Enhancing Diagnostic Accuracy in Oral Radiology: A Case for the Basic Sciences

by

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Abstract

Background: Cognitive processing in diagnostic oral radiology requires a solid foundation in the basic sciences as well as knowledge of the radiologic changes associated with disease. Although it is generally assumed that in dentistry, students must acquire both knowledge sets, little is known about the role or impact of the basic sciences on clinical reasoning because the two have traditionally been taught separately in the curriculum. Objectives: This dissertation investigates the role of basic sciences in oral radiology and its effects on diagnostic accuracy. The studies were designed to satisfy the following research aims: 1) to examine and compare the effects of integration and segregation of the basic and clinical sciences on diagnostic accuracy; 2) to examine the effects of basic science instructional methodology and diagnostic strategy on diagnostic outcomes; 3) to explore the potential interactions between instructional methodologies used to teach disease categorization and diagnostic strategies; and 4) to examine the effects of testing the basic sciences on diagnostic accuracy in an
integrated instructional methodology. **Methods:** We conducted three quantitative studies, all of which involved a learning phase and an immediate testing phase that assessed diagnostic performance and memory. In each of the studies, learning strategies, and or testing frequency were varied. We also included performance assessment of diagnostic ability and memory, one week after the initial learning phase. **Results:** Our results show that students who learned basic sciences explanations had higher diagnostic accuracy when using a holistic System 1 type diagnostic strategy than those who did not. We also demonstrated that basic science knowledge was the most effective when directly integrated with the clinical sciences, and this result is further enhanced with testing. **Conclusions:** We conclude that integrated basic science learning provides a coherent framework that has the potential to significantly improve the diagnostic accuracy of training dentists.
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1.1 Current Curriculum:

Modern day healthcare professions education has been shaped by the famous Flexner report of 1910. Flexner called for an education founded in basic science knowledge, and strengthened connections between the biomedical and clinical sciences. His report led to the closure of many proprietary medical schools that failed to provide sound basic science foundations. Shortly thereafter, William Hunter criticized dentistry for “violating biological tolerance”, and this gave way to a detailed report of dental education by Gies in 1926. As a result of the Gies report, dentistry too incorporated biomedical sciences as an integral part of its curriculum. A three-to-four-year course of study that incorporated biomedical and clinical sciences was set as the new standard. The curricular structure adopted in medicine and dentistry was a partitioned system in which students began with two years of foundational pre-clinical courses and then completed the remaining years training in clinical courses and practicums.

Currently in medicine and dentistry, the basic sciences of biochemistry, anatomy, histology, and physiology are taught in the “pre-clinical” years. These subjects are considered foundational knowledge that serve to provide the scientific basis for future clinical decision-making and therapeutics. However, the current presentation of the basic sciences does not seem to serve this purpose. It has been observed that the pre-
clinical basic science curriculum emphasizes the acquisition of a vast amount of biomedical knowledge but does little to highlight its utility in the clinical setting. Plus there is an assumption in the clinical years that students will carry over the basic sciences they have learned from their preclinical training and apply it appropriately in the clinical context. This segregation between the basic and clinical sciences and the lack of connection between the two has initiated a contentious debate around the importance of the basic sciences in the development of the healthcare professional.

The basic science debate has lead to a number of studies that have been devoted to identifying the role of biomedical knowledge in undergraduate clinical training. Most notably, Patel and colleagues suggest that basic sciences and the more practical clinical knowledge are two separate learning processes and that clinical information cannot be embedded within basic science structure. A study in 1988 by Patel compared the performance of students at different levels of training, requesting that students provide a biomedical explanation of a clinical case after having read three related basic science texts. It was noted that students made very little use of basic science information in diagnostic explanations. In fact, when basic science was used, they used it incorrectly and it consequently hindered diagnostic reasoning. This work, and others like it, serve as a basis for Patel’s “two-world hypothesis”. This theory proposes that the basic and more clinical knowledge form two different domains in the mind and are not entirely compatible knowledge bases.
Taking a different view of the structure of basic and clinical knowledge, more recently Woods compared two different approaches to learning clinical diagnosis\textsuperscript{12}. The first approach required that students learn how clinical features of a disease relate to underlying pathologic mechanisms. A second instructional approach required students to learn the conditional probabilities associated with the features of the disease. Undergraduate psychology students were taught four neurological disorders using either basic pathophysiologic explanations or conditional probabilities. Diagnostic tests were administered immediately after the learning session and one week later. The authors found that both groups performed equally on the initial test. After a one week delay however, the performance of the basic science group was maintained, while the performance of the probability group decreased. The authors concluded that the basic science information helped students recall the diseases and their features after a time delay\textsuperscript{12}.

Using a larger sample of undergraduate medical students, Woods conducted a similar study where participants learned four neurologic and rheumatologic disorders. One group was taught the diseases based on basic science explanations and the second was taught the same diseases using only epidemiologic information. Woods again found that the students in the basic science group showed superior performance on the one week delayed test\textsuperscript{13}.

The studies by Woods challenge the original views commentators and researchers like Patel had on the importance of basic sciences in teaching the novice healthcare
professional. These studies actively integrated the basic and clinical sciences, which resulted in the enhancement of diagnostic outcomes.

In the two previously described studies, the authors found the difference between the basic science and the feature list groups only on delayed testing. The authors theorized that on immediate testing both groups relied on their immediate clinical knowledge. However, after a delay and with the attrition of memory over time, the basic science group used the causal explanations to reconstruct the features to arrive at a diagnosis. To further investigate the importance of basic sciences in clinical reasoning, the authors theorize that novices that learn basic science mechanisms would use this knowledge immediately after learning if presented with difficult cases\textsuperscript{14}. In this study, they taught four artificial diseases. The participants were divided into two learning conditions: basic science learning and feature list learning, and two experiments were conducted. The first experiment tested participants on two types of clinical challenges: case summaries with irrelevant findings and cases with unfamiliar terminology. These critical changes were made in order to increase the difficulty of the cases. Participants in the basic science causal group out-performed their feature-list counterparts on both types of cases. In the second experiment, participants were tested a week later after the learning phase. Participants in the basic science causal group performed better on cases with unfamiliar terminology. The results of these studies supported the role of biomedical knowledge in diagnosing difficult and unfamiliar cases by novices. The importance of these particular studies lies in the fact that students that learned the diseases through basic sciences demonstrated “expert-like” behavior by employing their knowledge of
underlying mechanisms when case were outside of their comfort zone\textsuperscript{14}. It has been found that experts do not explicitly use biomedical knowledge in simple cases. However, they appear to employ basic science knowledge when faced with difficult case.

A large part of the debate of the importance of basic sciences in clinical diagnosis has been fueled by the notion that expert clinician rarely utilizes biomedical knowledge during routine clinical duties. So what role does basic science knowledge play in the experienced healthcare professional? As of a result of observations just described, studies have focused on determining the value of basic science in the development of expertise. Work led by Patel\textsuperscript{15}, Schmidt and Boshuizen\textsuperscript{16} and Lesgold\textsuperscript{17} relied on laboratory studies of diagnostic reasoning to better understand how experts use basic science knowledge. Generally, the research teams asked clinicians to think out loud while working up a diagnostic case. The verbal reports collected from the expert participants were analyzed for instances of application of basic science knowledge\textsuperscript{18}.

Patel's analysis of the 'think aloud' data revealed that expert clinicians made very little reference to basic science knowledge and mainly focused on analysis of the clinical features of a disease. They concluded that expert clinicians did not routinely use basic science concepts in their practice. However, while these expert clinicians used feature-focused strategies for common problems, these strategies failed to assist them when faced with complex and more challenging cases. It appears that the clinicians fell back on biomedical principles to arrive at the solution when the answer to the clinical problem was less than obvious\textsuperscript{15,19,20}. The main limitation of Patel's ‘think aloud’ studies is that
the clinicians may not have consciously recognized, and in turn could not verbalize, the subtle ways in which basic science knowledge may have influenced their interpretation of the clinical information\textsuperscript{21}.

Similarly, Schidmt and colleagues observed that clinicians made little explicit reference to basic science concepts in their ‘think aloud’ studies. They were also confronted with the same limitations inherent in Patel’s work. Unlike Patel, Schmidt went further to explain why experts mention less basic science when reasoning through a clinical case. They observed that when novices were confronted with a clinical case, they focused on individual clinical features and attempted to relate each feature to a pathophysiologic process. In other words, the novice employed large amounts of explanatory biomedical knowledge to account for the observed signs and symptoms. The authors called this the “intermediate effect” where rich, detailed, and elaborate causal networks are formed based on biomedical knowledge. Schmidt then argued that through extensive repetition and application of this acquired knowledge in clinical cases over time leads to a structural change in knowledge. Schmidt postulated that the student’s biomedical knowledge gradually integrates with clinical knowledge. By the time the student becomes an expert, the biomedical knowledge becomes “packaged” with their clinical knowledge. This enables experts to make shortcuts in their line of reasoning. This process was labeled as “knowledge encapsulation”. Schmidt and his colleagues theorized that expert clinicians maintain their biomedical knowledge in an encapsulated form, indexed by words or phrases describing the underlying disease processes. Unlike novices, experts simply had more efficient “tools” available to them during diagnosis\textsuperscript{22-26}.
A different observation was seen in the studies conducted by Lesgold and colleagues in diagnostic radiology. They asked clinicians to diagnose a series of radiographic images and found that choosing a correct diagnosis was associated with the precise use of anatomical and pathophysiological knowledge. Apart from recognizing more anatomical structures, the expert radiologists produced more extensive think-aloud protocols that contained many connections between the findings in the radiographic images and basic science knowledge compared to the novices. These observations are different than those reported by both Patel and Schmidt. It is important to note that the radiographic cases used by Lesgold in his study were not considered to be challenging. In the studies by Schmidt and Patel, when experts are faced with easy cases, they relied mainly on feature-focused strategies to arrive at a diagnosis and rarely verbalize any basic science connections. Only when the expert were faced with difficult cases did they appear to rely on biomedical explanations. Even so, Lesgold found that experts use accurate and rich basic science explanations to arrive at a diagnosis of straightforward cases. They concluded through their findings that diagnostic accuracy is determined mainly by the extent to which the expert possesses rich explanatory biomedical knowledge structures in memory.

Prompted by the conflicting findings of Patel, Schmidt and Lesgold, De Bruin and colleagues conducted a study to examine four theories on the role of basic science knowledge and clinical knowledge in diagnostic reasoning in expert and novice diagnosticians. The authors tested the basic science knowledge, clinical knowledge,
and diagnostic performance of family physicians and undergraduate medical students and used structural equation modeling to determine the relationship between knowledge and diagnostic performance. Four possible theoretical models were tested. In the first model only basic science knowledge was involved in diagnostic reasoning. This theory was based on the findings from Lesgold and colleagues’ study. In the second model only clinical knowledge was related to diagnostic reasoning, as suggested by Patel’s studies. The third model was based on the knowledge encapsulation theory that was put forward by Schmidt and Boshuizen. Encapsulation theory predicts that clinical knowledge directly influences diagnostic performance, whereas basic science knowledge has an indirect effect on diagnostic reasoning by contributing to clinical knowledge. In the fourth model, both clinical knowledge and basic sciences independently influenced diagnostic reasoning. Participants in the study completed three tests: a diagnostic test, a basic science knowledge test and a clinical knowledge test that covered clinical sub-disciplines of medicine. An analysis of the data revealed that the third model based on the knowledge encapsulation theory, provided the best fit. Models that had directly related basic science knowledge with diagnostic performance did not fit the data adequately. The results of this study support the knowledge encapsulation theory proposed by Schmidt and Boshuizen and suggests that basic science knowledge is utilized in expert reasoning through its relation with clinical knowledge.

As a direct test of the direction of the relationship between basic science knowledge and expert diagnostic performance, Woods and colleagues conducted two studies on
psychology students learning 4 artificial endocrine diseases. One group learned only the signs and symptoms of each disease. The second group learned the symptoms along with causal explanations. In the first experiment, the participants were given a recognition memory task. In the second experiment, students were asked to diagnose new cases either as quickly as possible or taking their time. They observed that novices who learned causal explanations were more likely to recognize words and phrases that reflect encapsulated causal knowledge than students who learned only the clinical features of disease. They also found that when diagnosis was performed at a faster rate those who had a causal explanation available were able to avoid errors and showed improved performance. This expert-like performance achieved with causal training shows the value of basic science in learning medical diagnosis and the important role of this knowledge to put novices on the road to clinical expertise.

In summary basic sciences appear to have an active role in diagnostic reasoning in experts. Even though it appears that experts may not employ their basic science knowledge with simple cases, difficult cases trigger the spontaneous use of this knowledge. It was also found that novice diagnosticians demonstrated expert-like performance when taught clinical cases with biomedical explanations.

1.2 Basic Sciences and Oral Radiology:

Oral radiology is an integral part of undergraduate dental training. By graduation, dental students are expected to have basic skills in interpreting and diagnosing intra-oral and extra-oral radiographs. Through the course of their training, dental students are provided
with the clinical and radiographic knowledge that are believed to be fundamental in developing the ability to interpret radiographs. Basic science knowledge is usually limited to the understanding of the physics, mechanics of imaging and normal radiographic anatomy. Not much emphasis is put on principles of pathophysiology in the oral radiology curriculum itself and it is often assumed that students have already mastered basic pathophysiology elsewhere in the dental curriculum. In a recent study, we have shown that biomedical knowledge, especially pathophysiology, plays an important role in increasing novices diagnostic accuracy. We compared the educational efficacy of three learning strategies in diagnostic radiology. The first of these strategies utilized basic scientific (i.e. pathophysiologic) information, while the second used feature lists structured with an organizational tool (a structured algorithm). A third learning strategy used traditional unstructured feature lists. The participants were taught four confusable intra-bony entities on diagnostic radiographs in the learning phase of the experiment, then completed a diagnostic test and a cued recall (memory) test. We found that when participants learned about the diseases with basic science explanations that underpinned the radiologic features, they demonstrated higher diagnostic accuracy than those who learned unstructured feature lists or the structured algorithm regardless of their performance in the memory test. The results of this study support the critical role of the basic sciences in enhancing diagnostic accuracy in oral radiology in novices. It also sheds light on the possible cognitive mechanism that the basic sciences play in enhancing the diagnostic performance of students. Initially two potential mechanistic theories were proposed. First, using organizational theory, we hypothesized that the basic sciences act as an elaborate organizational tool or
mnemonic. The function of basic science would be to organize the clinical features, which would then lead to better memorization of the individual features and in turn lead to better diagnostic accuracy.

In contrast, conceptual coherence theorizes that the basic science provides more than just organization that aids in memorization of the clinical features. According to this theory, basic sciences may assist in “true understanding” of the diagnostic entities, not by increasing the quantity of the information, but by creating coherent networks supported by concepts and examples.

Although we found the basic science condition out-performed the structured algorithm group on the diagnostic test, the two groups showed no difference on the memory test. We interpreted this result to mean that higher diagnostic accuracy could not be attributed to better memorization of the features. Furthermore, if the role of basic sciences were merely organizational in nature, then performance of the group that was given a simple organizational tool would have been superior or equal to the basic science group. Hence, we concluded that when basic sciences were used as causal mechanisms underpinning clinical features, coherent mental representations of the disease categories formed resulting in higher diagnostic accuracy. We concluded that the conceptual coherence theory appears to better explain the higher diagnostic accuracy achieved by participants who learned radiographic abnormalities using basic sciences.
1.3 The Diagnostic Task in Oral Radiology:

To further understand how basic sciences may play a role in teaching novice diagnosticians in oral radiology, a two-phase model has been proposed that represents the learning process which is needed to acquire the diagnostic skill in oral radiology.

