfast organ or scolex. In a fully developed adult tapeworm, all stages of development are displayed in a linear array starting at the scolex and terminating at the distal end. There are no organs of predigestion or digestion; all nutrients are absorbed through the tapeworm's specialized integument. The body of an adult tapeworm is so flattened that for the purposes of argument it can be said to have two surfaces and two edges. This shape affords maximum surface area per unit volume, a distinct asset for an animal that absorbs all of its nourishment through its skin.

Two orders of the class Cestoda are of greatest interest to veterinarians: Pseudophyllidea and Cyclophyllidea. The order Pseudophyllidea is represented by only two genera of importance to most veterinarians: Dipylidium caninum and Spirometra. Both use copepods as the first intermediate host in which the oncosphere develops into a second-stage larva called a procercoid. The second intermediate host may be a fish, amphibian, or reptile and supports development of the procercoid into a third-stage larva called a plerocercoid. The definitive host becomes infected when it ingests a second intermediate host containing plerocercoids. Pseudophyllideans are associated with aquatic food chains. The order Cyclophyllidea contains five families of veterinary importance: Taeniidae, Mesocestoidae, Anoplocephalidae, Dipylidiidae, and Hymenolepidae. Most cyclophyllideans require only one intermediate host. Depending on the family of tapeworm, the intermediate host may be a mammal (Taeniidae) or an arthropod (Anoplocephalidae, Dipylidiidae, Hymenolepidae). Members of the Mesocestoidae are thought to require two intermediate hosts, the second of which may be a mammal, bird, or reptile. Cyclophyllideans are associated with terrestrial food chains.

Almost all tapeworms require at least two and some require three hosts to complete their life histories. *Dipylidium caninum*, a cyclophyllidean parasite of mice and sometimes of humans, is exceptional in being able to complete its life history within the confines of a single individual.

Cestodes produce eggs that when fully developed contain a first-stage larva called an oncosphere. Oncospheres develop into second-stage larvae in the body cavities or tissues of an intermediate host. Usually, the second-stage larva is infective for the definitive host on ingestion. However, in certain cases, the second-stage larva must first develop into a third-stage larva in a second intermediate host before it is ready to infect the definitive host. The oncosphere is the first-stage larva and is infective for the first (or only) intermediate host. The first-stage larva develops in this host into a second-stage larva. In most cyclophyllideans, there is only one intermediate host, and the second-stage larva is the stage infective to the definitive host in which it matures. In the Mesocestoidae and in the Pseudophyllidea, the second-stage larvae are infective to the second intermediate host in which it develops into a third-stage larva. The third-stage larvae of mesocestoids and pseudophyllideans are the form infective for the definitive host. The second and third larval stages of these various tapeworms have their own names that are presented later in the discussion of their respective life histories. The objective of larval development is to form a scolex in a kind of intermediate host that is likely, for one reason or another, to be ingested by a suitable definitive host.

Depending on the kind of tapeworm, fertilized eggs either are discharged through a uterine pore or accumulate in the segment. Therefore the terminal segments of a mature tapeworm are found to be empty in the former case and packed full of eggs like ripe seedpods in the latter.

A reliable identification usually can be made on the basis of host identity and somewhat more accessible morphological features as outlined later. However, differences do exist between cyclophyllideans and pseudophyllideans that are important in diagnosis and in understanding their particular life histories.
Pseudophyllidean Tapeworms

The holdfast of pseudophyllideans has only two shallow, longitudinally grooved bothria for locomotion and attachment. The two most important genera, Diphyllolothrium and Spirometra, have no hooks to assist the weak grip of the bothria.

Pseudophyllidean segments have a uterine pore that permits the escape of eggs. Segments discharge their eggs until their supply is exhausted. The terminal segments of pseudophyllidean tapeworms become senile rather than gravid and are usually detached in short chains rather than individually. Thus the diagnosis of pseudophyllidean infection depends on distinguishing the operculate eggs in fecal sediments from those of trematodes, which sometimes is not an easy matter.

The pseudophyllidean oncosphere is surrounded by an operculated shell. The oncosphere pops open the operculum of the shell and swims away. The ciliated pseudophyllidean oncosphere is called a coracidium.

Family Diphyllobothriidae

The scolex of Diphyllolothrium latum and Spirometra mansonioides has two slitlike grooves. The uterus consists of a spiral tube and opens to the outside through a midventral uterine pore behind the genital pore. Operculated eggs are discharged through the uterine pore.

