The Role of Basic Sciences in Diagnostic Oral Radiology


Abstract: Although it is generally taken for granted that dental education must include both basic science and feature-based knowledge components, little is known about their relative roles in visual interpretation of radiographs. The objectives of this study were twofold. First, we sought to compare the educational efficacy of three learning strategies in diagnostic radiology: one that used basic scientific (pathophysiologic) information, one that used feature lists structured with an organizational tool, and one that used unstructured feature lists. Our second objective was to determine whether basic scientific information provides conceptual coherence or is merely a simple means for organizing feature-based knowledge. Predoctoral dental and undergraduate dental hygiene students (n=96) were randomly assigned into three groups (basic science, structured algorithm, and feature list) and were taught four confusable intrabony entities. The students completed diagnostic and memory tests immediately after learning and one week later, and these data were subjected to a 3x2 repeated measures ANOVA. For the diagnostic test, students in the basic science group outperformed those assigned to the feature list and structured algorithm groups on immediate and delayed testing (p<0.05). A main effect of learning condition was found to be significant. On the memory test, performance was similar across all three groups, and no significant effects were found. The results of this study support the critical role of basic scientific knowledge in diagnostic radiology. This study also refutes the organized learning theory and provides support for the conceptual coherence theory as a possible explanation for the process by which basic science aids in diagnosis.

Keywords: dental education, oral radiology, basic science, diagnostic reasoning, clinical reasoning

Submitted for publication 3/30/09; accepted 7/1/09

A n introductory oral radiology course at the predoctoral level typically emphasizes the teaching of the radiographic features of a vast number of diseases without referring to the basic mechanistic underpinnings inherent to the disease process. It is assumed that students have acquired basic biomedical knowledge at an earlier stage in their training and are able to incorporate this information into their current diagnostic clinical training. The term “basic science” in this study is used to represent the pathophysiological basis of abnormalities at the cellular and biochemical levels. It also represents the knowledge of normal anatomy and physiology of the body.

This separation of biomedical knowledge from clinical studies in the dental curriculum was introduced by Dr. William Gies in 1926 through his advocacy of a three-to-four-year course of study that incorporated both biological and clinical sciences. The result was the establishment of a dental degree with sound foundations in the basic and clinical sciences.1,2

Supporters of basic science integration into the dental curriculum argue that this knowledge provides an important foundation for diagnostic reasoning. In oral radiology, for example, it has been suggested that most radiographic features can be explained by understanding the mechanism(s) underlying a disease process and that this approach can benefit students who are learning visual diagnosis. In his textbook Principles and Practice of Oral Radiologic Interpretation, renowned oral and maxillofacial radiologist Dr. H.M. Worth argues precisely this view, stating that “It must be emphasized that it is only with acquisition of a firm knowledge of basic principles, simple as many of these are, that a foundation is prepared on which to build the capacity to interpret radiographs.”3

Despite such statements and the widely accepted belief in the value of the basic scientific com-
ponent of dental education, the specific role of basic science in diagnostic radiology is still unclear. The presentation of the basic sciences in the preclinical curriculum emphasizes the acquisition of biomedical knowledge but does little to highlight its utility in clinical settings.\(^6\)\(^,\)\(^7\) Quite the opposite, the separation of teaching basic medical sciences from diagnostic radiology seems to suggest that biomedical knowledge is not necessary for the successful interpretation of radiographs. Therefore, the importance and precise role of basic science in the education of future dentists are topics of much contention.

The broader health professions education literature contains several studies devoted to systematically identifying the role of biomedical knowledge in predoctoral clinical training. Notably, a 1988 study by Patel et al.\(^6\)\(^,\)\(^7\) compared the performance of students at various levels of training. These students were asked to provide a diagnostic explanation of a clinical case after having read three related basic science texts. The students made very little use of basic science information in their explanations; indeed, when basic science was used, it was used incorrectly and consequently hindered diagnostic reasoning. In contrast, other studies in the education literature have suggested a facilitative role for basic science training in diagnosis. A 2005 study by Woods et al.\(^8\) compared two different approaches to learning clinical diagnosis. Undergraduate psychology students were taught neurological disorders using either basic pathophysiologic explanations or conditional probabilities. Tests of diagnostic ability were administered immediately after a learning session and again one week later. While both groups performed equally well on the initial test, the performance of the probability group decreased after a one-week delay. The authors concluded that the basic science information helped students better recall the diseases and their features.

A similar study by Woods et al.\(^9\) used a larger sample of predoctoral medical students who learned four neurologic and rheumatologic disorders. Again, one group was provided with basic pathophysiologic information, and the second was given only epidemiologic information on the diseases. When the researchers compared the results of the delayed test in this study, they found that the students in the basic science group showed superior performance. Again, it was concluded that basic science knowledge improved diagnostic accuracy after a time delay.