1.3.1 Instructional Methodology: Diagnosis as “categorization”

Traditionally, novices are introduced to disease categories using a feature-oriented approach. This has been the main approach used in the classroom and in many medical and dental textbooks. A classic example in radiology is the textbook series “Diagnostic Imaging.” In this series of textbooks, radiographic abnormalities are introduced accompanied by a list of all the possible radiographic features seen using each imaging modality. This feature-by-feature analysis is based on older models of categorization that assume that categorization is based on the presence of necessary and sufficient features. The problem with applying this model of categorization to oral radiology, is that it does not take into account that the absence of one or some of the features does not rule out a certain diagnosis. More importantly, this model of instruction might not take into account the psychological principles that govern categorization and concept formation.
In essence, medical diagnosis is considered to be a categorization task. Murphy and Ross\textsuperscript{32} define categorization as:

“...a central part of intelligent thought, allowing us to apply knowledge learned about a limited set of objects to a potentially infinite class of new, previously unseen, objects.”

Custers et al\textsuperscript{30} state that

“...the simplest and oldest way to describe category structures is in terms of features that are individually necessary and jointly sufficient to define a concept or category, such as for example, a disease.” Based on these general definitions of categorization, a disease category may be defined as a condition resulting from various causes and characterized by an identifiable group of features (i.e. signs and symptoms). Three main frameworks from the cognitive psychology literature have been proposed to explain the process of categorization and knowledge representation in diagnosis\textsuperscript{30}.

The first is the prototype theory. In this framework, diseases are represented as prototypes. It assumes that a person’s experience with individual examples is, over time, averaged into a prototype that contains most of the critical features of that category. When a new case is seen it is compared with a category that contains most of the features in common with the new case. This type of mental representation is based on a feature-by-feature matching against a prototype\textsuperscript{30,33,34}.

The second is the exemplar theory, also known as the instance-based framework\textsuperscript{30}. It posits that for categories, we store individual exemplars, and then make our category judgment by matching the current example against exemplars in memory. The
exemplars in this theory remain “intact” and a new case is compared to the entirety of the exemplar and not to its individual features as with the prototype model. This model relies heavily on the notion of similarity. In other words things that look alike tend to be categorized together.\textsuperscript{30 33 34}

A third model is the semantic network model.\textsuperscript{30} In this framework, medical knowledge is represented in the mind as networks that consist of “nodes” connected by links. The nodes represent units of meaning connected together in this network. The semantic network model takes into account the structure and relationship of different bodies of knowledge. A review by Murphy in “The Big Book of Concepts” reported on an emerging literature that has focused on documenting how knowledge structure in which categories are embedded, have a large effect on how categories are formed and how we classify objects.\textsuperscript{35} From this work, the “theory-based” accounts of categorization also known as “causal based categorization” in psychology can be drawn upon. Research in this domain has shown that causal knowledge that provides explanations for how things work and how they are related to one another can be beneficial for retaining and applying newly learned information. Rehder and colleagues examined this through a group of studies. They concluded that an understanding of causal relationships, create long lasting connections between the individual features of a category.\textsuperscript{36 37} By providing these links the causal theories gives structure to the mental representation of a category by transforming a list of random features into a network of meaningful components of a category. When comparing his theory to exemplar based theory of categorization, Murphy and Medin state in a review done on the role of theories in conceptual
coherence, that they believe that exemplar theories in categorization that are based on
similarity are inadequate in fully explaining categorization. These theories do not take
into account background knowledge and fall short in explaining conceptual coherence\textsuperscript{32}.

The semantic network framework and theory-based categorization best explain the
conceptual coherence theory discussed earlier in the studies by Woods and Baghdady.
Basic sciences may provide the necessary causal knowledge needed to explain clinical
features and to link the features of different disease categories to form conceptual
coherence\textsuperscript{21 29 38}.

1.3.2 The Diagnostic Phase: Diagnostic Strategies
Having categorized diseases, a novice is now ready to start the diagnostic task in a
step we refer to as the “diagnostic phase”. In this phase, the student must apply a
diagnostic strategy to solve the problem at hand. When first faced with a diagnostic
problem, the clinician engages in a complex perceptual phase that involves
differentiating normal and abnormal anatomic structures on two-dimensional images
that represents three-dimensional structures. After the search process, if a finding is
deemed abnormal, the clinician forms a mental three-dimensional image of the
abnormality that includes the precise location, size, internal structure and how the
abnormality affects the surrounding normal structures\textsuperscript{39}. How does the clinician process
all the relevant information to arrive at a final diagnosis?
Diagnostic reasoning represents a complex process involving both non-analytic and analytic cognitive processes, which have recently been defined in terms of the dual-process theory\textsuperscript{40}. Dual processing theory accounts for human behavior in cognitive psychology, and two fundamental modes of reasoning have been defined, namely System 1 and System 2 processes. System 1 represents an unconscious, implicit, automatic, rapid and non-analytic approach to reasoning. System 2 on the other hand, represents a conscious, explicit, controlled, slow, and analytic reasoning process\textsuperscript{40}.

Traditionally medical educators have focused their efforts on System 2 or analytic models of clinical reasoning\textsuperscript{41}. Students are encouraged to systematically gather data or features of a clinical or radiographic case before creating a diagnostic hypothesis. It is argued that analytic reasoning will prevent premature closure until all the data is collected\textsuperscript{42}. Premature closure may be defined as the tendency to stop too soon without appropriate consideration of alternative possibilities, which may lead to diagnostic error\textsuperscript{33}. Analytic reasoning processes come in different forms. In oral radiology, students are encouraged to follow a strict algorithm used to gather radiographic features from a suspected radiographic abnormality\textsuperscript{39}. Only after this process, are students encouraged to arrive at a differential diagnosis. This again means the diagnosis is formulated only after careful consideration of all the apparent clinical and/or radiographic features.

The alternative method of problem solving is using System 1. This form of reasoning is automatic and without conscious awareness\textsuperscript{40}. It assumes that a diagnostic hypothesis
is made based on the totality of the presented features. Non-analytic reasoning has also been described as “pattern recognition”; a case is diagnosed based on similarity to a specific instance of the disease that has previously been seen. Pattern recognition has its roots in the exemplar theory of categorization, where categorizing a new case is done by matching the case to a previously seen example in memory\textsuperscript{33, 34}. Brooks and colleagues have shown that diagnostic accuracy in dermatology was strongly linked to similarity with previously seen cases. They found that diagnostic accuracy was higher for cases that were seen previously compared to cases that had a novel appearance. Similarity to a previous case results in an increase of accuracy of about 40\% with the experienced residents and 28\% with the more novice medical students\textsuperscript{18, 43}. It has also been found that the physician will be influenced not only with similarity in the presentation of the disease, but also by irrelevant factors in the case. Hatala and colleagues found that diagnostically irrelevant facts, for example the patient’s profession, to have an impact on the diagnosis of a subsequent case in which this irrelevant piece of information is similar\textsuperscript{41, 44}.

Several studies have directly investigated the efficiency of the two diagnostic strategies. There is empirical evidence that non-analytic reasoning can be successful employed by novices. In a study by Norman et al, two approaches to diagnosing an electrocardiogram (ECG) by novice undergraduate psychology students were examined. After receiving some basic training on ECGs, participants were divided in two groups for testing. One group was encouraged to use an analytic approach. They were instructed
to carefully consider all the data on the ECG by checking off features on a response sheet, and then use this information to synthesize a diagnosis. The second group was instructed to first diagnose the case and then identify the individual features on a response sheet, essentially taking a more non-analytical approach to clinical reasoning. Participants instructed to first come up with a diagnosis achieved an accuracy 50% higher than those who used the analytic approach. This study demonstrates the significant advantage of a non-analytic approach to diagnostic reasoning in rank novices.

The question that arises from these studies is, should clinical teachers emphasize analytic or non-analytic reasoning strategies? Theories in dual processing do not only describe the two systems that define reasoning, but also the relationship of these two processes with one another. Some view these systems as parallel and competing, while others view them as complementary, additive, and sometimes even sequential. Generally in the diagnostic reasoning literature, System 1 and System 2 processes are not viewed as being mutually exclusive. It is highly probable that both processes contribute significantly to the final diagnosis. One model proposed by Eva suggests that when faced with a clinical problem, the clinician forms a mental representation of the case, which leads to the generation of a hypothesis. System 1 processes dominate this phase. The next step would be hypothesis testing; this occurs by gathering “data” or features from the clinical case. System 2 dominates this phase. Hypothesis testing will obviously affect the original mental representation the clinician
had created. This model demonstrates the interactive relationship between analytic and non-analytic reasoning rather than viewing them as competing mechanisms\textsuperscript{41}.

Recently Ark and colleagues set out to experimentally test the effect of instructing novices to use combined reasoning strategies on diagnostic accuracy. In their study they compared the diagnostic accuracy of novice psychology students learning to read ECGs. One group was instructed to carefully consider all features presented on the EGC before committing to a final diagnosis. This represents an analytic reasoning process. The second group was instructed to trust familiarity, a non-analytic reasoning strategy. The third group was instructed to trust familiarity but to re-check by carefully considering the features of the ECG. This represents the combined analytic/non-analytic strategy. The results of the study showed that the combined group out performed both groups on the diagnostic test, and suggest that novices would potentially benefit from specific instructions on using a combined reasoning technique\textsuperscript{47}.

From the above discussion on instructional methodologies and diagnostic strategies, it is obvious that both have an effect on diagnostic accuracy. It is also evident that studies of clinical reasoning have typically focused on either the effect of instructional methodology or diagnostic strategy on diagnostic accuracy. To further our understanding of the role of basic sciences in enhancing diagnostic accuracy, it is essential that we take a closer look at the potential interaction between instructional methodology and diagnostic strategy. What has been found so far is that basic sciences
used as causal mechanisms to teach disease categorization (as an instructional methodology) has a positive effect on diagnostic outcomes\textsuperscript{12-14, 21, 29, 38}. However, the effect of basic science on diagnostic strategy and vice versa, may provide important insights on the effectiveness of basic science instruction in clinical reasoning. We intend through our studies to take a closer look at this delicate relationship.

### 1.4 Lessons from Test Enhanced Learning:

Test enhanced learning has the potential to offer some insight to the cognitive role basic sciences play in the diagnostic task.

Several studies have found that assessment has a direct effect on learning. Traditionally, examinations have been viewed as assessment tools to measure knowledge. Although this is certainly one function of testing, recent work suggests that testing not only measures knowledge, but also can enhance retrieval of that knowledge\textsuperscript{48}.

Tests have been found to have both extrinsic and intrinsic effects on learning\textsuperscript{49}. Educators and students can easily appreciate the extrinsic effects (i.e. the effects of assessment on curriculum and teaching). For example, the results of the formative assessment provided after an examination may influence a teacher’s future instruction and a student’s future study goals\textsuperscript{48}. Intrinsic effects of testing are those that involve student learning and the impact test has on retrieval and memory. A large body of research has been dedicated to the effect of testing on the ability of students to learn and retain information\textsuperscript{48, 50-56}. Tests have been found to have an indirect effect on
learning, as they require students to spend time studying to prepare for a test. Presumably, students are motivated by the testing situation to both increase study time and improve study quality which lead to increase in their knowledge of the material\textsuperscript{48}. More importantly, it has also been shown that the act of taking the test itself directly enhances learning and long-term memory, a phenomenon known as the “testing effect”\textsuperscript{48}. The precise cognitive mechanism underlying the testing effect is not known. However, several theories have been put forward to account for these findings. The total-time hypothesis suggests that the testing effect is simply the result of additional exposure to the material. As the students complete the test, they essentially have additional time to engage the material they were expected to learn. This leads to an over-learning of the material that is being tested\textsuperscript{48,51}. This may seem true, however, it does not explain the testing effect observed when time with material is equated between groups that are either taking a test or given additional study time. Another competing theory is the retrieval hypothesis. This theory suggests that recalling information during a test requires that the student be engaged in active mental processing. The active retrieval of information from memory in a testing scenario essentially practices the skill that will be needed if the student needs to recall the information long after the test is over\textsuperscript{48}. Even though the debate continues regarding the underlying mechanism of the testing effect, it is clear that tests can enhance student memory.

Several factors have been found to increase the positive effect of testing. Repeated testing has been shown to promote better retention than taking a single test. This effect is enhanced if multiple tests are distributed over time, a phenomenon also known as the
spacing effect\textsuperscript{48, 50, 55}. The format of the assessment tool has also shown to influence the testing effect. For example, production tests that require the learner to construct a response (e.g. short answer questions, fill-in-the-blanks) lead to better retention than recognition tests (e.g. multiple choice, true/false). Presumably this is because production tests require more effortful retrieval of information from the memory than recognition tests\textsuperscript{48, 57}. Finally, the provision of feedback has been shown to increase the educational efficacy of testing. Although testing can improve retention in the absence of feedback, providing feedback enhances the positive effects of testing by correcting errors and reinforcing correct responses\textsuperscript{48, 57}.

1.4.1 Test Enhanced Learning and Healthcare Professions Education

Test enhanced learning is now being considered a useful tool in medical education. Larsen and colleges have called for adopting frequent testing protocols in medicine to capitalize on the positive effects it has on learning\textsuperscript{57}. A study by Larsen and colleagues evaluated the effect of repeated testing of material taught in a didactic conference for pediatric and emergency residents\textsuperscript{58}. They found that repeated testing with accompanied feedback resulted in greater long-term retention of the information taught at the conference than repeated spaced studying of the same material\textsuperscript{58}. Kroman et al determined that incorporating a test in a resuscitation skills course increased learning outcomes\textsuperscript{49}. They found that students who were required to take a test as the final activity showed better resuscitation skills than those who spent an equal amount of time practicing the skill with no test\textsuperscript{49, 59}. While previous studies focused mainly on the
increased retention of facts, this study was unique because it demonstrated enhanced learning outcomes associated with skill acquisition.

Whether it be skill acquisition or learning clinical and biomedical facts, it is critical that medical and dental curricula also be designed to impart students with a deeper understanding of complex concepts and theories. So while rote recall is certainly important, true understanding and comprehension are more critical in medical education. Little research has been done to examine the effects of testing on knowledge that goes beyond just basic recall. Our 2009 study demonstrated that students who learned the basic pathophysiologic mechanisms that underpinned the appearances of disease on radiographic images developed a more coherent mental representation of clinical disease categories. We hypothesized that the basic sciences acted as causal pathways between the features, and that the radiographic features were “held” together in the conceptual framework that was created. If this is true, then testing the basic sciences should strengthen the framework and manifest in higher diagnostic accuracy. This type of indirect effect has yet to be explored in the existing test-enhanced learning literature. Traditionally the outcome measures in empirical studies of the testing effect are simple assessments that are very similar in format and content to the interventional tests. For example, if the task were to learn word pairs, the interventional test would be a test on word pairs. The outcome measure would be a memory test that tests how well the participant remembered the word pairs. Instead, we would propose the use of test-enhanced learning as a “tool” to further advance our understanding of the relationship between the clinical and basic sciences. Using an intervention test centered
on knowledge of basic science and an outcome measure that consists of a diagnostic accuracy, we could determine whether augmenting basic science knowledge through testing in fact translates into better diagnostic accuracy.
Chapter 2

Research Aims and Hypothesis:

This dissertation investigates the role of basic sciences in diagnostic oral radiology and its effect on diagnostic accuracy. As discussed previously, many cognitive theories have been proposed to explain the relationship between basic biomedical knowledge and clinical knowledge. Our proposed “conceptual coherence theory”, argues that the basic sciences enhances diagnostic accuracy by creating coherent mental representations of disease categories. We attempt to further explore the theory of conceptual coherence in teaching novice diagnosticians interpretive oral radiology. The studies were designed to satisfy the following research aims:

1. To examine and directly compare the effect of the integration and segregation of the basic and clinical sciences on diagnostic accuracy.