*Diphyllolothrium latum* IH 1: copepod IH 2: fish DH: dog, human, etc

Whereas cyclophyllidean development involves only one intermediate host, pseudophyllideans require at least two, of which the first is a copepod and the second is a vertebrate. When ingested by a copepod, the coracidium develops into a solid wormlike proceroid within the body cavity. When the infected copepod is ingested by a second intermediate host, the proceroid enters its musculature or connective tissues and develops into a plerocercoid. The plerocercoid is notable for its ability to parasitize a series of predatory paratenic hosts until a suitable definitive host is found. When a pike eats a minnow infected with the plerocercoids of *D. latum*, these merely invade the flesh of the pike and remain plerocercoids. However, when a human, a dog, or a cat eats either the minnow or the pike, the plerocercoid matures into an adult tapeworm, *D. latum* plerocercoids develop in copepods, and its plerocercoids develop in fish. Definitive hosts of *D. latum* include humans, dogs, mongooses, walruses, seals, sea lions, bears, foxes, and mink. Diphyllolothrium infection is acquired by eating uncooked predatory freshwater fish.

*Spirometra mansonioides* IH 1: copepod IH 2: any vertebrate except fish DH: cat

*S. mansonioides* proceroids develop in copepods of the genus Cyclops. The natural intermediate host is probably the water snake *Natrix*, and the natural definitive host is probably the bobcat *Lynx rufus*. Other definitive hosts of *S. mansonioides* include the domestic cat and dog and the raccoon. Coracidia develop and hatch from eggs deposited in water and swim about until they are ingested by copepods of the genus Cyclops. Shedding its ciliated coat, the hexacanth embryo develops into a proceroid larva in the body cavity of the copepod. If an infected copepod is swallowed by any vertebrate except a fish, the proceroids develop into plerocercoids, which tend to locate in the subcutaneous tissues and fat muscles of the body wall. Plerocercoids survive predation of their hosts and remain plerocercoids in their new hosts until the new host happens to be a cat. Plerocercoids develop into adult *S. mansonioides* tapeworms in the small intestine of the domestic cat and bobcat.
D. latum and S. mansonioides are less obtrusive than other tapeworm parasites of dogs and cats because they do not detach segments but release their eggs more or less continuously through the uterine pores of their mature segments. Therefore the client usually is unaware of Diphyllobothrium and Spirometra infection unless a whole tapeworm or a long chain of proglottids is discharged at once.

Cyclophyllidean Tapeworms

Segments of cyclophyllidean strobila have genital pores for fertilization but no opening to allow the eggs to escape from the uterus. Thus the eggs accumulate until the segment becomes packed full like a ripe seedpod. As they reach the end of the chain, these gravid segments are detached and pass out with the feces or crawl out the anus onto the perianal skin. Therefore cyclophyllidean infections are usually diagnosed by identifying gravid segments on the host or in its environment. Cyclophyllidean oncospheres are fully developed when passed in the feces of the definitive host and are immediately infective for the intermediate host.

Family Taeniidae

Taenia
Adult tapeworms of the genus Taenia measure from tens to hundreds of centimeters in length, depending on the species in question and degree of maturity of the specimen.

Gravid taeniid segments are shed and exit from the carnivorous definitive host through the anus. The segments crawl about on the pelage of the host or surface of the fecal mass, emptying themselves of their eggs (oncospheres) in the process. Therefore any segment collected after it has been out for more than a few minutes may contain few if any eggs. If ingested by a suitable vertebrate intermediate host (usually a species normally taken as prey by the definitive host), the egg hatches and the hexacanth embryo enters the wall of the intestine and migrates to its organ of predilection, usually the liver and peritoneal membranes or the skeletal and cardiac muscles. Here the hexacanth embryo grows, cavitates, and differentiates to form the second-stage larva, which is infective to the definitive host. The fully developed second-stage larva of the family Taeniidae consists of a fluid-filled bladder with one or more scolexes (often called a bladderworm) and is surrounded by a connective tissue capsule formed by the vertebrate intermediate host.

When a second-stage larva is ingested by a suitable definitive host, the bladder is digested away, the scolex embeds itself in the mucosa of the small intestine, and the neck begins to bud off segments to form the strobila.