Although the Woods et al. studies demonstrated the value of basic science knowledge for novices, the precise cognitive mechanism underlying the use of causal knowledge has not been addressed. Shedding light on the specific role of basic science knowledge in these studies could prove useful in guiding instructional development in the dental curriculum. We propose two possible explanatory theories for the results of the Woods et al. studies. First, basic science may be used as a framework for organizing information. Work in cognitive psychology has shown that memory retrieval or recall is easiest when the material to be learned is well organized.\(^10\) Information that is naturally well organized will automatically be easier to remember. If organization cannot be found naturally, then often an “external” organizational strategy may be applied with the same memory benefit. Such external organizational strategies may include everyday mnemonic devices such as acronyms or algorithms.\(^10\) It is possible that the basic science knowledge in the Woods et al. studies served as an elaborate mnemonic device for the participants.

An alternate explanation is that basic science knowledge provides more than just organization and subsequent memorization. Understanding the basic mechanisms of disease may also create a coherent mental representation of diseases and their features. That is, students who have an understanding of the basic scientific mechanisms underlying a disease may be capable of describing the features of a disease, but more importantly, they may understand why those features occur and occur together. This deeper understanding enhances diagnostic accuracy independent of memory.\(^8\) Some evidence for this comes from experimental psychology. In 2001, Rehder and Hastie\(^11\) examined the role of underlying theoretical knowledge in categorization. They observed that knowledge of causal relationships was used to identify features, guide in similarity judgments, and introduce new items to the different categories. They argued that the role of causal theories is to provide explanations and create connections between features. By providing these links, the causal theories gave structure to the mental representation of a category by transforming lists of random features into a network of meaningful items for that category. Thus, unlike a mnemonic device, the primary goal of theoretical knowledge has been found not to aid recall, but to provide coherent mental representation of the different categories.

There is no literature in medical education to address these specific explanations. Moreover, there have been no empirical efforts to study these phenomena in dental education specifically. The current study attempted to examine the underlying cognitive role of
basic science in oral radiology. Specifically, our goals were to, first, examine the value of basic pathophysiologic information (basic sciences) in oral radiologic diagnosis by predoctoral dental and undergraduate dental hygiene students; and, second, to compare the educational efficacy of three learning strategies in diagnostic radiology: one that used basic scientific (pathophysiologic) information, one that used feature lists structured using an organizational tool, and one that used unstructured feature lists. Finally, we will delineate the specific role of basic science in visual diagnosis by comparing deep understanding and conceptual coherence to organized learning.

Materials and Methods

Human research ethics approval was obtained from the University of Toronto. Thirty-four second-year students enrolled in the undergraduate dentistry program at the University of Toronto and sixty-two second-year dental hygiene students from George Brown College were recruited for participation in the study. This population was chosen specifically to ensure that the participants would be able to understand basic terminology and identify normal radiographic anatomy, but have minimal prior exposure to the specific diseases selected for the study groups or radiographic interpretation.

Learning Materials

The learning materials consisted of sets of images accompanied by audio recordings that narrated the written material on each slide. The participants learned about the radiographic features of four potentially confusable diseases: periapical cemento-osseous dysplasia, complex odontoma, periapical sclerosing osteitis, and dense bone island (Figure 1).

The radiographic descriptions and the basic science explanations for all the intrabony abnormalities were obtained from the textbook *Oral Radiology: Principles and Interpretation* by White and Pharoah. The participants were randomly divided into three learning groups. In the basic science group (BaS), the training material presented the radiographic features of each disease and the underlying pathophysiology by providing causal explanations for the radiographic features. In the structured algorithm group (AL), the training included the same radiographic features but without the basic disease mechanism information. Instead, the students learned a general algorithm to analyze intraosseous lesions and then applied it to the given disease. In the feature list group (FL), the training material included only the radiographic features of the diseases. The students were not provided with a structured algorithm or any causal explanations for the features (Table 1).

Testing Materials

The participants completed three tests:
1. **Comprehension test:** This test was used to ensure the participants learned and understood the material at hand. These results were not, however, included in the final analysis. Each participant answered ten true/false questions. For the participants in the basic science group, the
Table 1. Example of the radiographic features of a complex odontoma explained in the three learning conditions