2. To examine the effects of basic science instructional methodology and diagnostic strategy on diagnostic accuracy.

3. To explore the potential interaction between instructional methodologies used to teach medical categorization and diagnostic strategies.

4. To examine the effect of testing the basic sciences on diagnostic accuracy in an integrated instructional methodology.
To address our research aims, three studies were proposed using quantitative methodologies.

1. In chapter 4, we describe a study where descriptions of disease categories were accompanied by basic science explanations that were either integrated or segregated in their descriptions. We hypothesize that participants in the integrated basic science group demonstrate higher diagnostic accuracy than participants who learned the disease categories and the causal basic science underpinnings in a segregated manner.

2. Chapter 5 describes a study where participants learn disease categories using either basic science explanations or organized feature lists. This study examined the effects of analytic and non-analytic diagnostic strategies in oral radiology and its effect on diagnostic accuracy, and the potential interaction between instructional methodology and diagnostic strategies and its effect on diagnostic outcomes. The participants were encouraged to use either an analytic or a non-analytic diagnostic strategy in the testing phase. We hypothesize that participants that use a non-analytic reasoning strategy will show higher diagnostic accuracy then those using an analytic technique, regardless of instructional methodology.

3. Furthermore, we also hypothesize that there is a significant interaction between the instructional methodology used to teach the diagnostic categories and the diagnostic strategies employed by the participants.
4. Chapter 6 is a test-enhanced learning study where participants learn disease categories using an integrated (basic/clinical science) instructional methodology. Participants take either a basic science test or are given additional study time on the basic sciences. We hypothesize that participants that are tested on the basic sciences will have higher diagnostic accuracy than those who spend extra study time on the basic disease mechanisms.
Chapter 3
General Methods

This chapter discusses the general methodological aspects of the studies in this dissertation.

3.1 Participants:

The participants in our studies were second year students enrolled in the undergraduate Doctor of Dental Surgery (DDS) program at the University of Toronto (U of T). To be eligible for the study, students must have had completed their first course in oral radiology (DEN317Y1 Oral Radiology), which consists of lectures and seminars introducing the student to the principles of radiation physics and hygiene, radiation biology, radiographic technique and radiographic interpretation of normal anatomy. This population was chosen specifically to ensure that participants could understand basic terminology in radiology and identify normal anatomy, but had minimal exposure to radiographic interpretation and specifically, to the intrabony abnormalities selected for the learning materials. To increase the number of potential students available for the study, 2nd year dental hygiene students from a local community college were also invited to participate. These students were determined to be at the same academic level as the 2nd year dental students. These students had completed courses #DENT1064 and #DENT1065 which focused on the principles and application of intraoral and extraoral radiographic techniques, infection control, and normal radiographic anatomy.
Ethics approval for the project was granted by the Research Ethics Board (REB) at the University of Toronto and from the REB of the local community college.

3.2 Materials:

The materials for our studies were adapted from the Baghdady et al (2009) study. The following section summarizes the materials used to conduct the studies in this dissertation.

3.2.1 Learning material

The learning materials were designed as a set of slides accompanied by audio recordings that narrated the written material on each slide. The participants learned about the radiographic features of four different, but confusable diseases. The diseases included: periapical cemental dysplasia (a bone dysplasia), complex odontoma (a benign odontogenic tumour), periapical sclerosing osteitis (an inflammatory lesion), and dense bone island (bony hyperostosis). These abnormal intrabony entities were chosen specifically for inclusion for several reasons. First, they all contain mixed radiolucent and radiopaque elements that occur in the tooth bearing areas of the jaws. Second, these four entities may appear quite similar radiographically. Third, these entities are also considered to be common lesions that are seen regularly on dental radiographs. Fourth, it is essential to differentiate these lesions radiographically because the choice of treatment (or no treatment) will differ drastically based on the radiographic interpretation of the abnormality (Appendix #1).
The radiographic descriptions and the basic science explanations for all the intrabony abnormalities were adapted from the textbook “Oral Radiology: Principles and Interpretation” by White and Pharoah.

Participants were divided into different groups depending on the study. Generally, the learning materials can be divided into two main categories:

**Integrated basic science learning:**

The learning materials focused on radiographic features of each disease and the underlying pathophysiology of the abnormality. The basic science information provided causal explanations to the radiographic features seen visually. An example of a causal explanation of the radiographic features of a complex odontoma follows:

- Odontomas are benign tumours 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 (i.e. cysts and benign slow growing tumours). 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 teeth complete development. Because of the slow
and space-occupying nature of the growth of this tumour, frequently it displaces nearby
teeth and obstructs the normal eruption of adjacent teeth.

**Feature based learning (structured algorithm):**
The learning material covered the same radiographic features as the basic science
instructions, but without the basic mechanism of the disease. The students learned a
general algorithm to analyze intraosseous lesions and then applied it to the given
disease (Appendix #2). For example, in the case of complex odontoma:

Complex Odontomas are the most common odontogenic tumours in the jaws.

• **Location:** 70% of complex odontomas occur in the mandibular first and second molar
region.

• **Periphery:** Odontomas are well defined and have a corticated boarder. 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.
70% of odontomas are associated with abnormalities such as impaction, malpositioning
of adjacent teeth, diastema, and devitalization of adjacent teeth.
3.2.2 Outcome measures:

There are two main outcome measures in the studies: diagnostic accuracy and memory.

To measure diagnostic accuracy and memory, two tests were created:

**Diagnostic test:** The participants were presented with 22-28 different radiographic cases with a list of the four intrabony abnormalities they had learned previously in the learning phase. The participant had to choose the correct diagnosis from the given list. This test was used to assess the diagnostic accuracy (Appendix #3).

**Cued recall test (memory test):** This test consisted of a laundry list of twelve features. The participant had to choose the correct features from this list for a given disease without a radiographic example. This test was designed to assess how well the participants in each learning condition could retrieve the radiographic features for each intrabony abnormality (Appendix #4). An example of the cued recall test is as follows.

The phrases in bold were considered to be correct answers:

*Complex Odontoma:*

1) Multiple and bilateral.

2) **Well-defined.**

3) Ill-defined.

4) Periphery exhibits an irregular radiolucent band.

5) **Periphery exhibits a regular radiolucent line (soft tissue capsule).**

6) No trace of a radiolucent boarder at its periphery.
7) **Displaces surrounding teeth.**

8) Does not cause displacement of surrounding teeth.

9) Causes widening of the periodontal ligament space.

10) May contain globular cementum like masses at the apices of teeth.

11) **Contains nondescript masses of dental tissue.**

12) Contains bone only.

There were two versions of the diagnostic test (tests A and B) for the purpose of counter-balancing, and both tests were matched for difficulty. Participants that took test A immediately following the learning session took test B for the one week later, and vice versa.

### 3.2.3 Radiographic Case Selection for the Learning and Testing Material:

Case selection and creation of the learning and testing materials were completed in 2007 in preparation for the Baghdady et al (2009) study. For the sake of completeness, the process in which the materials were created, and how they were refined for the studies in this thesis is explained in the next section.

Clinical cases were selected from the patient database and the teaching archives of the Discipline of Oral and Maxillofacial Radiology at the University of Toronto. A total of 82 cases were selected based on the labels on each image that indicated the diagnosis of the case. All patient identifiers were removed from the images. An agreement test was performed by four oral and maxillofacial radiologists. The primary investigator was not
included in this test. Each radiologist was presented individually with a Power Point® (Microsoft Corp., Redmond, WA) presentation that included the 82 images. They were then asked to provide a diagnosis for each case. Only cases that received full agreement on the diagnosis (100%) between the radiologists were considered for the learning and testing material. A total of 66 cases met this criterion. The selected 66 cases were then scanned on to 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 56 cases were used for the testing phase. The 56 radiographic cases for the testing phase were equally divided between test A and test B. Both tests were matched for difficulty. The effect of test order was routinely explored in each study to ensure there was no effect of test order on diagnostic ability. For the integrated/segregated study no main effect of test order (p=0.1) or interaction with the learning condition (p=0.4) was found. In the instructional methodology/diagnostic strategy study no main effect of test order (p=0.5) or interaction with learning condition (p=0.34-0.43) was found. For the test enhanced learning study no main effect of test order (p=0.82) or interaction with testing condition (p=0.6) was found.

Post hoc analysis was conducted on the testing scores from the Baghdady et al (2009) study to test for reliability and validity. To test for internal consistency, Cronbach’s alpha was calculated for both test A and test B. Test A presented a Cronbach’s α=0.84 and test B α=0.70. To further explore the results of the diagnostic test, items that demonstrated a ceiling effect (< 80% of participants answered the question correctly) or
a flooring effect (> 80% of participants answered the question correctly) were removed from the testing materials. Lastly, cases that highlighted the difference between learning conditions in either direction were maintained in the study and equally distributed between test A and test B.

For each study an individual computer program was created using the Revolution® software version 3.5.1 (Runtime Revolution Ltd., Edinburgh, Scotland). This was set up to organize the training and testing phases and to allow the investigator to control for certain matters that will be discussed in the next paragraph.

Generally, the program starts by instructing the participants to enter an identification number, the learning and/or testing condition, the session number (day 1 or day 2), and to select test A or test B. When this was completed, the program automatically continues to the learning phase depending on the learning condition. The slides with the learning materials and radiographs are accompanied by audio recordings. The program was created in a way that participant were not allowed to continue to the next slide until the audio component was completed. This prevents students from skimming through the slides without reading the material. The program also prevented participants from going back to previous slides once they had passed them. After the learning phase, the program automatically forwards the participant to the testing phase. The program randomizes the slides for each participant in the diagnostic test so each participant looked at the slides in a different order. After the participant has completed the test, the program generates Excel® (Microsoft Corp., Redmond, WA) files that contained the
results of the testing phase for each participant. These Excel files were then used by the investigator for data analysis.

3.3 Procedure:

This section will address the general procedures of the experiments at the University of Toronto (U of T) and at the local community college.

The U of T students were asked to participate in groups of no more than 8 students because of space limitations. The community college students participated in two large groups of 30 to 40 students. The participants were then randomly assigned to a learning and/or testing condition.

Each participant was assigned to a computer and given instructions on the task. The participants were instructed to choose an identification number that was known to them but not to the primary investigator. The participants then went through the learning phase. After the learning session was completed, the participants immediately took the tests. After one week, the participants came back for the delayed tests. The delayed tests consisted only of the diagnostic test and the cued recall test. Those who had taken test A the previous week were given test B, and vice versa.

Students were compensated for their time. For the studies reported in chapter 4 and 5, compensation was in the form of a participation bonus mark in the Oral Radiology DEN317Y1 course. For the study reported in chapter 6, financial compensation of $35
dollars was offered.

This chapter has covered the general methodological aspects of the studies in this thesis. Specific methodological consideration will be discussed with each individual study.
Chapter 4
The Integration of Basic Sciences and Clinical Sciences in Oral Radiology

4.1 Introduction:

Oral radiology is an integral part of undergraduate dental training, and by graduation, all dental students are expected to have developed skills in interpreting intra-oral and extra-oral radiographs. The development of skills in radiologic interpretation requires a sound understanding of the basic or foundational sciences, especially the pathophysiology of disease. Once pathophysiology of disease is clear, students are introduced to the fundamentals of radiographic interpretation.

Recent research suggests that the fundamental basic sciences are more than just an educational pre-requisite. Rather, basic science knowledge plays an essential role in enhancing diagnostic accuracy in novice clinicians. Baghdady et al, compared the educational efficacy of three learning strategies in radiologic image interpretation. The first strategy provided subjects with basic scientific (i.e., pathophysiologic) descriptions of four potentially confusable, radiopaque disease entities that related disease pathophysiology to radiologic features. The second strategy used feature lists structured with an organizational algorithm for the same radiologic entities and their
features, and a third employed a traditional unstructured list of radiologic features of each entity. All participants were taught the same four confusable intra-bony disease entities using only one of the learning strategies, and were then tested on their diagnostic abilities and basic memory. Participants in the first group who learned the links between disease pathophysiology and radiologic features, demonstrated higher diagnostic accuracy than those who learned using unstructured feature lists or the structured algorithm regardless of their performance on the memory test. The results of this study suggest that an understanding of the basic science of disease pathophysiology can enhance diagnostic accuracy, and that this strategy may be more beneficial than using organizational tools alone 29.

There are several additional studies in the clinical reasoning literature that highlight the value of the basic sciences as a tool for teaching about human diseases. Woods et al. taught undergraduate psychology students four neurological disorders linking the underlying pathologic mechanisms of the diseases with the clinical features, or the same clinical features in relation to the conditional probabilities associated with the features of the disease. Diagnostic tests were administered immediately after the learning session and then again one week later. Although both groups performed equally on the initial test, the performance of the probability group decreased significantly after a one-week delay 12. A similar study has also been performed using a larger sample size and used undergraduate medical students who learned neurologic and rheumatologic disorders in a similar manner. This study reaffirmed the principles
demonstrated in the earlier study by Woods; that providing students a link between the basic sciences and disease features improves diagnostic accuracy in medical novices, even after a time delay\textsuperscript{13}.

The work by Woods and Baghdady demonstrates the importance of biomedical knowledge in diagnostic accuracy. These laboratory findings have the potential to be translated to the undergraduate classroom by making strategic changes to both the medical and dental curricula. One strategy would be to teach the basic and clinical sciences in close proximity or in parallel, but confined to segregated courses. For example aligning a basic science course that teaches cariology with a clinical dental restorative course that teaches the clinical management of caries. At first glance, providing basic science and clinical instruction in close proximity or in parallel may seem an appropriate and convenient way to bring the two areas together. In this way, students gain the benefit of being exposed to both instructional areas, and this sets the stage to link the two to gain a complete understanding of a topic. It is, however, also possible that segregated teaching cannot create the causal explanations that linked the basic sciences to the clinical features. This has been echoed in some studies that have shown that left to their own devices, students seldom make correct connections between biomedical knowledge and clinical features\textsuperscript{10}.
An alternative and preferred model would be to embed basic science instruction into the clinical context, and the two would be taught in a fully integrated fashion. Using the example of caries presented above, the basic concepts of cariology would be taught within a clinical restorative dentistry course, and the basic mechanisms of caries development could serve to explain the clinical and radiologic appearances, and possible management options for caries. This integrated model more accurately reflects the manner in which the participants in the Woods and Baghdady studies learned. However, it is still not clear whether the segregated or integrated model for teaching oral radiology is optimal.