There are four basic kinds of taeniid second-stage larvae: the cysticercus, strobilocercus, coenurus, and hydatid. Members of the genus Taenia typically form cisticerci, strobilocerci, and coenuroi, depending on the species in question. A cysticercus consists of a single bladder with one scolex. A strobilocercus is a cysticercus that has already begun to elongate and segment while still in the intermediate host, and a coenurus consists of a single bladder with many scolexes, each with the potential of developing into a mature tapeworm. Hydatids are formed by members of the genus Echinococcus and are of two kinds, unilocular hydatid cysts and alveolar hydatids, both of which often contain thousands of scolexes.
Appendix P: Experiment 2: Intervention 4 (Full + partial concept maps)

*Taenia hydatigena*  III: cattle, sheep, swine  DH: dog
The cysticercus of the canine taeniid tapeworm *T. hydatigena* migrates through the liver tissue and encysts on the peritoneal membranes of cattle, sheep, swine, and certain wild ungulates. Massive invasions, such as when entire tapeworm segments are ingested, result in acute traumatic hepatitis, and even small numbers of migrating *T. hydatigena* larvae are capable of precipitating "black disease" in the presence of *C. novyi*. However, frank disease is rarely caused by this larval tapeworm, and the principal economic loss results from condemnation of infected livers by meat inspection authorities.

*Taenia ovis*  III: sheep  DH: dog
The cysticercus of a second canine taeniid tapeworm, *Taenia ovis*, infects the cardiac and skeletal muscles of sheep and represents the most important pathological lesion found by United States inspectors in imported Australian mutton.

*Taenia pisiformis*  III: rabbit  DH: dog
The cysticercus of a third canine taeniid tapeworm, *Taenia pisiformis*, is found in the liver and peritoneal cavity of rabbits. This tapeworm is the most common taeniid tapeworm of dogs in the United States. Every dog that is so infected must have eaten a rabbit or parts of a rabbit and this means that many rabbits are infected by grazing near where *Taenia pisiformis* segments have been shed.

*Taenia saginata*  III: cattle  DH: human
The cysticercus of the human tapeworm *T. saginata* encysts in the striated muscles of cattle, especially the heart and muscles of mastication. Taenid eggs survive the rigors of the septic tank, as well as many contemporary municipal sewage treatment processes, and because defecating out-of-doors is unavoidable when hunting or camping out (and because the segments can leave the host by crawling out through the anal opening), it is easy to see how cattle pastures become contaminated with *T. saginata* eggs. The cysticerci that develop when these eggs are ingested by cattle are relatively inconspicuous and easily overlooked by the lover of rare or raw beef. Consequently, *T. saginata* is a common parasite in the United States.

*Taenia solium*  III: swine, human  DH: human
The cysticercus of the human tapeworm *T. solium* represents a significant hazard to human health. People become infected with *T. solium* by ingesting the cysticerci in undercooked pork. After the tapeworm matures, the person's feces contain a steady supply of eggs, which may be conveyed to the mouth at any time by a lapse in personal hygiene. When the eggs reach the stomach, the oncospheres hatch out, enter the gut wall, and wander far and wide in the body, slowly developing into cysticerci. Apparently the milieu intérieur of humans resembles that of swine closely enough to satisfy the development requirements of the cysticercus. In humans, the signs depend on where the cysticerci localize, and sites may include the eye, brain, or spinal cord.

*Taenia taeniaeformis*  III: meadow vole  DH: cat
The larva of the cat tapeworm *T. taeniaeformis* is a strobilocercus. This larva is a very common parasite of meadow voles. Meadow voles are relished by cats, which serve as definitive hosts of *T. taeniaeformis*.

*Taenia multiceps*  III: sheep, goats, cattle  DH: dog
The coenurus of the canine taeniid tapeworm *T. multiceps* invade the cranial cavity of sheep, goats, and sometimes cattle. As the cyst grows over a period of 6 or 8 months, neurological signs of progressive space occupation slowly develop. There may be blindness, incoordination, walking in circles, and pressing the head against walls, tree trunks, and the like. Finally, the animal lies down and dies. The most common diseases that might be confused with cerebral coenuriasis are bacterial encephalitis (listeriosis) and paralaphostomonyelitis. Intracranial surgery is the only cure for cerebral coenuriasis. As in the case of *T. hydatigena* and *T. ovis*, control can be based only on excluding dogs and other canids from sheep pastures.
Appendix P: Experiment 2: Intervention 4 (Full + partial concept maps)

Echinococcus granulosus, E. multilocularis  
IH: sheep, human  
DH: dog

The genus Echinococcus contains two species of special importance to veterinary medicine, Echinococcus granulosus and Echinococcus multilocularis, which are very small (2 to 8mm long) adult tapeworms having only four or five segments.