<table>
<thead>
<tr>
<th>Feature group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic science group (BaS)</td>
<td>Odontomas are benign tumors that originate from remnants of the dental lamina in the jaws. The histological appearance is characterized by the production of mature enamel, dentin, cementum, and pulp tissue. In complex odontomas, the tumor forms nondescript masses of dental tissue. This is manifested radiographically as an irregular radiopaque mass. The degree of radiopacity is equivalent to adjacent tooth structure. Radiographically, odontomas are well defined with a corticated border, which represents reactive bone. Corticated borders are typically seen in slow-growing lesions (cysts and benign slow-growing tumors). Immediately inside and adjacent to the cortical border, there is a smooth uniform radiolucent space, which represents the soft tissue fibrous capsule surrounding the tumor. Odontomas develop and mature while the related teeth are forming and cease development when the associated tooth complete development. Because of the slow and space-occupying nature of the growth of this tumor, frequently it displaces nearby teeth and obstructs the normal eruption of adjacent teeth.</td>
</tr>
<tr>
<td>Structured algorithm group (AL)</td>
<td>Complex odontomas are the most common odontogenic tumors in the jaws. Location: Seventy percent of complex odontomas occur in the mandibular first and second molar region. Periphery: Odontomas are well defined and have a corticated border. Immediately inside and adjacent to the cortical border is a soft tissue capsule appearing as a smooth radiolucent space. Internal structure: Complex odontomas contain an irregular mass of calcified tissue. The degree of radiopacity is equivalent to adjacent tooth structure. Effect on surrounding structures: Odontomas interfere with normal eruption of teeth. Seventy percent of odontomas are associated with abnormalities such as impaction, malpositioning of adjacent teeth, diastema, and devitalization of adjacent teeth.</td>
</tr>
<tr>
<td>Feature list group (FL)</td>
<td>Odontomas are the most common odontogenic tumors in the jaws. They often interfere with the eruption of permanent teeth. The lesion has no gender predilection, and most begin forming while the normal dentition is developing. Most odontomas occur in the second decade of life and are found during investigation of delayed eruption of adjacent teeth. Seventy percent of complex odontomas occur in the first and second mandibular molar area. Radiographically, they appear as well-defined corticated lesions with a fibrous capsule internally. The contents of these lesions are mixed radiolucent and radiopaque but are largely radiopaque. Complex odontomas contain an irregular mass of calcified tissue. The degree of radiopacity is equivalent to adjacent tooth structure. Odontomas interfere with normal eruption of teeth. Seventy percent of odontomas are associated with abnormalities such as impaction, malpositioning of adjacent teeth, diastema, and devitalization of adjacent teeth.</td>
</tr>
</tbody>
</table>

Case Selection, Procedures, and Analyses

Clinical cases were selected from the patient database and teaching archives of the discipline of oral and maxillofacial radiology at the University of Toronto. An agreement test was performed by four oral and maxillofacial radiologists other than the primary investigator. Only cases that had full agreement on the diagnosis (100 percent) between the radiologists were considered for the learning and testing material. A total of sixty-six cases met this criterion. The selected sixty-six cases were then scanned onto a computer and optimized using Adobe Photoshop (Adobe Systems Incorporated, San Jose, CA) to remove any artifact, noise, dust particles, and pixilation. Ten cases were used for the learning phase, and fifty-six cases were used for the testing phase. The fifty-six radiographic cases for the testing phase were equally divided between test A and test B.

A computer program was created using the Revolution software, version 2.1 (Runtime Revolution Ltd., Edinburgh, Scotland), which incorporated...
the learning material and radiographs along with an audio recording. A student was not allowed to proceed to the next slide until the accompanying audio recording was complete. This prevented them from skimming through the slides without reading the material. After the learning phase was completed, the program automatically took the student to the testing phase.

In the testing phase, test items were randomized for each participant in the comprehensive, diagnostic, and memory tests. For the diagnostic test two versions (A and B) were created. After one week, the participants completed the diagnostic test again, as well as the cued recall test. Those who had taken diagnostic test A the previous week were given test B, and vice versa.

The data collected were the scores for the diagnostic test and the cued recall test. For each student, the percentage of correct responses was calculated for the immediate and delayed tests. To compare the performance of the dental students and the dental hygiene students, a $3 \times 2 \times 2$ repeated measures ANOVA was utilized, using the educational background of the participants (dental vs. dental hygiene students) and learning condition as between-subject variables and using time (immediate vs. delayed) as a within-subject variable. The diagnostic and cued recall tests for all the participants were analyzed separately using a $3 \times 2$ repeated measures ANOVA, with the learning group (basic science, structured algorithm, and feature list) as a between-subject variable and time (immediate vs. delayed) as a within-subject variable. A series of planned comparison $t$-tests were also performed.

### Results

A comparison between the performance of the dental and dental hygiene students on the diagnostic revealed no main effect of educational background, $F(1, 89)=1.084$, $p=0.30$, nor interaction between educational background and learning condition, $F(2, 89)=0.723$, $p=0.48$. Since our interest was in the difference in performance between the learning conditions and students from both institutions were distributed evenly across learning groups, we collapsed across education level for the remainder of the analyses.