The effective use of biomedical knowledge in dental curricula continues to be a topic of discussion in the literature, leading to the emergence of research that concentrates on the most effective teaching methodologies in these areas. Diagnostic accuracy in radiologic interpretation is an important focus of undergraduate dental training. The study presented in this paper is the first comparative study of segregated versus integrated teaching of the basic and clinical sciences in dentistry, and specifically in oral radiology. In the present study we compare the diagnostic efficacy of teaching biomedical knowledge in close proximity with, yet segregated from the radiologic features of disease versus teaching radiologic features with biomedical knowledge integrated as causal mechanisms. We hypothesize that integrated learning will yield students with higher diagnostic accuracy.
4.2 Materials and Methods:

4.2.1 Participants:

Human research ethics approval was obtained from the University of Toronto Research Ethics Board. Students enrolled in the undergraduate dentistry program were invited to participate in the study. This population was chosen because they had completed the introductory course in oral radiology and were assumed to have an understanding of basic radiologic terminology and could identify normal radiologic anatomy, but had no prior exposure to the specific diseases selected for the study groups.

4.2.2 Learning Material:

The learning and testing materials were adapted from a previous study. The learning materials included sets of intra-oral periapical images accompanied by audio recordings that narrated the written material on each slide. The participants learned about the radiologic features of four potentially confusable intra-bony entities: periapical osseous dysplasia, complex odontoma, periapical sclerosing osteitis and dense bone island. These entities were chosen because the disease mechanisms underlying the development of each entity differed.

Participants were randomly divided into two learning groups. In the integrated basic science group (IN), the training material presented the radiologic features of each
disease integrated with the underlying disease mechanism. The basic science in this
group provided causal explanations for the radiologic features. In the segregated basic
science group (SG), the disease mechanisms were taught, and immediately after this
instruction was concluded, subjects were taught the radiologic features of the individual
intrabony abnormalities. An example of the radiographic features of periapical
sclerosing osteitis explained in the two learning groups (IN and SG) is demonstrated in
Table 1. The time spent on learning was equated for both learning conditions.

4.2.3 Testing Material:

Each participant completed two tests:

a. Diagnostic test:

As a test of diagnostic ability, the participants were presented with 22 intra-oral
radiographs and asked to choose the correct diagnosis from a list of the four learned
diseases that was in multiple-choice format. Two versions of the diagnostic test, A and
B, were created for the purpose of counter-balancing. Both tests were matched for
difficulty.

b. Cued recall test (memory test):

This test was designed to assess the ability of participants in each learning condition to
recall and identify the radiologic features for each intrabony abnormality. Participants
were provided with a list of twelve features without being provided with an image of the abnormality. The participants were then asked to choose the correct features of each disease.

4.2.4 Procedure:

A customized software program was created using Revolution® software version 2.1 (Runtime Revolution Ltd., Edinburgh, Scotland) that incorporated the learning material, radiographs, audio recordings, and the tests. Each participant was provided with a computer, and instructions for viewing, and testing.

Participants were randomly assigned a computer number that determined their learning condition (IN or SG) and test version (test A or test B). Participants were informed that they were going to learn about four intrabony abnormalities and would then participate in a series of tests. All participants first went through the learning phase. After this was completed, the participants were immediately directed to the testing phase. They first took the diagnostic test, and then the memory test. After one week, the participants were instructed to return to take the diagnostic and memory tests again. Those who had taken test A the previous week were given test B, and vice versa. The participants were instructed not to review any of the material in the one-week period between tests. Figure 1 represents a diagrammatic representation of the general study design.
4.3 Analyses:

Fifty-one participants completed both immediate and delayed sessions. For each participant the percentage of correct responses was calculated for the immediate and delayed diagnostic and cued recall tests. The diagnostic and cued recall tests for all the participants were analyzed separately using a 2x2 repeated measures ANOVA with the learning group (IN versus SG) as the between-subject variable and time (immediate versus delayed) as the within-subject variable.

4.4 Results:

4.4.1 Diagnostic test:

Participants in the IN basic science group outperformed those in the SG basic science group. Participants in the IN group obtained a mean score of 77% (SD=11), and those in the SG group had a mean score of 70% (SD=11) on the immediate test. On the delayed test, the IN group had a mean score of 75% (SD=11), and the SG group a mean score of 68% (SD=11). A significant effect of learning condition was found, F (1, 49)=6.61, p=0.01. These results are presented in Figure 2.

4.4.2 Cued Recall Test:

Participants in the IN basic sciences group obtained a mean score of 78% (SD=9), and those in the SG group had a mean score of 72% (SD=10) on the immediate test. On delayed testing a reduction in performance was apparent in both learning groups. On
the delayed test, the IN group had a mean score of 73% (SD=10), and the SG group a mean score of 70% (SD=11). The ANOVA revealed a significant main effect of time $F(1,49)=5.63$, $p=0.02$. Unlike the diagnostic test, the ANOVA showed no main effect of group $F(1, 49) =3.11$, $p=0.08$. These results are presented in Figure 3.

### 4.5 Discussion:

The IN group outperformed the SG group on immediate and delayed testing only for the diagnostic test, but not for cued recall test. This difference in diagnostic accuracy was captured between the two groups despite the fact that in the SG group the basic disease mechanism and the radiographic features were taught only minutes apart. This suggests that integration is key to fully utilizing the basic sciences.

This resonates with attempts made in the clinical reasoning literature to understand the cognitive role of basic sciences in enhancing diagnostic accuracy. It has been suggested that understanding the basic mechanisms of disease may create a coherent mental representation of disease categories and their features. That is, students who have an understanding of the basic scientific mechanisms underlying a disease are not only capable of describing the features of that disease, but more importantly, they may understand why those features occur together. This theory has been termed the “conceptual coherence” explanation for the role of basic science in enhancing diagnostic accuracy. It suggests that students do not rely solely on memory to arrive at the correct
diagnosis. Rather, because they understand why certain features occur, students with basic science knowledge are able to make the diagnosis that “makes sense” rather than simply focusing on the presence or absence of individual features.

In the current study, we used the SG learning condition as a laboratory model of teaching biomedical and clinical sciences separately but in close proximity. This appears to disrupt the conceptual coherence and diminishes the value of incorporating basic sciences into clinical teaching. This finding is consistent with previous studies of the role of biomedical knowledge in clinical reasoning. In a study by Patel and colleagues, medical students were provided with a basic science text relevant to a clinical problem. The participants were asked to first study the basic science then learn the clinical problem. They were then given a diagnostic test and were asked to provide an explanation for the underlying pathophysiology. When basic science information was segregated and given before the clinical problem, it was either used incorrectly or inconsistently in explaining clinical feature. This finding is similar to the effect observed in the segregated group in our study; when the basic sciences were explained before the radiographic features, the participants do not appear to use the basic sciences in a way that would help them with the radiologic abnormalities. However, when the same biomedical information was presented in an integrated fashion and embedded within the context of clinical radiologic features as mechanistic explanations, links were readily created between the two domains. In this manner, the basic science
appeared to be used to its full potential and overall, this effect was demonstrated as better diagnostic accuracy.

This study has some potential limitations. The study was conducted in an artificial educational setting. Moreover, the learning experience was tightly controlled as participants learned the material using a software program with standardized audio recordings. The learning process in the classroom might 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 somewhat different than in a lab setting.

4.6 Conclusion and Educational Implications:

Given the importance of diagnostic accuracy for dental students soon to be in independent practice, a major focus of research should be discerning the most effective teaching methodologies. To our knowledge this is the first comparative study of segregated versus integrated teaching of the basic and clinical sciences in oral radiology. This study supports the critical role of the basic sciences in enhancing diagnostic accuracy in oral radiology, and the role that information integration has on this process. Based on these results, and others like them, we recommend that biomedical concepts be embedded in clinical teaching. The educator could present radiographic examples of abnormalities and simultaneously explain the pathophysiology
that caused the radiographic changes. This could be a more effective way for students to retain knowledge that is meaningful to them than using incoherent feature lists.

Biomedical knowledge should not be emphasized only in undergraduate lectures but also in clinical training. To increase students' diagnostic accuracy in real life clinical scenarios and to increase the effectiveness of using basic science explanations, clinical instructors should be keen to re-emphasizing biomedical concepts on the clinical floor. This will allow the student to practice using the basic science knowledge to analyze radiographic images in real life clinical scenarios.

Furthermore, additional qualitative studies are needed in dental education to identify attitudes, challenges, and barriers toward the integration of clinical and basic science teaching. This type of collaboration between clinical teachers and scientist has been looked at in other health care professions. This type of research would be crucial to develop future programs that encourage interaction between clinical and basic sciences.
**Table 1:** Example of the radiographic features of periapical sclerosing osteitis explained in the two learning groups: segregated and integrated basic science learning

<table>
<thead>
<tr>
<th>Integrated</th>
<th>Basic Science</th>
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</table>

The body responds to microbiological injury with inflammation. Normally, bone metabolism represents a balance of osteoclast bone resorption and osteoblastic bone formation. Inflammatory mediators (cytokines, prostaglandins, etc.) tip this balance either to bone resorption or bone formation. Radiographically the affected cancellous bone will appear either radiolucent (resorption) or radiopaque (bone formation). Usually there is a combination of both processes. When most of the lesion consists of increased bone formation the term “periapical sclerosing osteitis” is used; when most of the lesion is undergoing bone resorption the term “periapical rarefying osteitis” is used.

The initial source of inflammation in periapical inflammatory lesions is a necrotic pulp. Toxic metabolites from the necrotic pulp exit through the root apex or the accessory canals causing an inflammatory reaction in the surrounding bone. Radiographically, the lesion is restricted to a region around the tooth with a center typically located at the apex of the root. However, lesions of pulpal origins also may be located anywhere along the root surface because of the accessory canals.
The periphery of periapical inflammatory lesions is ill defined, showing a gradual transition from the surrounding normal trabecular bone into the abnormal bone pattern.

Radiographically, there is loss of lamina dura and widening of the periodontal ligament space around the affected tooth, the bone resorption being stimulated by the inflammatory process.

Segregated Basic Science

1. Basic Science explanation

The body responds to microbiological injury with inflammation. The inflammatory response destroys or walls off the injurious stimulus and sets up an environment for repair of damaged tissue. Inflammatory lesions are the most common pathological lesions in the jawbones. Normally, bone metabolism represents a balance of osteoclastic bone resorption and osteoblastic bone formation. Inflammatory mediators (cytokines, prostaglandins, etc.) tip this balance either to bone resorption or bone formation. Usually there is a combination of both processes. The initial source of inflammation in periapical inflammatory lesions is necrotic pulp. Toxic metabolites from the necrotic pulp exit through the root apex or the accessory canals causing an inflammatory reaction in periapical structures and the surrounding bone.
2. Radiographic features using the structured algorithm

Sclerosing osteitis is a local response of bone around the apex of a tooth that occurs secondarily to necrosis of the pulp.

**Location:** In most cases the epicenter of periapical inflammatory lesions is found at the apex of the involved tooth. Less often, such lesions are centered around other regions of the tooth root. Most cases occur in the premolar-molar area in the mandible.

**Periphery:** The periphery of periapicals inflammatory lesions is ill-defined with a gradual transition from normal to abnormal bone.

**Internal Structure:** Internally, these lesions may appear either mainly radiolucent (periapical rarefying osteitis) or mainly radiopaque (periapical sclerosing osteitis) or more commonly a mixture of both.

**Effect on surrounding structures:** Periapical inflammatory lesions usually cause loss of lamina dura and widening of the apical portion of the periodontal ligament space.
Participants were divided into 2 learning conditions (Integrated Basic Sciences vs. Segregated Basic Sciences) and learn about 4 radiographic abnormalities. On day one, participants complete the learning phase, a diagnostic and a memory test. After a week, they complete a diagnostic test and the cued recall test.

**Figure 1: Diagrammatic representation of the study design**

Two learning Conditions

- Integrated Basic Science
- Segregated Basic Science

4 confusable Abnormalities

2 sessions

**Day 1**

- Learning phase
- Diagnostic test
- Cued Recall Test

**1-week delay**

- Diagnostic test
- Cued Recall test
**Figure 2:** Mean score percentages and standard error bars of the diagnostic test immediately after the learning phase and one week later for the integrated basic science group (IN), and segregated basic science group (SG) groups.
Figure 3: Mean score percentages and standard error bars of the cued recall test immediately after the learning phase and one week later for the integrated basic science group (IN), and segregated basic science group (SG) groups.

$P > 0.05$
Chapter 5
The Effects of Diagnostic Strategy and Instructional Methodology on Diagnostic Accuracy
Baghdady M, Carnahan H, Lam E, Woods N. Advances in Health Sciences
(submitted)

5.1 Introduction:

Oral radiology is an essential part of undergraduate dental training. By graduation, all dental students are expected to have basic skills in interpreting intra- and extra-oral radiographic images. This requires a mastery of two identifiable and non-separable components of visual diagnosis; perception, the ability to recognize abnormal patterns on a radiograph, and cognition, the ability to interpret these abnormal patterns to arrive at a diagnosis.65

There has been much debate surrounding the best way to teach diagnostic radiology to novices. The debate tends to focus around diagnostic strategies and the most appropriate training models for the novice clinician. In oral radiology, most educators argue that novices’ diagnostic strategies should follow an analytic or systematic approach, using a step-by-step analysis of all the radiographic features of an abnormality so that a diagnosis can be made on the basis of these findings.39 The analytic process is believed to reduce bias and premature closure of the decision
making process. However, others have argued that simply viewing an image will automatically lead to a holistic diagnostic hypothesis. This is then followed by a deliberate search for features that support the initial hypothesis. This non-analytic approach allows the clinician to make a decision based on a comparison of the radiographic image to a similar image seen previously. Critics of teaching novices to rely on non-analytic processing argue that the success of this diagnostic strategy is limited by the novice’s minimal experience and the varied radiographic appearances of both normal anatomy and pathologic disorders. However, there is some empirical evidence that novices can employ non-analytic reasoning successfully. For example, in a study by Norman and colleagues, one of two approaches was taught to novice undergraduate psychology students learning to interpret electrocardiograms (ECG): an analytic diagnostic strategy or a non-analytic diagnostic strategy. Students in the analytic group were encouraged to carefully consider all the data on the ECG by checking off features on a response sheet, and then synthesizing a diagnosis. The non-analytic group was told to first diagnose the case and then identify the individual features. Participants required to diagnose first, achieved accuracy level 50% higher than those who used the analytic approach. This study demonstrates the significant advantage of a non-analytic approach to diagnostic reasoning in rank novices.

Studies such as this one provide critical insight into the diagnostic strategies used by novice clinicians. However they do not take into account the impact of the specific instructional method used to introduce students to novel radiographic or clinical
abnormalities. This distinction is important because before a novice clinician may begin to employ any specific strategy in the interpretation of radiographic images, they must first learn about the definitions, signs and features associated with various radiographic abnormalities.

Undergraduate dental training traditionally provides students with core knowledge in the foundational or basic biomedical sciences that will be used to underpin their future clinical education. Note that our use of the term ‘basic science’ refers to the pathophysiological basis of abnormalities at the cellular and biochemical levels, as well as the normal anatomy and physiology of the body. Recent research suggests that the fundamental basic sciences play an essential role in enhancing diagnostic accuracy in novice clinicians. A study by Baghdady and colleagues, attempted to shed light on the possible cognitive mechanism basic sciences played in enhancing diagnostic accuracy in a visual domain. The study compared the efficacy of three instructional methodologies in teaching the interpretation of intrabony abnormalities: 1. Providing basic science explanations to the radiographic features; 2. Using a structured algorithm to organize the features; 3. Relying on an unstructured list of radiographic features of each entity. It was found that students in the basic science learning group had higher diagnostic accuracy than those in the other two groups. A basic recall test revealed no difference in rote memory for clinical features. It was argued that knowledge of causal mechanisms of disease allowed for the development of a coherent mental representation of diagnostic disease categories and their features.
Moreover, it was surmised that the basic science knowledge aided in “true understanding” of the disease entities not by increasing the quantity of the information, or by acting as a structural mnemonic, but by creating coherent networks of concepts and examples. 