E. granulosus is a parasite of the dog, coyote, wolf, and dingo. Its larva is a hydatid cyst in sheep, swine, cattle, humans, moose, caribou, kangaroos, and others. The hydatid membrane may bud off daughter cysts either internally or externally. The whole structure occupies progressively more space as it grows, but hydatid cysts do not infiltrate, in contrast to alveolar hydatids. Pathogenic effects of hydatid cysts include pressure atrophy of surrounding organs and allergic reactions to hydatid fluid leaks. Rupture of a fertile hydatid cyst may scatter bits of germinative membrane, scolices, and brood capsules throughout the pleural or peritoneal cavity and result in multiple hydatidosis.

HYDATID DISEASE

The unicocular hydatid cyst is the second-stage larva of E. granulosus and is infective to dogs and other canids that serve as definitive hosts. Starting as an oncosphere less than 30 um in diameter, the larva grows very slowly and infrequently exceeds more than a few centimeters in diameter in slaughtered sheep and cattle. Because humans live longer, a fertile hydatid infecting man may grow very large and interfere with the function of neighboring organs by pressing against them. The hydatid membrane is surrounded by an inflammatory connective tissue capsule. Brood capsules, each containing many scolices, develop from the germinial epithelium lining the laminated hydatid membrane. Some of these rupture, releasing scolices to form a sediment of so-called hydatid sand in the hydatid fluid.

Alveolar hydatid cysts are second-stage larvae of E. multilocularis and are infective to dogs, foxes, and cats, which serve as definitive hosts. Alveolar hydatids develop in voles, lemmings, cattle, horses, swine, and humans. They are characterized by exogenous budding that does not remain contained within the reactive connective tissue capsule but continuously proliferates and infiltrates surrounding tissue like a malignant neoplasm. Alveolar hydatid infection proves invariably fatal in a few years.

Both E. granulosus and E. multilocularis tend to establish sylvatic cycles when suitable predator-prey relationships exist in the wildlife population of a region. Therefore E. granulosus cycles are maintained among wild ruminants and wolves in the Canadian north woods and among wallabies and dingoes in Australia. Natural nidi of E. multilocularis are maintained in various rodents and foxes. The sylvatic cycle reaches humans through their domesticated animals. Dogs that scavenge the entrails of wild game infected with Echinococcus spp. become direct sources of hydatid infection to humans and their domestic animals. Contamination of pastures with the feces of infected wild carnivores also results in hydatid infection of domestic ruminants and swine. The establishment of a pastoral cycle may then result from the feeding of uncooked offal from these domestic animals to dogs and, in the case of E. multilocularis, to cats. The direct source of human infection is, in most instances, the domestic dog or cat, and scrupulous hygiene is the first line of defense.

Other Cyclophyllidean Tapeworms

The second-stage larvae of all of the following cyclophyllidean families are cysticercoids of one kind or another. A cysticercoid may be thought of as a cysticercus small enough to fit into the body of an arthropod.
Family Anoplocephalidae

The tapeworms of cattle, sheep, and goats all belong to the family Anoplocephalidae. The life histories involve an arthropod intermediate host in which the infective cysticercoid develops. Infection results from the incidental ingestion of these infected arthropods by the grazing animal. Adult tapeworms are relatively nonpathogenic.

Moniezia
Moniezia spp. are found in the small intestine of cattle, sheep, and goats (Moniezia benedeni, Moniezia expansa, and Moniezia caprae). The egg of Moniezia sp. found in cattle feces is one of the few eggs that appears square. Free-living oribatid mites serve as hosts for cysticercoids of Moniezia spp. of sheep and cattle.

Thysanosoma actinioides
Thysanosoma actinioides, the "fringed tapeworm," is found in the common bile duct and duodenum of virtually all ruminant species except cattle. Thysanosoma actinioides is apparently transmitted by "booklice" or "barklice" of the family Psocidae, order Pscoptera. Pscopterans resemble mallophagan lice but are entirely free living and have no other known relationship to parasitic life histories.

Anoplocephala
Anoplocephala magna is a relatively harmless parasite in the small intestine of horses. Anoplocephala perfoliata is found mainly in the cecum but also tends to cluster in the ileum near the ileocecal valve. This clustering results in ulceration of the mucous membrane and inflammation with thickening and induration of the deeper layers of the intestinal wall. These pathological changes probably account for some cases of persistent diarrhea and may predispose to intussusception of the ileum into the cecum or rupture of the bowel wall in the vicinity of the ileocecal valve.