On the immediate diagnostic test, participants in the basic science group (BaS) outperformed those assigned to the feature list (FL) and structured algorithm (AL) groups. Participants in the structured algorithm group showed the poorest performance. The basic science group obtained a mean score of 0.67, the feature list group a mean score of 0.64, and the structured algorithm group a mean score of 0.61. On the delayed test, one week later, a reduction in performance was noted in all three groups. The basic science group had a mean score of 0.61, the feature list group a mean score of 0.51, and the structured algorithm group a mean score of 0.48. The ANOVA showed a main effect of time, $F(1, 94)=37.89$, $p<0.05$. The main effect of group was also found to be significant, $F(2, 94)=4.49$, $p<0.05$. No significant interaction between time and group was observed, $F(2, 94)=1.65$, $p=0.19$. The main effect of group observed in the ANOVA appeared to be driven by the difference between the performance on the basic science group and the structured algorithm group on the immediate and delayed diagnostic tests. These results are presented in Figure 2.

A series of planned comparison $t$-tests were performed on the results of the diagnostic test to examine the effect of time. These tests showed that the basic science group outperformed the structured algorithm group ($t[64]=3.37, p<0.05$) and the feature list group ($t[59]=2.42, p<0.05$) on the delayed diagnostic tests.

On the immediate cued recall test, the basic science group scored higher than the feature list and structured algorithm groups. The basic science group obtained a mean score of 0.71, the feature list group a mean score of 0.66, and the structured algorithm group a mean score of 0.67. On the delayed test one week later, a reduction in performance was apparent in both the basic science and feature list groups. The structured algorithm group maintained the same mean score after the one-week delay. The basic science group obtained a mean score of 0.66, the feature list group a mean score of 0.63, and the structured algorithm group a mean score of 0.67. The ANOVA revealed a significant main effect of time, $F(1, 92)=5.08$, $p<0.05$. Unlike the diagnostic test, the ANOVA showed no main effect of group, $F(2, 92)=1.93$, $p=0.15$, and no significant interaction between group and time was observed, $F(2, 92)=1.59$, $p=0.21$. These results are presented in Figure 3.

### Discussion

The basic science group outperformed the feature list group and the structured algorithm group on
Figure 2. Score percentages of the diagnostic test immediately after the learning phase and one week later for the structured algorithm (AL), feature list (FL), and basic science (BaS) groups.

Note: A main effect of time and learning group was found to be statistically significant (p<0.05). No significant interaction between learning groups and time was found.

Figure 3. Score percentages on the cued recall test immediately after the learning phase and one week later for the structured algorithm (AL), feature list (FL), and basic science (BaS) groups.

Note: A main effect of time was found (p<0.05), but no main effect of learning group.
the diagnostic tests. After a delay, the smallest decline in performance was seen in the basic science group. If the role of basic sciences were merely organization, performance of the participants who were provided with an organizational tool (a structured algorithm) should have shown superior performance to the feature list group and be equal to the basic science group. However, the structured algorithm group performed the poorest amongst the three groups on immediate and delayed testing. These results refute the organized learning theory we originally proposed as a possible explanation for the process by which basic science aids novice diagnosticians.

Despite superior diagnostic performance, analysis of the cued recall test reveals the basic science group did not display an increased ability to remember or retrieve the features of a particular disease when compared to the feature list or structured algorithm groups. This interesting observation lends support to the conceptual coherence explanation for the role of basic science in diagnosis. The causal explanations increased the participants’ overall ability to identify and diagnose the disease, but did not play a role in increasing their ability to memorize the individual features related to the disease. It seems that participants in this group did not rely solely on memory to arrive at the correct diagnosis. Because these students understood why certain features occurred, they were able to make the diagnosis that “made sense” rather than simply focusing on feature counting.

This study has some possible limitations. The study was conducted in an artificial educational setting. Moreover, the learning experience was tightly controlled, as participants learned the material using a computer program with standardized audio recordings. The learning process in the classroom does not necessarily occur in the same fashion. Time constraints, greater numbers of students, and different lecturers teaching different disease categories might make the integration of basic science knowledge with the clinical knowledge less effective in enhancing diagnostic accuracy in the classroom.

**Conclusion**

This study supports the critical role of the basic sciences in enhancing diagnostic accuracy in oral radiology. It also supports the conceptual coherence theory as a possible explanation for the process by which basic science aids in diagnosis. Furthermore, our findings support the idea that teaching diagnostic features and disease categories with basic science explanations can be more beneficial than using organizational tools alone in a visual-based domain.

Future studies should examine the effect of combining basic scientific knowledge with an organizational tool in teaching disease categories. Instead of using the structured algorithm to merely organize features of different lesions, the algorithm could function as a visual checklist, enabling the student to assess abnormal radiographic changes on an image. In theory, if we combine the algorithm and biomedical knowledge at the time of initial instruction and reinforce these concepts in the clinical setting, students may show diagnostic accuracy that is comparable to or surpasses those who learn only the basic sciences.

**REFERENCES**