Based on the findings supporting conceptual coherence theory, the findings of Norman and colleagues and the larger body of research on clinical reasoning, there is ample evidence to expect that the success of an integrated basic science instructional methodology might also be influenced by the specific diagnostic strategy (e.g. analytic versus non-analytic) that students are encouraged to use. The basic science explanations led to better overall diagnostic accuracy but did not enhance participants’ memory for individual features of a disease category. Thus, basic science instruction should work well with a holistic non-analytic diagnostic strategy. Alternatively, analytical reasoning strategies focus on feature-by-feature analysis of the disease. If basic science students are forced to use an analytical reasoning strategy and conduct a feature-by-feature analysis of the abnormality, then we can expect the benefits of basic science instructions to be mitigated.

There have been no studies in the literature that explore the relationship between instructional methodology and diagnostic strategy on clinical reasoning. The present paper describes an experiment that evaluates the relative effectiveness of non-analytic
and analytic strategies in the context of oral radiology. It also explores the relationship between basic science instructional methodology and diagnostic strategy (analytic and non-analytic reasoning). We hypothesize that diagnostic accuracy will be impacted by diagnostic strategy. Specifically, we expect that novices will have higher diagnostic accuracy using a non-analytic diagnostic strategy. This would replicate what has been shown in the literature in other medical domains. Unlike the findings of our previous studies manipulating basic science instruction, we predict that participants who learn disease categories through basic science but are forced to use an analytic diagnostic strategy will not maintain the advantage previously seen with basic science instructions.

5.2 Materials and methods:

Human research ethics approval was obtained from the University of Toronto Research Ethics Board and the ethics board of a local community college. Second year undergraduate dental and second year dental hygiene students were recruited for participation in the study. These populations were chosen because the participants had completed introductory courses in oral radiology, were assumed to have developed an understanding of basic radiographic terminology and could identify normal radiographic anatomy, but had no prior exposure to the specific diseases selected for the study or radiographic interpretation.
5.2.1 Learning Material:

The learning and testing materials were adapted from a previous study. The learning materials included sets of intra-oral periapical images accompanied by audio recordings that narrated the written material in the presentation. The participants learned about the radiographic features of four potentially confusable intra-bony entities: periapical osseous dysplasia, complex odontoma, periapical sclerosing osteitis and dense bone island. The participants were then randomly divided into two instructional conditions. In the basic science learning condition (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 learning condition (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 this was then applied it to the given disease.

5.2.2 Testing Material:

Each participant completed two tests:

Diagnostic test:

As a test of diagnostic ability, the participants were presented with 28 different radiographic images of the four intrabony pathologies they were exposed to in the learning phase. To manipulate diagnostic strategy, half of all the participants were
directed to first identify all the radiographic features and then choose the correct diagnosis from the list of the four intrabony entities provided. The remaining half of the participants were directed to choose a diagnosis first, and then identify the radiographic features. Feature identification was done by pointing at the feature on a computer screen, clicking on that feature using a desktop mouse, and then typing a description. This was done until all the features visible to the student were exhausted (Appendix #5).

Two versions of the diagnostic test, A and B, were created for the purpose of counter-balancing. Both tests were matched for difficulty. Participants that took test A immediately following the learning session took test B for the one week delayed test, and vice versa.

**Cued recall test (memory test):**

This test was designed to assess the ability of participants in each learning condition to recall and identify the radiographic features of each intrabony abnormality. Participants were provided with a list of twelve features with no accompanying images. The participants were then asked to choose the correct features for each disease. Its main role is to assess rote memory.
5.3 Procedure:

A customized software program was created using Revolution® software (Version 2.1, Runtime Revolution Ltd., Edinburgh, Scotland) that incorporated the learning material, radiographs, audio recordings, and the tests. Each participant was provided with a computer and instructions for viewing/testing. Participants were randomly assigned to a learning condition (basic science or structured algorithm) and testing condition (diagnosis first or features first). Participants first completed the learning phase and were then directed to the testing phase. After one week, the participants returned to take the diagnostic and memory tests again. Those who had taken test A the previous week were given test B, and vice versa. A diagrammatic representation of the study design is represented in Figure 4.

5.4 Analyses:

Eighty students participated in the study. Only 73 participants completed both immediate and delayed sessions and were included in the study. For each participant the scores on the diagnostic tests were calculated on day 1 and day 2. The data was subjected to a 2x2x2 repeated measures ANOVA with the learning condition (basic science or structured algorithm) and testing condition (diagnosis first or features first) as the between-subject variables, and time (immediate or delayed) as the within-subject variable. The same analysis was conducted for the cued recall test.
5.5 Results:

5.5.1 Diagnostic test:

Participants that were directed to diagnose first and then identify the radiographic features (Dst condition) out-performed participants that were directed to identify the features first, and then commit to a diagnosis (Fst condition) on immediate and delayed testing regardless of learning condition. We found a main effect of testing condition to be statistically significant $F (1,70)=4.79$ $p=0.03$ with a moderate effect size of 0.07 (eta square). No main effect of learning condition was found $F (1,70)=0.39$ $p=0.53$. Although the interaction between learning condition (basic science or structured algorithm) and testing condition (Diagnosis 1st or features 1st) was not found to be significant $F (1,70)=0.4$ $p=0.5$, participants in the basic science condition and the algorithm condition had similar diagnostic scores when assigned to the diagnosis first condition on both immediate and delayed testing. When students were asked to identify features first, their scores appeared to drop; the basic science condition less than the structured algorithm condition. The results of the diagnostic test are summarized in Table 2.

5.5.2 Cued Recall Test:

The main effects of learning $F (1,69)=0.55$ $p=0.5$ and testing conditions $F (1, 69)=0.3$ $p=0.6$ were not found to be significant. The interaction between learning condition and testing condition, was also not significant $F (1,69)=1.34$ $p=0.5$. The results of the cued recall test are summarized in Table 3.
5.6 Discussion:

The results show that participants who were directed to make a diagnosis first, and then identify the radiographic features (i.e. the non-analytic reasoning condition) had higher diagnostic accuracy then those who were directed to identify visual features first, and then commit to a diagnosis (i.e. the analytic reasoning condition). This was observed regardless of their learning condition (basic science or structured algorithm), and is consistent with many studies in the literature. When novices are encouraged to use pure analytical strategies to make a diagnoses, their diagnostic accuracy tends to decrease compared to those who are directed to go with their first impression or to use a combined approach of both analytic and non-analytic reasoning.

In the Baghdady et al 2009 study, in which basic science instruction was compared to using a structured algorithm, novices in the basic science condition out performed the structured algorithm condition on a test of diagnostic accuracy. When we compare these observations with the current study we find that the advantage the basic science group had in the Baghdady 2009 study is not seen in the current study. Critically, the main difference between these experiments is that participants in the earlier study were not forced to use a specific diagnostic strategy. In the current study, when the diagnostic strategy was manipulated and participants were “forced” to adopt a specific approach, the advantage of the basic science instruction, appears to have been mitigated.
To further explain this finding it is necessary to revisit the proposed role for basic science knowledge in clinical reasoning. It has been argued that basic science instruction allows for the development of a holistic coherent mental representation of a particular disease. Students who learned the basic science mechanisms underpinning a disease might be more likely to make a diagnosis that made sense and not rely solely on counting the number of identifiable features on the image. This instructional methodology is in line with a non-analytical reasoning strategy, in which the student would make a holistic diagnosis based on the totality of the identified features. Thus, left to their own devices, students that learn through basic science instruction should be more likely use a non-analytic reasoning diagnostic strategy. Once the student is forced to analyze the abnormality feature by feature, as was the case in the feature first testing condition, the coherence created by the basic sciences is disrupted and a decline in accuracy is observed. Conversely the structured algorithm instructional method may naturally lead to an analytical strategy when students were left to their own devices. In the Baghdady 2009 study, this resulted in low diagnostic accuracy for this group of students. In the present study, however, when participants were forced to make a diagnosis first (i.e. the non-analytic approach), diagnostic accuracy improved.

The results of this study demonstrate the importance of non-analytical reasoning in novices in oral radiology. These results are a significant addition to the ongoing debate surrounding the training of new clinicians particularly for the domain of oral radiology. Traditionally, analytical reasoning has been highly advocated in the oral radiology
curriculum, and students were discouraged from using any non-analytical diagnostic strategies. Our findings challenge this practice. Even though this study directly compares analytic and non-analytic strategies as if they were competing, other research provides evidence that these two processes are complementary and should not be viewed as being mutually exclusive. Students learning oral radiology could potentially benefit from specific training in the use of combined analytic and non-analytic diagnostic strategies.

This study also demonstrates that the use of a specific diagnostic strategy has an impact on diagnostic accuracy beyond that of the instructional method. Despite several studies in which basic science instruction was found to lead to improved diagnostic performance, the positive effects of basic science instruction were mitigated in the current study. This is a key issue for educators who may devote effort to the design of instructional materials that integrate basic science and clinical findings with little consideration of diagnostic strategy. Educators should be mindful of the potential influence of analytic and non-analytic approaches on the effectiveness of instructional method. By understanding the holistic presentation of diseases created by an integrated basic sciences instructional methodology, educators should be aware that a holistic based diagnostic strategy such as non-analytical reasoning, is likely to preserve the benefit of basic sciences and may continue to develop an integrated practitioner. Further, students may benefit from specific training on diagnostic strategy that emphasizes both analytic and non-analytic approaches.
This study has some potential limitations. The number of participants in the study may have affected the ability to detect a significant interaction between instructional methodology and diagnostic strategy. When the participants were divided into four groups, the number of participants per group was fairly low (observed power=0.07). An interaction may have been statistically significant with more participants in each combined condition.

To further our understanding of the relationship between diagnostic strategies and instructional methodology, a third testing condition with combined diagnostic strategies (analytic and non-analytic) may be useful. In this group, students would be encouraged to use both techniques. This would be a valuable consideration for future studies as it has been shown that students who use a combined technique tend to have better diagnostic accuracy. However, this has not been tested using an integrated basic science instructional methodology.
Figure 4: Diagrammatic representation of the study design: Participants were divided into two learning conditions (Basic science vs. Structured algorithm) and learn about 4 radiographic abnormalities. They were then divided into 2 testing conditions (Diagnosis 1st vs. Features 1st). On day one, participants completed the learning phase, a diagnostic/visual test and a memory test. After a week, they completed a diagnostic/visual test and the cued recall test.
Table 2: Mean scores and standard deviations (proportion correct) on the diagnostic test immediately after learning and after a one-week delay

<table>
<thead>
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<th></th>
<th>Immediate</th>
<th></th>
<th>Delay</th>
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<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
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<tr>
<td>Basic Science Diagnosis 1st</td>
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<td>Algorithm Feature 1st</td>
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<td>N=18</td>
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**Table 3**: Mean scores and standard deviations (proportion correct) on the **cued recall test** immediately after learning and after a one-week delay

<table>
<thead>
<tr>
<th>Description</th>
<th>Immediate Mean</th>
<th>Immediate SD</th>
<th>Delay Mean</th>
<th>Delay SD</th>
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<td>0.72</td>
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<td>Basic Science Features 1&lt;sup&gt;st&lt;/sup&gt;</td>
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<td>Algorithm Feature 1&lt;sup&gt;st&lt;/sup&gt;</td>
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Chapter 6

Testing the Basic Science Framework: The effects on Diagnostic Accuracy

Baghdady M, Carnahan H, Lam E, Woods N: Medical Education

(submitted)

6.1 Introduction:

The impact of testing on learning is an emerging area in health professions education research. Traditionally, educators have viewed examinations primarily as devices to measure students’ knowledge, and while this is certainly one function of testing, recent work suggests that testing can also change knowledge\(^48\). Testing has been found to have a positive effect on learning, and in particular, the retention of knowledge, and this phenomenon has been termed the “testing effect”\(^{48,51,52,54}\). Both educators and students can appreciate the indirect effects of assessment. When students prepare for a test, the quality and amount of study time positively affect retention. There are, however, also less obvious direct effects of testing that have been identified by researchers in cognitive psychology. The act of taking a test itself has been shown to enhance learning and long term memory\(^{48}\).

Several theories have been proposed to account for improved retention after testing. The total-time hypothesis suggests that the testing effect is the result of additional exposure to the material. As students complete a test, they have an additional
opportunity to engage with the information being tested, and this leads to “over-learning” of material. The retrieval hypothesis suggests that recalling information during a test requires the student to be engaged in active mental processing. The active retrieval of information from memory in a testing scenario simulates a skill that will be needed should the student be required to recall the information long after the test is over.

Although largely confined to cognitive psychology and research in secondary education, test enhanced learning is beginning to find its way into the realm of medical education. Larsen et al argued convincingly that frequent testing should be adopted in medicine in order to capitalize on the positive effects that test enhanced learning has on learning and memory. Kroman et al. determined that incorporating a test in a resuscitation skills course increased learning outcomes. They found that students who were required to take a practical test as the final activity, showed better resuscitation skills than those who spent an equal amount of time practicing the skill with no test. This positive effect was found even after a significant time delay. While previous studies focused mainly on the increased retention of facts, the Kroman study was unique because it demonstrated enhanced learning outcomes associated with skill acquisition immediately after learning and after a time delay.

Unfortunately, little research has been done to examine the effects of testing on knowledge that goes beyond just basic recall. Whether it be skills acquisition or learning
clinical and biomedical facts, it is critical that medical curricula also be designed to impart students with a deeper understanding of complex concepts and theories. A higher level of understanding may be of particular importance in health professions education because this provides the student with a basis for which to manage patient care. We and others have examined the value of a deeper understanding of disease processes in clinical reasoning. Our previous work examined the impact of basic science knowledge on radiographic diagnosis by novices. We demonstrated that students who learned the basic pathophysiologic mechanisms that dictate the appearances of disease on radiographic images developed a more coherent mental representation of clinical disease categories. The literature in test-enhanced learning suggests that the inclusion of formal assessments of basic science knowledge as part of the learning process might be useful in improving students’ understanding of disease mechanisms and theoretically could in turn improve their diagnostic accuracy.

To operationalize the important concepts found from our previous study and studies in test enhanced learning, we examined whether testing could be used as a practical measure to enhance students’ abilities to make radiographic diagnoses. Participants in this study were taught the radiographic features and basic science disease mechanisms underlying four intrabony abnormalities. The diagnostic abilities of those students who completed a test of this basic knowledge were compared with students who were given the answers to the test, but were not required to actually take the test. We hypothesize
that the inclusion of the test improves students' understanding of the underlying mechanisms of the abnormalities, leading to improved diagnostic accuracy.

6.2 Materials and Methods:

6.2.1 Participants:

The study population was second year students enrolled in the undergraduate dentistry program at the University of Toronto (U of T) and 2nd year dental hygiene students from a community college dental hygiene program. This population was specifically targeted because participants had an understanding of basic terminology in radiology and could identify normal anatomy on radiographic images, but had minimal prior exposure to radiographic interpretation or the specific diseases selected for the learning material. Human research ethics approval was obtained from the University of Toronto and the community college.