Family Dipyldiidae

Dipylidium caninum
Dipylidium caninum segments are shaped like cucumber seeds and have bilateral genital pores. Each egg capsule may contain from 5 to 30 eggs.

Gravid segments discharge their egg packets as they move about. Larvae of Ctenocephalides chew their way into egg packets and ingest the oncospheres of the tapeworm. The hexacanth embryo enters the body cavity of the flea larva and remains there through its metamorphosis. After the adult flea emerges from the cocoon, the hexacanth develops into a cysticercoid in 2 or 3 days. If such a flea is ingested by the definitive host as during self-grooming, the cysticercoids develop into adult tapeworms in the small intestine.

Cysticercoids of D. caninum develop in fleas (Ctenocephalides spp.) and biting lice (Trichodectes canis), and the dog acquires this tapeworm while nipping its insects. Children also may become infected in this way. D. caninum requires only 2 to 3 weeks to develop from a cysticercoid into a segment-shedding
tapeworm. Thus the benefits of anthelmintic therapy are particularly short-lived unless fleas and biting lice also are brought under control.

**Family Hymenolepididae**

*Hymenolepis diminuta* is a parasite of the small intestine principally of rodents but occasionally also of dogs and even humans. The cysticercoid of *H. diminuta* develops in fleas, flour beetles, and a rather wide range of other insects.

**Vampirolepis nana**

*Vampirolepis nana* is also a parasite of rodents and humans, and its second-stage larva is a cysticercoid in fleas and flour beetles or in the intestinal mucosa of its definitive host. *V. nana* can complete its life history within the intestinal tract of a mouse or a human. Some of the eggs hatch within the intestine, and the hexacanth embryos burrow into the mucous membrane to form cysticercoids that later reenter the lumen to complete their development as mature tapeworms. The rest of the eggs pass out with the fleas to await ingestion by flour beetles or fleas, in which the cysticercoids develop. Thus *H. diminuta* requires fleas, flour beetles, or other insects as intermediate hosts, whereas *V. nana* may or may not.

**Family Mesocestoididae**

*Mesocestoides*

*Mesocestoides* infection of dogs and cats results from predation on snakes, birds, and small mammals. *M. corti* tapeworms multiply asexually in the intestines of dogs. If this species is not totally eliminated by anthelmintic medication, it will repopulate the intestine even without further exposure.
### Summary of Class Cestoda

<table>
<thead>
<tr>
<th>Order Pseudophyllidea</th>
<th>Intermediate Host</th>
<th>Definitive Host</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Diphyllobothrium latum</em></td>
<td>1*: copepod</td>
<td>dog, human, etc</td>
</tr>
<tr>
<td><em>Spirometro mansonoides</em></td>
<td>2*: fish</td>
<td>cat</td>
</tr>
<tr>
<td>2*: any vertebrate except fish</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Order Cyclophyllidea**

- Terrestrial food chain
- No uterine pore
- Egg not operculated
- Requires intermediate host

<table>
<thead>
<tr>
<th>Family Taeniidae</th>
<th>Requires mammal intermediate host</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Taenia hydatigera</em></td>
<td>cattle, sheep, swine</td>
</tr>
<tr>
<td><em>Taenia ovis</em></td>
<td>sheep</td>
</tr>
<tr>
<td><em>Taenia pisiformis</em></td>
<td>rabbit</td>
</tr>
<tr>
<td><em>Taenia saginata</em></td>
<td>cattle</td>
</tr>
<tr>
<td><em>Taenia solium</em></td>
<td>swine, human</td>
</tr>
<tr>
<td><em>Taenia taeniaeformis</em></td>
<td>meadow vole</td>
</tr>
<tr>
<td><em>Taenia multiceps</em></td>
<td>sheep, goats, cattle</td>
</tr>
<tr>
<td><em>Echinococcus granulosus</em></td>
<td>sheep, human</td>
</tr>
<tr>
<td><em>Echinococcus multilocularis</em></td>
<td>sheep, human</td>
</tr>
</tbody>
</table>

**Family Anoplocephalidae**

- Requires arthropod intermediate host

| Moniezia | mites |
| Thysanosoma actiniaeides | booklice |
| Anoplocephala | mites |

**Family Dipyldiidae**

- Requires arthropod intermediate host

<table>
<thead>
<tr>
<th>Dipyldium caninum</th>
<th>fleas</th>
</tr>
</thead>
</table>