6.2.2 Learning material

The learning materials, adapted from a previous study, included a set of text and image slides accompanied by recorded narration. The students learned about the radiographic features and the underlying pathophysiology of four confusable intrabony diseases; periapical cemental dysplasia (a bone dysplasia), complex odontoma (a benign odontogenic tumor), periapical sclerosing osteitis (an inflammatory lesion), and
dense bone island (a bony hyperostosis). Each abnormality represents a different disease category. The training passages described the radiographic features of each disease as well as the basic pathophysiology underpinning the radiographic features. The radiographic descriptions and the basic science explanations for the learning materials were adopted from “Oral Radiology: Principles and Interpretation” by White and Pharoah.

**Intervention Test (basic science test):**

A basic science comprehension test was used as the educational intervention. The test was composed of 23 multiple-choice questions. The questions were created to test the pathophysiology knowledge that was presented to the participants in the learning phase. Items were developed by the research team and distributed to 3 certified specialists in oral and maxillofacial radiology for review and revision.

**Additional study material:**

Study passages were created to provide an alternative to the intervention test. This material contained the same information as the intervention test but in narrative form. The passages were timed specifically to equate time on task for both the study and test conditions.
6.2.3 Outcome Assessment Material

a. Diagnostic skills assessment:

As a test of diagnostic ability, participants were presented with 22 intra-oral periapical radiographs and were instructed to choose the correct diagnosis from a list of the four learned abnormalities. Two versions of the diagnostic test, A and B, were created for the purpose of counter-balancing. The tests were matched for difficulty.

b. Feature list assessment:

This test was designed to assess the ability of participants in each condition to recall the individual radiographic features of each intrabony abnormality. Participants were provided with a list of twelve radiographic features without providing an image for each learned abnormality. The participants were then asked to choose the correct features from the list that match the features of the specific intrabony abnormality.

6.3 Procedure

A customized software program was created using Revolution® software version 2.1 (Runtime Revolution Ltd., Edinburgh, Scotland) that incorporated the learning material, radiographs, audio recordings, and the tests. Each participant was provided with a computer and instructions for viewing and testing.
One hundred and twelve students participated in the study. Participants were randomly assigned to either the test-enhanced condition (TE) or the study condition (ST). All participants began with the learning phase and reviewed the material at their own pace. Once the learning was completed, participants in the TE condition were directed to complete a multiple-choice test; the intervention (basic sciences) test. Participants were provided with feedback during the test. After each response the computer program displayed the word “correct” or “incorrect” as well as the correct answer. Participants in the ST condition were instructed that they would be given additional study time instead of taking the multiple-choice test. These students were presented with the additional study material composed of the correct answers to the basic science comprehension test in paragraph form and were asked to listen to the audio recordings of each paragraph. The total time spent on these tasks across the two conditions (TE and ST) was equated. Participants in both conditions then proceeded to the diagnostic skill and feature list assessments. After one week, the participants returned to complete a novel version of the diagnostic and feature list assessments. Figure 5 represents the diagrammatic representation of the study design.

6.4 Analysis:

The data collected were the scores for the diagnostic skill and the feature list assessment. For each student the percentage of correct responses was calculated for
the immediate and delayed tests. The diagnostic skill and feature list assessment for all
the participants were analyzed separately using a 2x2 repeated measures ANOVA with
the testing condition (TE, ST) as the between-subject variable and time (immediate vs.
delayed) as the within-subject variable. One hundred and twelve participants were
included in the study: 55 participants in the TE condition and 57 in the ST condition.

6.5 Results:

6.5.1 Diagnostic skill assessment:

Participants in the TE condition (n=55) outperformed those in the ST condition (n=57) on
both immediate and delayed testing. Participants in the TE condition obtained a mean
score of 0.74, and those in the ST condition had a mean score of 0.67 on the immediate
test. On the delayed test, the TE condition had a mean score of 0.72, and the ST
condition a mean score of 0.68. A significant effect of testing condition was found,
\( F(1,110)=4.27, p=0.04 \). These results are shown in Figure 6.

6.5.2 Feature list assessment:

On the immediate cued recall test, the TE condition obtained a mean score of 0.73 and
the study ST condition a mean score of 0.75. One week later, on delayed testing, a
reduction in performance was apparent in both conditions. The TE condition obtained a
mean score of 0.60 and the ST condition a mean score of 0.61. The ANOVA revealed a
significant main effect of time $F(1,110)=128.23$, $p<0.01$. Unlike the diagnostic test, the ANOVA showed no main effect of testing condition $F(1,110)=1.23$, $p=0.3$. These results are presented in Figure 7.

6.6 Discussion:

The test-enhanced condition outperformed the study condition on both immediate and delayed diagnostic skill assessment. It is important to note, that students in the TE condition outperformed students in the ST condition, even though the interventional test was on basic science, not diagnostic skill. This may be explained by examining the specific mechanism through which basic sciences knowledge theoretically enhances diagnostic accuracy. Basic science knowledge provides a supportive framework that helps create coherent mental representations of disease categories $^{12,21,38}$. By administrating a test on the basic science material, we are encouraging students to engage in an effortful retrieval process of the basic science framework. This additional engagement with the basic science mechanisms of the abnormalities allowed students to make the diagnosis that “made sense”. Thus, the testing effect strengthened the basic science framework leading to higher diagnostic accuracy.

The results showed no difference between the TE condition and the ST condition on the feature list assessment that was designed to test memory of individual radiographic
features. Unlike the diagnostic test, taking a basic science interventional test did not improve memory on the feature list test. There may be two explanations for this finding. First, the intervention test did not match the feature list assessment in content or format. The interventional test strictly enforced the deeper understanding of disease mechanisms underpinning the abnormalities, while the feature list assessment focused on the memory of individual radiographic features.

It has been shown that when deeper understanding is promoted by an instructor, as was the case in the intervention test, students performed poorly on assessments that emphasized recognition of isolated facts such as individual radiographic features. Second, a basic science framework allows students to understand disease categories in a holistic manner rather than focusing on individual features. Therefore, administering a basic science test improves diagnostic accuracy and not rote memory of radiographic features.

### 6.7 Educational implication and conclusion:

Test enhanced learning has the potential to be a useful tool in health professions education. While some educators have questioned the utility of test enhanced learning beyond improving basic recall, this study provides evidence that testing may be
used effectively to enhance students’ diagnostic abilities. Indeed, this may be an additional strategy to strengthen the connection between the basic and clinical sciences, and maximize their interplay. Educators who teach the basic and clinical sciences together in an integrated fashion may benefit from adding formative assessment opportunities that test the basic sciences as they relate to clinical practice.
**Figure 5:** Diagrammatic representation of the study design: Participants learned about 4 radiographic abnormalities using basic sciences explanations. They were divided into 2 testing conditions (test group vs. study group). On day one, participants completed the learning phase, a diagnostic and a memory test. After a week, they completed a diagnostic test and the cued recall test.
Figure 6: Mean scores of the diagnostic task assessment immediately after the learning phase and one week later for the test-enhanced condition (TE), and study condition (ST).
**Figure 7**: Mean score of the feature list assessment immediately after the learning phase and one week later for the test-enhanced condition (TE), and study condition (ST).

* $p > 0.05$
Chapter 7
General Discussion

7.1 Conceptual Coherence: Theoretical Development and Framework

This research began with the hypothesis that basic science knowledge is an integral part of the diagnostic task. It was proposed that the basic sciences enhance diagnostic accuracy by creating coherent mental representations of disease categories and their features. This cognitive theory is referred to as “conceptual coherence.” Throughout these studies, our goal was to examine the role of conceptual coherence in multiple ways. Specifically, we hypothesized that if basic sciences acted as the framework connecting clinical features and creating coherent conceptual models of disease categories, the integrity of these models could be created and disrupted by altering the specific circumstances under which novices are trained or assessed. In the study testing the integration of basic and clinical sciences (Chapter 4), we were able to demonstrate the process of creation and disruption of coherence by either integrating or segregating biomedical and clinical knowledge. We found that integration of basic sciences and radiographic features were achieved when the basic sciences were used as explanatory links between the radiographic features. As a result of this integration, the learner was able to create coherent conceptual models of disease categories as manifested by an increase in diagnostic accuracy. On the other hand, when the exact same information
was intentionally segregated, connections between the basic and radiographic sciences were not formed, and conceptual coherence failed to develop. This disruption was revealed as a loss of diagnostic accuracy.

Another way to disrupt conceptual coherence and affect diagnostic accuracy was to manipulate the diagnostic strategies used by participants. Conceptual coherence theory posits that basic science instruction allows for the development of whole, holistic coherent mental representations of disease categories. Thus we hypothesize that students who learned through basic science explanations may be more inclined to make a diagnosis based on a holistic impression of the lesion, rather than relying on clinical feature counting. This approach relies on the totality of the identified features, and is consistent with a non-analytic diagnostic strategy rather than a more deliberate feature-by-feature analytic diagnostic strategy. In our study presented in Chapter 5, when participants learned disease categories through basic science explanations and then were instructed to make a diagnosis, coherence was formed and maintained through the non-analytic diagnostic strategy. This was manifested as maintenance of diagnostic accuracy. When the students were forced to analyze the abnormality feature-by-feature (analytic reasoning), the coherence created by the basic sciences was disrupted. This diagnostic strategy encouraged students to cognitively dissect features that would have otherwise been organized in a coherent framework. This led to a drastic reduction of the positive effect basic sciences had on diagnostic accuracy consistently seen in previous studies. 


Lastly, we attempted to strengthen the basic science framework using test-enhanced learning. We hypothesized that basic sciences was as a framework that “connected the dots” between clinical features. From our previous studies, it is clear that for this to take place, the basic sciences must explain why features occur, the relationship between different features, and why features can occur together in certain disease categories. One may assume based on the conceptual coherence model, that students need to have a solid understanding of the basic science links and mechanisms in order to achieve coherence. By administrating a test on basic science links, we encouraged the students to engage in an effortful retrieval process of the basic science framework. This additional engagement in basic science mechanisms allowed students to strengthen the retrieval of the basic science framework and in turn made it more useful in the diagnostic process. Thus the testing effect re-enforced the basic science framework, leading to higher diagnostic accuracy.

This body of research furthers our understanding of the cognitive role basic sciences play in clinical reasoning. This work must be viewed in the greater context of the ongoing debate on the use of biomedical knowledge by novices and experts.

In an effort to compare the two-world theory by Patel and their own encapsulation theory, Rikers and colleagues asked the question, “…is biomedical knowledge two worlds apart, or is it encapsulated?”

As discussed earlier, Patel concluded that biomedical knowledge and clinical knowledge are two separate and not entirely compatible bodies of knowledge. She states that
“...the basic sciences and the more practical clinical knowledge form two separate domains with their own individual structures and the clinical information cannot be embedded into the basic science knowledge structure.”

When examined critically, it can be appreciated that the basic and clinical knowledge were presented in a traditional segregated manner. Medical students were provided with basic science text relevant to a clinical problem first. The clinical case was then presented, followed by a diagnostic test. The students were asked to provide an explanation for the underlying pathophysiology, and were expected to make the correct links between the basic science text and the clinical cases. The students were, however, not successful at using the basic science text to explain the clinical cases, and in fact the disease mechanisms appeared to have confused them.

We would argue that the findings in this study are inconclusive in explaining whether basic science has a role in diagnostic accuracy. In our study integrating and segregating clinical and biomedical knowledge, we observed effects similar to those seen. When the clinical and basis sciences were segregated the novices exhibited low diagnostic accuracy. This could be explained by the fact the students may not have used the basic sciences correctly. However, when integration was used, diagnostic accuracy increased. The observed increase in diagnostic accuracy using basic sciences has also been seen in the studies conducted by Woods and colleagues. Integration was achieved in their studies by creating a cause and effect narrative that linked the basic sciences to the clinical features. They found that students given integrated explanations had a two folds advantage at diagnosis after a time delay. In conclusion, the two-world theory can be considered a reasonable explanation by Patel in the specific context of their study. When the basic and
clinical sciences are taught independently with no attempt to directly link them together, connections fail to form and they do become two separate entities (Figure 8). When the basic sciences are used as causal links to explain the underlying mechanism of how clinical features arise, the two bodies of knowledge no longer form separate, incompatible knowledge bases. In fact, together they create a framework within the learner’s mind that allows for the creation of the coherent mental models of disease categories (Figure 9).

The encapsulation theory proposes that students start their training by learning basic science information that gradually becomes encapsulated in clinical knowledge after gaining clinical expertise. The expert clinician now has elaborate biomedical knowledge that is strongly integrated with clinical knowledge. This allows the expert to make shortcuts in their lines of reasoning, and in turn, may not need to refer to basic science mechanisms in routine cases. However, if the expert is faced with a difficult case, they tend to revert to biomedical mechanisms. The encapsulation theory however, does not explain the immediate increase in diagnostic accuracy seen with complete novices that have not had the opportunity to develop their clinical expertise through multiple encounters with clinical cases. It also does not explain the ability of novices to use basic science to diagnose difficult case and demonstrate expert like behavior. We believe that the conceptual coherence theory may provide a better explanation to these issues than the encapsulation theory. When we compare the encapsulation and conceptual coherence theories, there appears to be differences in the structural relationship between the basic and clinical sciences. In the conceptual coherence model, the clinical
features and the basic sciences form complex mental schemas of disease categories where the clinical features are embedded in a basic science narrative. The basic science links the features of a disease through explanatory pathways (Figure 9). These features might have otherwise been viewed as random lists of unrelated facts related to a disease entity. When students are introduced to disease concepts using basic sciences, coherent mental representations of abnormalities are created at the initial time of learning. This may explain why we observe an immediate positive effect of basic sciences even though students have minimal clinical experience. The encapsulation theory, on the other hand, has a different view on the structure of basic and clinical sciences. It describes clinical knowledge as being layered over a core understanding of basic sciences (Figure 10). This process happens over time and after encountering may clinical cases. The encapsulation theory predicts that clinical knowledge has direct effects on diagnostic performance, while basic science only has indirect effect\textsuperscript{23,25}. In the conceptual coherence model, the basic science has a direct effect on clinical reasoning by forming the main framework that enables accurate categorization of a disease and hence diagnostic accuracy.

In summary we believe the conceptual coherence theory provides the most accurate explanation to the cognitive role basic science plays in enhancing diagnostic accuracy in novice diagnosticians when compared to the two-world theory and the encapsulation theory. Figures 8-10 represent diagrams that depict the structural relationships between the basic and clinical sciences according to the two-world hypothesis, the encapsulation theory and conceptual coherence.
Figure 8: Diagrammatic representation of the structural relationship between the basic and clinical sciences according to the *two-world hypothesis*. Patel: “The basic sciences and the more practical clinical knowledge form two separate domains with their own individual structures.”
**Figure 9:** Diagrammatic representation of the structural relationship between the basic and clinical sciences according to the *conceptual coherence theory*. The clinical features and the basic sciences form complex mental schemas of disease categories where the clinical features are embedded in a basic science narrative. The basic science links the features of a disease through explanatory pathways.
**Figure 10:** Diagrammatic representation of the structural relationship between the basic and clinical sciences according to the *encapsulation theory*. The clinical knowledge is layered over a core understanding of basic sciences. Clinical and basic science knowledge becomes encapsulated over time, and the expert rarely uses the basic sciences except when faced with a difficult case.
7.2 Conceptual Coherence: Principles in Educational Application

There have been frequent calls for the incorporation of basic sciences into clinical teaching. Medical and dental schools are looking to move away from the traditional Flexnarian curriculum where the basic sciences are taught only as foundational knowledge followed by clinical training. Many have outlined innovative educational interventions at different curricular levels to incorporate the basic sciences in clinical training. However, little attention has been given to the cognitive aspects of “integrating” biomedical and clinical sciences.