**Family Hymenolepididae**

- Requires arthropod intermediate host

| Hymenolepis diminuta | fleas, beetles |
| Vampirolepis nana | fleas, beetles (optional) |

**Family Mesostoididae**

- Requires arthropod intermediate host

| Mesocestoides | arthropod and vertebrates |

**Definitive Host**

- dog, human
## Appendix Q: Experiment 2: Pretest

### PRE-TEST

1. For each family listed below, indicate whether it belongs to the order Cyclophyllidea or to the order Pseudophyllidea by checking the appropriate box. Each row should have only one box checked.
   - a. Anoplocephalidae
   - b. Diphyllobothriidae
   - c. Dipylididae
   - d. Hymenolepididae
   - e. Taeniidae
   - [ ] Cyclophyllidea
   - [ ] Pseudophyllidea

2. For each genus listed below, indicate the family that it belongs to by checking the appropriate box. Each row should only have one box checked.
   - a. Spirometa
   - b. Echinococcus
   - c. Moniezia
   - d. Thysanophora
   - e. Vampirolepis
   - [ ] Anoplocephalidae
   - [ ] Diphyllobothriidae
   - [ ] Dipylididae
   - [ ] Hymenolepididae
   - [ ] Taeniidae

3. For each characteristic listed below, check the box(es) for the taxonomic family(ies) that have that characteristic. Each row may have one or more boxes checked.
   - a. Aquatic food chain
   - b. Terrestrial food chain
   - c. Copepod intermediate host
   - d. Arthropod intermediate host (other than copepods)
   - e. Mammal intermediate host
   - f. Definitive host eats meat or fish
   - g. Has operculated egg
   - h. One or more species can be found as adult worm in humans
   - i. One or more species can be found as larval form in humans
   - [ ] Anoplocephalidae
   - [ ] Diphyllobothriidae
   - [ ] Dipylididae
   - [ ] Hymenolepididae
   - [ ] Taeniidae
**PRE-TEST**

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

4. Your client brought in one of his dogs, a 3-year-old intact male coon hound, because he saw a white ribbon-like object several inches long in the dog’s stool that morning. History reveals that the client - an avid outdoorsman - took the dog on a fishing and hunting trip to southeast Alaska 4 months ago. The dog’s diet consists of commercial dog food occasionally supplemented with raw meat and fish scraps. Physical examination is unremarkable. A CBC and chemistry profile are within normal limits. A fecal examination reveals a few oval, operculated eggs. Assume that the dog is infected with a single species of parasite.

___ 1. What is the most likely parasite?
   
   A. *Diphyllobothrium*
   
   B. *Dipylidium*
   
   C. *Echinococcus*
   
   D. *Moniezia*
   
   E. *Taenia*

___ 2. The type of eggs observed in the fecal examination is also characteristic of what other parasite?
   
   A. Whipworms
   
   B. Flukes
   
   C. Hookworms
   
   D. Ascarids
   
   E. Kidney worms

___ 3. How did the dog become infected?
   
   A. Eating raw fish
   
   B. Eating raw meat
   
   C. Eating fleas
   
   D. Eating food contaminated with animal feces
   
   E. None of the above

___ 4. Which of the following is a characteristic of the taxonomic family to which this parasite belongs?
   
   A. Life cycle requires a predator-prey relationship
   
   B. Life cycle requires a mammal intermediate host
   
   C. Life cycle requires a snail intermediate host
   
   D. Transmission to intermediate host occurs in a terrestrial environment
   
   E. None of the above

___ 5. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?
   
   A. It would be eaten by an copepod
   
   B. It would be eaten by a fish
   
   C. It would be eaten by a mammal
   
   D. It would hatch to release a worm-like stage into the environment
   
   E. It would hatch to release a ciliated stage into the environment

___ 6. What is an intermediate host for this parasite?
   
   A. Fish
   
   B. Mite
   
   C. Flea
   
   D. Mammal
   
   E. Snail
PRE-TEST

5. You are an avid mountain climber and are on an expedition to climb Mount Everest. You are now at advance base camp at approximately 23,000 feet above sea level. During your stay in advance base camp, you notice several yaks (Bos grunniens) wandering freely around the camp. You learn that the yaks are "meat on the hoof" – the camp kitchen prepares meals using meat from yaks and that a yak is slaughtered just before the meat is needed for cooking. You are in the camp kitchen watching the cook butcher a side of yak beef when you suddenly notice small white parasite larvae in a cyst in the meat. Assume that the larvae are tapeworm larvae.