Our studies provide additional insights of the cognitive role played by the basic sciences in enhancing diagnostic accuracy. This body of research not only provides support for the cognitive theory of “conceptual coherence”, but it may also provide core principles needed to successfully integrate the basic sciences a clinical curricula.

7.2.1 Integration is Key

A key principal that can be concluded from our studies is that to achieve conceptual coherence, integration of the basic and clinical sciences is crucial. Moreover, the basic science should be embedded in the clinical context as explanatory pathways emphasizing the mechanistic underpinnings of clinical and/or radiographic features.
Basic science should also link individual clinical features to one another in a particular disease. The importance of the causal nature of the basic sciences in enhancing diagnostic accuracy was clear in the Woods and Baghdady studies. In these studies, the main biomedical science used was pathophysiology. However, a recent study by Goldszmidt has shown that learning may be affected by other non-biomedical sciences if it were to also be used in a causal manner\textsuperscript{75}. In this study, novice students who learned respiratory disorders in combination with basic physics explanations of sound conduction in the lungs, out-performed the control group that learned the abnormalities without the aid of physics explanations on diagnostic tests. Even through the type of basic science in this study was not biomedical in nature, it was able to link causal explanations to the clinical features, and a positive affect was observed\textsuperscript{75}.

The integration process between basic and clinical sciences should not be left for the learners to deduce on their own. Accurate transfer of basic science concepts to clinical problems by novices is unlikely to occur. Psychologists have defined transfer as the act of applying conceptual knowledge learned in one context to solve a problem in a novel context\textsuperscript{76}. Transfer has been shown to be a difficult process in the literature. Researchers have found that students who know a concept will typically only be able to access it to solve a novel problem 10\% to 30\% of the time\textsuperscript{77}. This has also been demonstrated in the inability of students to transfer or utilize basic science knowledge in a clinical context\textsuperscript{15,76}. This fails to happen even when the biomedical information was provided only minutes before a clinical scenarios\textsuperscript{21}. The educator must make the causal relationships explicit. When examining the literature, a classic example of unsuccessful
integration can be observed in the studies by Patel and colleges who suggested the “two world hypothesis”. As discussed earlier, it is clear that the basic sciences and clinical scenarios in their studies were presented separately. The students were then left to their own devices, and it was assumed that they would transfer the biomedical knowledge to the clinical scenarios accurately. Unfortunately, this was not achieved\(^{15}\). We believe that the lack of integration of the biomedical knowledge and the clinical knowledge resulted in the inability of the students to use the information correctly to their advantage. This finding is similar to the effect observed in the segregated group in our study. The lack of proper integration of the basic and clinical sciences led to the inability of the students to transfer their basic sciences knowledge to the clinical context which lead to the inability of the student to form coherence. As a result, a decline in diagnostic accuracy was observed.

The lack of integration is the main problem with the structure of the traditional two stage model of learning, where basic sciences are taught first followed by clinical training at a later time. The traditional curriculum may not be conducive to integrated learning\(^ {21}\). In response to this new realization, many medical and dental schools have attempted to solve the problem by actively reforming their curricula to embrace “integration”. Integration has been defied in the literature as “an operational concept where separate areas of knowledge are deliberately unified”\(^ {78, 79}\). In general, integration in the literature can be seen at the program, course and session levels in the curriculum\(^ {78}\). Integration has taken multiple forms in the current literature. A common example of integration is “parallel teaching”. This has been achieved in different ways. One way this has been
described is sequential delivery of basic and clinical courses. This is achieved by moving courses around in the curricula to keep the basic and clinical subjects in close proximity. Another common model observed in the healthcare profession is shared teaching. In this model a course is arranged so that a basic science and a clinical instructor co-teach a particular course. Several studies have described courses where a clinical teacher is brought in early into a basic science course or a basic scientist is asked to contribute in a later clinical course. An example from the diagnostic domain in dentistry is synchronizing oral radiology (clinical science) and oral pathology (a basic science) courses. It is agreed that both courses cover the same topics during the same timeframe. Alternatively, oral radiology and oral pathology may co-teach a combined course. An instructor from each discipline will teach a common course each from his or her own perspective. For example, during a 2 hour lecture on odontogenic tumours, the oral radiologist will cover the radiographic appearance of the tumours and the oral pathologist will cover the histopathologic characteristics of the tumours. These serve as examples of parallel teaching that do not necessarily integrate the basic and clinical sciences. In general, parallel teaching strategies may serve well in reducing redundancy in the curriculum. However, if little attention is paid to the use of the basic sciences in explaining clinical abnormalities, the program will merely become a reflection of the current two stage traditional curriculum. Two main problems may be observed in parallel teaching. First, as discussed earlier, without explicitly linking the basic and clinical sciences, we once again run into the issue of relying on spontaneous transfer of knowledge by virtue of proximity and/or repetition. This has been proven to be unsuccessful. Second, attempting to teach a clinical topic and relating it to a
specific biomedical science may be insufficient. Different bodies of basic sciences may be necessary to explain radiographic and or clinical features. For example, one must draw upon principles from anatomy, biochemistry, and other basic sciences to properly understand clinical/radiographic features and not only rely on pathophysiology\(^{39, 61}\).

Another common example of curricular integration is problem-based learning (PBL). In PBL, clinical and basic science knowledge are extracted from clinical cases or problems. It appears to be an effective way to demonstrate how basic and clinical knowledge are related in a specific context. However, PBL also has its own limitations when it comes to integration. The “problem” or the case becomes the central element in the curriculum, and it tends to ignore the critical role of meaning in learning. This is evident by the fact that concepts in PBL are learned in random sequence where the basic sciences do not necessarily serve as causal mechanisms to explain clinical features\(^{84}\). Under these circumstances, students may display serious deficiencies in understanding the relationships between the two sciences and in turn do not get the full advantage of integrated learning\(^{84}\).

An interesting study conducted by Schmidt and colleagues compared the diagnostic performance of students educated in a PBL, integrated and traditional curricula,\(^{85}\). The integrated curriculum was defined as a teacher driven curriculum that integrates the biomedical and clinical sciences around major organ systems. They found that the students in the integrated curriculum out-performed students in the PBL and traditional systems early in training. Later in training, students in the integrated system remained
superior to the traditional system, however, no difference was found between the PBL and the integrated curriculum. This study provides some evidence that integration at the curricular level is beneficial and that the content of the curriculum matters more than the type of presentation as seen in PBL\textsuperscript{85}.

In general, the discussion of integration must go beyond structural changes to the curriculum. Educators must change the way integration is currently viewed and focus on integration that occurs at the level of cognition. Integration must be a “way of teaching”, whether it is in the classroom, the clinic or during chairside/bedside care. Explaining clinical features using basic sciences and the utility of the science at every opportunity will eventually lead to effortless integration in the curriculum.

In summary, our studies show that integration between basic and clinical sciences have positive effects on learning, however to achieve meaningful effects, integration must be context specific, and the basic science used must serve as clear, plausible, and stable causal explanations to the clinical features. These links should be made explicit and should not be left for the learner to deduce.

7.2.2 Diagnostic Strategy Matters:

The issue of diagnostic strategy has been of great interest in the clinical reasoning literature. Traditionally, analytical reasoning (System 2) has been the main diagnostic strategy advocated in teaching novices interpretative oral radiology\textsuperscript{39,61}. Students are
also actively discouraged from using non-analytical (System 1) diagnostic strategies, as it is believed to result in more diagnostic errors\textsuperscript{39,41}. Many authors have in fact described non-analytic reasoning as one of the main sources of diagnostic error. For example, Elstein and Schwarz stated in 2002,\textsuperscript{86}, “…because of the cognitive limitations, systemic biases and errors result from employing simpler rather than complex cognitive strategies.”.

These views have, however, been challenged. Studies have shown that novices can indeed employ non-analytical reasoning strategies successfully\textsuperscript{34,45}. This has been true, especially in the case of familiarity-driven pattern recognition; an example of a non-analytic reasoning strategy. Large effects have been shown especially in tasks that rely heavily on visual perception like dermatology. In these domains, similarity to previously seen cases may result in a 44% increase in diagnostic accuracy in medical students\textsuperscript{18,87}. Similar results were also seen using electrocardiograms (ECG)\textsuperscript{44}.

In our study, participants that provided a diagnosis first then identified features were most likely engaging in a non-analytic, System 1 type reasoning. Consistent with the literature, our results also showed that engaging in a non-analytic reasoning process produced higher diagnostic accuracy on immediate and delayed testing. However, the participants in our study had the opportunity to view only 2 cases of each abnormality during the learning phase. The lack of the participants’ exposure to case examples coupled with the vast variation of the radiographic appearance of the abnormalities on the tests makes it is difficult to assume that the non-analytic diagnostic strategy at play is simply pattern recognition. The clinical reasoning literature in medical education has
generally viewed non-analytic reasoning strategies to be “familiarity-based” strategies. This has been based on a framework derived from exemplar models of categorization in psychology. As discussed in the introduction, one must acquire a large number of examples to be able to carry out categorization based on similarity. Moreover, many of the studies that examine non-analytic reasoning in experts and novices have learning and testing materials structured specifically to test the effects of similarity. In order to show the influence of prior examples, these studies typically have two phases, a learning phase, where specific examples are learned, and a testing phase, where the effects of the examples are examined. As discussed earlier large effects of similarity are usually shown in these studies. However, in our study, the students had only a couple of examples to refer to in the learning phase. A possible alternative explanation to pattern recognition can be found in the dual processing literature. Dual processing suggests that categorization decisions can be classified into System 1, which represents an unconscious, implicit, automatic, rapid, and holistic process, and System 2, which represents a conscious, explicit, controlled, slow, analytic process. It has been found that there are multiple types of implicit processes in System 1 described by different theorists. Most appropriate to the observations in our study is the theory by Nisbett et al. They describe System 1 to be a holistic process and System 2 to be an analytic process. They describe holistic as something that “…only the whole that exists, and the parts are linked relationally, like the ropes in a net” (Munro, 1985). This theory better explains the observations in our study. The basic sciences serve to explain the underlying mechanisms of radiographic features and provide relations between the features acting as “the rope” in the network. The student now has a holistic
understanding of an individual category that is viewed more in “whole” than in “parts”. Murphy and Medin also describe causal theories (i.e. basic science) as the “glue” that holds a concept together and in turn, seen as “whole”\textsuperscript{32}. This seems to explain our observations more accurately. When System 1 or a non-analytic strategy is encouraged, students seem to have higher diagnostic accuracy. The same may be applied to the structured algorithm group. When these students were forced to make a holistic judgment of a clinical case and to focus on the case as a “whole” instead of the “parts” (i.e. features), they too performed better. However, it is unclear based on our results what participants in the structured algorithm group condition could be using to relate the features together. One may only theorize that students when left to their own devices will try to find relationships and connections even if they are not readily available. Additional research is needed to examine this phenomenon.

What are the implications of our results on teaching clinical reasoning? Educators tend to focus their effort on the content and the delivery of the instructional material needed to teach disease categories. However, the results of our study suggest that we should be equally mindful of how to educate the learner about diagnostic strategies. For starters, in oral radiology in particular, we need to steer away from the traditional approach of warning students against the “dangers” of non-analytic reasoning\textsuperscript{41}. In fact, educators who adopt an integrated basic and clinical science instructional methodology should also be aware of the potential influence analytic and non-analytic approaches have on the effectiveness of this learning paradigm. Over reliance on analytic reasoning
may undermine the perceived cohesiveness of a case. From our study, holistic interpretation of radiographic cases should actually be encouraged.

Even though our study directly compares analytic and non-analytic strategies as if they are competing, other studies provide evidence that these two processes are complementary and should not be viewed as being mutually exclusive. Studies have shown that students that were encouraged to use a combined analytic/non-analytic reasoning strategy in diagnosing ECGs showed higher diagnostic accuracy than students instructed to use either technique exclusively\textsuperscript{42,46,47}. Additional research in using combined diagnostic strategies with integrated learning would be beneficial as students learning oral radiology could potentially benefit from specific training in the use of combined analytic and non-analytic approaches.

7.2.3 Assessment with Integration in Mind:

We have established that basic sciences form the framework in the conceptual coherence theoretic model. To achieve superior diagnostic accuracy, basic and clinical sciences must be integrated in a meaningful way. The learner must understand and master the underlying mechanisms and links between the features. Based on this theory and the results of the test enhanced learning study, there appears to be evidence that tests may be effectively utilized to enhanced students’ diagnostic accuracy. This was achieved in our study by deliberately engaging the learner with basic science mechanisms through administering a basic science test, which lead to higher diagnostic
accuracy. When teaching basic and clinical sciences in an integrated fashion, adding formative assessment opportunities that tests the basic sciences may be deemed beneficial. Tests could possibly be an additional strategy to strengthen the connections between the clinical and basic sciences. By adding these assessment opportunities the basic science connections may be specifically targeted, and their utility in the clinical context tested. This type of assessment has the potential to indirectly effect the perception of basic sciences by students in the clinical context. Adding a basic science test will emphasize the importance of the biomedical portion of learning to the students. This will ultimately result in students adding more study time and effort to learning and understanding the relevant basic sciences being taught in the curricula \(^48\). Assessment will directly augment the learner’s memory of the basic science links through the positive testing effect \(^48\ 51\ 54\ 57\ 58\).

Educators may use this core principle when blueprinting assessment opportunities in their curricula. The content and timing of the tests are of great importance during implementation. From the literature on test-enhanced learning, to maximize the testing effect, multiple formative assessment opportunities must be presented throughout the learning process \(^48\ 50\). These tests should be placed strategically within the curriculum to strengthen what has been covered in the instructional material and should be thought of as and educational tool. Most importantly, the tests should target basic science knowledge used to explain clinical features and should test the students ability to make accurate connection between the basic and clinical features.
7.3 Summary

In conclusion, basic science knowledge can play a major role in achieving superior diagnostic accuracy. However, it has become evident that this effect does not occur spontaneously by merely exposing students to both basic and clinical sciences. It is thus imperative, that the underlying fundamental cognitive mechanisms of the learning process be explored and defined. What we have demonstrated in this body of research can serve to direct future innovation in medical education to target curricular “reform” that is theoretically grounded in research on the role of basic sciences in enhancing clinical performance. With a greater understanding of the cognitive role basic science plays in clinical diagnosis, creating integrated curricula and assessment blue printing, may be in part based on the theories elucidated in this body of research.
Chapter 8
Limitations

The studies conducted have potential general limitations. While the conceptual approach used in these studies yields generalizable and practical principles that may guide practice, the highly controlled nature of these studies may limit ecological validity. The studies were conducted in highly controlled artificial educational settings. Learning occurred through the use of computer programs with standardized timed slides and audio recordings. Learning in the classroom and in a clinical setting may be accompanied by other factors. Time constraints, greater number of students, and different lecturers teaching different disease categories are possible confounding factors that are not taken into account in our studies. These factors may lessen the effectiveness of basic sciences in enhancing diagnostic accuracy in the classroom.