___ 1. What is the most likely parasite?
   A  Diphyllolothrium
   B  Echinococcus
   C  Malaria
   D  Taenia
   E  Thysanosoma

___ 2. Where would you expect to find the adult form of this tapeworm?
   A  Yak intestine
   B  Pig intestine
   C  Dog intestine
   D  Human intestine
   E  None of the above

___ 3. How did the yak become infected?
   A  Eating food contaminated with booklice
   B  Eating food contaminated with copepods
   C  Eating food contaminated with mites
   D  Eating food contaminated with yak feces
   E  Eating food contaminated with human feces

___ 4. Which of the following is a characteristic of the taxonomic family to which this parasite belongs?
   A  Life cycle requires a predator-prey relationship
   B  Life cycle requires an arthropod intermediate host
   C  Life cycle requires a snail intermediate host
   D  Transmission to intermediate host occurs in an aquatic environment
   E  None of the above

___ 5. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?
   A  It would be eaten by a copepod
   B  It would be eaten by a mite
   C  It would be eaten by a mammal
   D  It would be eaten by an arthropod (other than a copepod)
   E  None of the above

___ 6. What is the intermediate host for this parasite?
   A  Booklice
   B  Flea
   C  Mite
   D  Human
   E  Yak
6. You are visiting a small farm that specializes in production of organic milk products. The dairymen mentions that while being milked that morning, one of his Jerseys passed a large ribbonlike object in her manure. He saved the object to show it to you since he knew you were coming out that afternoon. You examine the object and determine that it is a length of tapeworm.

___ 1. To what taxonomic family does the parasite belong?
   A  Anoplocephalidae
   B  Diphyllobothriidae
   C  Dipylididae
   D  Hymenolepidae
   E  Taeniidae

___ 2. How did the cow become infected?
   A  Ingesting booklice while grazing
   B  Ingesting copepods while grazing
   C  Ingesting mites while grazing
   D  Ingesting cow feces while grazing
   E  Ingesting human feces while grazing

___ 3. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?
   A  It would be eaten by an copepod
   B  It would be eaten by a fish
   C  It would be eaten by a mammal
   D  It would be eaten by an arthropod (other than a copepod)
   E  It would hatch to release a ciliated stage into the environment
## Appendix R: Experiment 2: Post-Test

### POST-TEST

1. For each family listed below, indicate whether it belongs to the order Cyclophyllidea or to the order Pseudophyllidea by checking the appropriate box. Each row should have only one box checked.

<table>
<thead>
<tr>
<th>Family</th>
<th>Cyclophyllidea</th>
<th>Pseudophyllidea</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Anoplocephalidae</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>b. Diphyllobothriidae</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>c. Dipylidiidae</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>d. Hymenolepididae</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>e. Teenilidae</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

2. For each genus listed below, indicate the family that it belongs to by checking the appropriate box. Each row should only have one box checked.

<table>
<thead>
<tr>
<th>Genus</th>
<th>Anoplocephalidae</th>
<th>Diphyllobothriidae</th>
<th>Dipylidiidae</th>
<th>Hymenolepididae</th>
<th>Teenilidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Spiromesra</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>b. Echinococcus</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>c. Moniliza</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>d. Thysanosoma</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>e. Vampirolois</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

3. For each characteristic listed below, check the box(es) for the taxonomic family(ies) that have that characteristic. Each row may have one or more boxes checked.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Anoplocephalidae</th>
<th>Diphyllobothriidae</th>
<th>Dipylidiidae</th>
<th>Hymenolepididae</th>
<th>Teenilidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Aquatic food chain</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>b. Terrestrial food chain</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>c. Copepod intermediate host</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>d. Arthropod intermediate host (other than copepods)</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>e. Mammal Intermediate host</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>f. Definitive host eats meat or fish</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>g. Has operculated egg</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>h. One or more species can be found as adult worm in humans</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>i. One or more species can be found as larval form in humans</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
POST-TEST

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

4. Your client brought in her cat, a 5-year-old spayed female domestic longhair, because the cat has not been "quite right" lately. The client lives in the Pearlland area, and the cat is an indoor-outdoor cat. The client proudly describes the cat as a "good hunter", regularly catching small animals and birds. A fecal examination reveals a few oval, operculated eggs. Assume that the cat is infected with a single species of parasite.

1. What is the most likely parasite?
   - A. *D. Dasyurum*
   - B. *Echinococcus*
   - C. *Moniezia*
   - D. *Toxoplasma*
   - E. *Spirocerca*

2. The type of eggs observed in the fecal examination is also characteristic of what other parasite?
   - A. Whipworms
   - B. Flukes
   - C. Hookworms
   - D. Ascarids
   - E. Kidney worms

3. How did the cat become infected?
   - A. Eating raw fish
   - B. Eating raw meat
   - C. Eating fleas
   - D. Eating food contaminated with animal feces
   - E. None of the above

4. Which of the following is a characteristic of the taxonomic family to which this parasite belongs?
   - A. Life cycle requires a predator-prey relationship
   - B. Life cycle requires a mammal intermediate host
   - C. Life cycle requires a snail intermediate host
   - D. Transmission to intermediate host occurs in a terrestrial environment
   - E. None of the above

5. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?
   - A. It would be eaten by an copepod
   - B. It would be eaten by a fish
   - C. It would be eaten by a mammal
   - D. It would hatch to release a ciliated stage into the environment
   - E. None of the above

6. What is an intermediate host for this parasite?
   - A. Fish
   - B. Frog
   - C. Flea
   - D. Arthropod (other than copepods)
   - E. Snail
Appendix R: Experiment 2: Post-Test

POST-TEST

5. You are a veterinarian working in a public health department. A physician has contacted you and asked for help investigating a case in which a 47-year-old man has multiple cysticerci in his brain (see image). The physician cannot explain how the man developed the cysticerci, as the patient's family says he is a strict vegetarian.

1. What is the most likely parasite?
   - A. *Diphyllobothrium*
   - B. *Echinococcus granulosus*
   - C. *Echinococcus multilocularis*
   - D. *Taenia saginata*
   - E. *Taenia solium*

2. Where would you expect to find the adult form of this tapeworm?
   - A. Pig intestine
   - B. Cow intestine
   - C. Dog intestine
   - D. Human intestine
   - E. None of the above

3. How did the person become infected?
   - A. Eating undercooked pork
   - B. Eating food contaminated with pig feces
   - C. Eating undercooked beef
   - D. Eating food contaminated with cow feces
   - E. Eating food contaminated with human feces

4. Which of the following is a characteristic of the taxonomic family to which this parasite belongs?
   - A. Life cycle requires a predator-prey relationship
   - B. Life cycle requires an arthropod intermediate host
   - C. Life cycle requires a snail intermediate host
   - D. Transmission to intermediate host occurs in an aquatic environment
   - E. None of the above

5. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?
   - A. It would be eaten by a copepod
   - B. It would be eaten by a mite
   - C. It would be eaten by a mammal
   - D. It would be eaten by an arthropod (other than a copepod)
   - E. None of the above

6. In this specific case, what is the intermediate host for this parasite?
   - A. Booklice
   - B. Flea
   - C. Mite
   - D. Human
   - E. Pig
6. You are discussing a health maintenance program for a herd of goats when the client mentions that he has occasionally observed tapeworms. In fact, he found one just this morning and he saved it to show to you. You examine it and confirm that it is a length of tapeworm.

   - 1. To what taxonomic family does the parasite belong?
     A. Anoplocephalidae
     B. Diphyllobothriidae
     C. Dipyldidae
     D. Hymenolepididae
     E. Taeniidae

   - 2. How did the goats become infected?
     A. Ingesting booklice while grazing
     B. Ingesting copepods while grazing
     C. Ingesting mites while grazing
     D. Ingesting cow feces while grazing
     E. Ingesting human feces while grazing

   - 3. Under ideal conditions for the life cycle of this parasite, what would happen to the egg?
     A. It would be eaten by a copepod
     B. It would be eaten by a fish
     C. It would be eaten by a mammal
     D. It would be eaten by an anthropod (other than a copepod)
     E. It would hatch to release a ciliated stage into the environment

7. Was this test more or less difficult compared to the one you took before reading the handout? Please check the corresponding circle below.

   - Much less difficult
   - Less difficult
   - About the same
   - More difficult
   - Much more difficult

8. On a scale of 1-9, with 1 corresponding to very, very low mental effort and 9 corresponding to very, very high mental effort, how much mental effort did it take you to study the material to answer these questions? Please circle your answer below.

   - Very, very low mental effort
   - Very, very high mental effort

   - 1  2  3  4  5  6  7  8  9