The materials used may also contribute to the limitations of this work. Even though our learning and test materials used descriptions of real radiographic abnormalities and images, the images presented were carefully chosen prototypical examples of the abnormalities being taught. A single definite diagnosis was set for each case based on the agreement test by the oral radiologist (as discussed in Chapter 3). This was necessary because participants were expected to give a single diagnosis for each case in the diagnostic test, as this was the main outcome measure of diagnostic accuracy.
However, this may be unrealistic in real-life clinical scenarios. The clinician will usually formulate a differential diagnosis that includes two or three abnormalities, and is sometimes not expected to arrive at a single diagnosis based on a single image. Other factors such as the patient’s demographics, history and clinical examination may also influence the clinician’s final diagnosis\textsuperscript{90,91}. These factors were not taken into account in our studies. The limitations in our materials may also contribute to the limited ecological validity of our studies.

Specific limitations were acknowledged in the study on the effect of instructional methodology and diagnostic strategy on diagnostic accuracy (Chapter 5). As discussed in this chapter, the number of participants in the study may have affected the ability to detect a significant interaction between instructional methodology and diagnostic strategy. When the participants were divided into 4 groups, the number of participants per group was fairly low (observed power=0.07). An interaction may have been statistically significant with more participants in each combined condition.

The study on the effect of test enhanced learning on diagnostic accuracy was limited by a few factors (Chapter 6). First, in our study we used multiple-choice questions (MCQ) as the interventional test. MCQ are easier to code and easier to incorporate into our computer program. However, there is evidence that the use of production tests (i.e. short answers) that require the students to construct a response, rather than being cued
to a correct answer (i.e. MCQ), produces stronger testing effects\textsuperscript{48,57}. That being said, both testing tools have been shown to produce positive effects. Second, a useful addition to this study would have been to administer a basic science test on the delayed session for both the testing and study conditions. This test would potentially assess the retrieval of the basic science information after a time delay. Based on the test-enhanced literature, one may hypothesize that the testing group will have higher scores on a basic science test after a time delay. The more interesting observation would have been to explore the correlation between basic science retrieval scores and diagnostic accuracy after a time delay. The basic science test on the second day should be placed strategically after the diagnostic test as not to interfere with diagnostic accuracy.
Chapter 9
Future Directions

The current studies further our understanding of the relationship between basic and clinical knowledge. We also have a better understanding on how novices use these sciences in the diagnostic task. It has also opened many doors to future research in this domain both experimentally and practically.

9.1 Theoretic Development and Experimental Interventions:

We have seen through our studies that integrated learning has positive effects on students’ diagnostic performance. These effects have been shown to be maintained after a time delay (one week). To determine whether these effects hold true over a significant amount of time (a year, for example), a study that would follow students for longer time periods could be beneficial. This would be a difficult task to achieve in a laboratory setting because of the difficulties associated with having participants come back for follow up sessions. Additionally, it would be difficult to ensure that students not be engaged with the abnormalities taught in the study through their training.

To further explore the effect of integrated basic science learning, future studies could incorporate manipulation of the difficulty of the diagnostic task. This might result in improved performance of the integrated basic science condition as it has been found
that basic science instruction may help novice diagnosticians particularly when solving atypical radiographic cases (cite Woods 2006 – difficult cases study).

I alluded to the possible extension to our study that examines the effects of diagnostic strategies and instructional methodologies. An additional group that would receive combined instructions on the use of both analytic and non-analytic reasoning strategies could be a potential addition to our study. As discussed previously, the main limitation was the low observed power, especially when participant were subdivided into subgroups. This study would require a large cohort of students to clearly appreciate group differences. Manipulating difficulty could also be a possible extension of this study. This may result in increasing the difference between the basic science diagnosis first group and the structured algorithm diagnosis first group.

Additional analysis of the existing visual data from the study in Chapter 5 is currently underway. Participants in the analytic group (features first) and the non-analytic (diagnosis first) groups were both required to detect features on the radiographic images in the testing phase. The perceptual data may shed light on what participants in the different learning and testing conditions are “seeing” and reporting. This may give more insight on whether integrated basic science learning effects what participants focus and report on. Preliminary analysis has shown that participants in the basic science condition appear to be reporting less irrelevant features, which may be interpreted as having a more focused search strategy then the algorithm group. More analysis of this data is required to arrive at any concrete conclusions. Further exploration of these
studies might include the addition of “normal” radiographic images to the diagnostic tests. This manipulation may further our understanding on whether basic science instructions may effect novices perceptual abilities to identify differentiate between normal/abnormal and relevant visual information from a radiographic image.

I might also expand this work to include the expert population to explore the diagnostic strategies used by expert radiologists. A study similar to our Chapter 5 may be conducted with an expert population. This would obviously be done without the learning phase. The difficulty with experts is that it can be very difficult to influence their decision to be either analytical or non-analytical. A manipulation of the difficulty and typicality of cases in the testing phase may be helpful in shifting experts’ diagnostic strategy one way or the other.  

9.2 Applied research:

The next step in this line of research is to apply the cognitive theories to an actual educational intervention, whether it is a course, a session or an entire curriculum. Several integration interventions have been described in the literature. Many of these studies are lacking and rarely go beyond describing their intervention and measuring satisfaction, attitudes or retention of facts. While these aspects may be important, we would propose a study that would achieve three main goals. First, to create integrated learning objectives and materials that would take into account the cognitive aspect of integration detailed in this dissertation. Second, to specifically assess the students’ understanding of basic sciences in relation to clinical concepts.
This may be used for both assessment and learning purposes. There are many tools available to assess this type of knowledge. For example, there has been an assessment tools for problem-based learning\textsuperscript{94}. Des Marchais and colleagues developed an assessment tool called the “problem analysis questions” \textsuperscript{95}. The questions consisted of short clinical vignettes followed by a group of short answer questions designed to assess students’ abilities to analyze information, generate and analytically evaluate diagnostic hypothesis. However this test showed low to moderate reliability\textsuperscript{94 95}. More recently, Neville and colleagues also described a written assessment tool for PBL learning. They named this tool the “The clinical reasoning exercise” \textsuperscript{94 96}. This is a written exam consisting of multiple clinical problems that are designed to assess students’ knowledge of the basic mechanisms of disease and require short written responses. Other more classic tools like well-designed multiple choice questions or script concordance questions designed to assess integration would be sufficient. And third, to develop an evaluation based on outcomes that convey transfer and application. While testing the retention of facts is important, the success of an integrated program should be measured through the degree in which the learned concepts are applied. One way would be to measure diagnostic accuracy using real cases as described in our studies. Another would be to assess clinical skills using a more authentic assessment tools like the objective structured clinical exam (OSCE). These assessment tools are more oriented to assess final outcomes like clinical skills rather than just the application of knowledge\textsuperscript{94}. 
In order to develop a successful integrated educational program, it would be best to begin with a pilot program at the course level. This course would incorporate all 3 goals of integrated learning discussed previously. For example, if this were a third year Oral Radiology course, integrated learning materials would be created to initially introduce the disease categories to students. These materials would include relevant basic science knowledge that could provide plausible mechanistic underpinnings for the radiographic features of diseases. The basic sciences material should draw on concepts from anatomy, pathophysiology, physics and any other basic sciences that might be useful in explaining the clinical/radiographic features.

Summative and formative assessment should be blueprinted onto the course appropriately. The aim of the formative assessment should be two-fold. First, to assess students’ ability to properly integrate the sciences, second, to act as a learning tool to further engage students in the causal explanations provided by the basic sciences. Summative assessment should be added to the end of the course as the final outcome measure to evaluate not only the students but also the course itself. This outcome measure should be aimed at testing the students’ radiographic interpretation skills, since improved diagnostic ability is the primary expected outcome. To fulfill these goals any instructor involved in teaching this course would be required to get training on our proposed concepts of cognitive integration and assessment. A series of quantitative and qualitative studies should be conducted throughout this pilot course. The qualitative studies would evaluate the outcomes of the teaching course. The qualitative study would be aimed to observe the barriers and unintended outcomes of the interventions.
This information would help when implementing an integrated educational system at a higher level in the system.

These are only some of the studies that may stem from this body of research. This type of research has the potential to be a viable research program that will be sustained through the many unanswered questions in the realm of clinical reasoning and the many challenges we need to overcome.
References


Appendices

Appendix #1: Sample images of the four confusible intrabony abnormalities:

Periapical osseous dysplasia  Odontoma  Sclerosing osteitis  Dense bone island
Appendix #2: Screen shot of structured algorithm taught to participants through the created software

<table>
<thead>
<tr>
<th>The Structured Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1: Localize the abnormality:</strong></td>
</tr>
<tr>
<td>Anatomic position (epicenter)</td>
</tr>
<tr>
<td>Localized or generalized</td>
</tr>
<tr>
<td>Unilateral or bilateral</td>
</tr>
<tr>
<td>Single or multifocal</td>
</tr>
<tr>
<td><strong>Step 2: Assess the Periphery and Shape:</strong></td>
</tr>
<tr>
<td>Well defined</td>
</tr>
<tr>
<td>Ill defined</td>
</tr>
<tr>
<td>Shape</td>
</tr>
<tr>
<td>- Circular</td>
</tr>
<tr>
<td>- Scalloped</td>
</tr>
<tr>
<td>- Irregular</td>
</tr>
<tr>
<td><strong>Step 3: Analyze The Internal Structure:</strong></td>
</tr>
<tr>
<td>Radiolucent</td>
</tr>
<tr>
<td>Radiopaque</td>
</tr>
<tr>
<td>Mixed</td>
</tr>
<tr>
<td><strong>Step 4: Analyze the effect of the lesion on the surrounding structures:</strong></td>
</tr>
<tr>
<td>Teeth, lamina dura, periodontal ligament space</td>
</tr>
<tr>
<td>Inferior alveolar nerve canal and mental foramen</td>
</tr>
<tr>
<td>Maxillary Antrum</td>
</tr>
<tr>
<td>Surrounding bone density and trabecular pattern</td>
</tr>
<tr>
<td>Outer cortical bone and periosteal reactions</td>
</tr>
</tbody>
</table>

**Step 5: Formulate a radiographic interpretation**
Appendix #3: Screen shot representing the diagnostic test from software used by the participants.
Appendix #4: Screen Shot representing the cued recall test from the software used by the participants.

From the list provided, please select the features present in cases of:
- Multiple and bilateral
- Well-defined
- Ill-defined

**Periapical Cemental Dysplasia**
- Periphery exhibits irregular radiolucent band
- Periphery exhibits a regular radiolucent line
- No trace of a radiolucent border at periphery
- Displaces surrounding teeth
- Does not displace surrounding teeth
- Widening of periodontal ligament space
- May contain globular cementum like masses
- Contains a mass of calcified tissue
- Contains bone only

Click SUBMIT when finished.
Appendix #5: Screen shot representing an example of feature identification in the diagnostic test from the software used by the participants.
Appendix #6: The interventional test used in the test-enhanced group after the learning phase in the test enhanced learning study:

The limited growth potential of dense bone islands indicates:

a. That this entity behaves like a benign tumor.
b. That there is an inherent inflammatory component of this entity.
c. That it can be considered to be a dysplastic change in bone.
d. That this entity is a hyperplasia in bone.

The radiopacity of dense bone islands is derived from:

a. cancellous bone  
b. cortical bone  
c. dysplastic bone  
d. fibrous tissue

Hyperplasia in bone can be defined as:

a. Increase in the number of normal cells in bone with normal arrangement of the tissue. 
b. A localized change in normal bone metabolism  
c. Abnormal area of bone formation in response to inflammatory mediators.

Dense bone islands are:

a. Overgrowths of disorganized normal tissue that have limited growth potential. 
b. Localized growths of normal compact bone that occurs within the cancellous bone  
c. Localized change in normal bone metabolism  
d. An inflammatory bone reaction
Because of the nature of dense bone islands, all of the following are correct except:

a. They cause displacement of surrounding teeth
b. They have no fibrous tissue capsule
c. Involved teeth remain vital
d. The radiodensity resembles normal cortical bone

**The origin of a complex odontoma is:**

a. Dental lamina
c. Cortical bone
d. Fibrous tissue
e. Hertwig’s epithelial root sheath

**The tissue with the greatest radiopacity in a complex odontome is:**

a. Tooth
b. Bone
c. Fibrous tissue
d. Pulp

**The radiopacities entities seen in a complex odontoma represent:**

a. Masses of dental tissue.
b. Globular cementum lesions.
c. Hyperplastic bone.
d. Areas of bone resorption

*A thin uniform radiolucent border surrounding an intrabony entity is radiographic feature of:*

a. a fibrous capsule surrounding a complex odontoma
b. a fibrous capsule surrounding a dense bone island
c. reactive bone surrounding a complex odontoma
d. reactive bone surrounding a dense bone island.

Which intrabony entity forms disorganized masses of different dental tissue?

a. Periapical cemental dysplasia (PCD)

b. Dense bone island

c. Periapical inflammation

d. Complex odontoma

The gradual transition to normal appearing bone at the periphery of sclerosising osteitis is due to:

a. The gradual decrease in the amount of inflammatory exudate at the periphery.

b. The invasion of surrounding bone by this tumor.

c. Less mature elements of this bone dysplasia.

The presence of periapical bone sclerosis in periapical inflammation is directly due to:

a. The presence of cortical bone from bone hyperplasia.

b. The presence of cementum-like material at the apical region of this tooth.

c. A increase in bone resorption.

d. An increase in bone formation.

In the early stages of periapical inflammatory disease widening of the periodontal membrane space at the apex of the tooth is due to:

a. The replacement of normal bone components by fibrous tissue

b. The presence of toxic metabolites at the tooth apex.

c. A reactive soft tissue hamartoma.

A tooth involved with the following entity is none vital:

a. Dense bone island

b. Sclerosing osteitis

c. Compound odontoma

d. Periapical cemental dysplasia
Initial source of inflammation in periapical inflammatory lesions are due to:

a. Remnants of dental lamina
b. Necrotic pulp
c. Centum like material
d. Disorganized masses of dental tissue

The radiolucent margin seen in periapical cemental dysplasia indicates:

a. That the most mature component is at the periphery.
b. That there is rapid growth.
c. That the most mature element is at the center.
d. The lesion is surrounded by fluid.

The radiolucent early stage of periapical cemental dysplasia is due to:

a. The collection of inflammatory exudate at the root apex.
b. Replacement of normal bone with fibrous tissue.
c. The presence of tumour originating in the periodontal ligament.
d. The growth of a soft tissue hamartoma.

The radiolucent border that is seen in periapical cemental dysplasia is:

a. air
b. fibrous tissue
c. inflammatory cell infiltrates
d. oral epithelium

The loss of lamina dura in periapical cemental dysplasia occurs when:

a. Normal bone is resorbed and replaced with fibrous tissue
b. Displacement of nearby teeth
c. Gradual transition from the surrounding normal trabecular
d. Sclerosing osteitis exists
5. Periapical cemental dysplasia can be defined as:

a. Increase in the number of normal cells in bone with normal arrangement of the tissue.

b. Uncoordinated growth of disorganized normal tissue.

c. A localized change in normal bone metabolism, where normal bone is replaced by fibrous tissue and abnormal bone.

d. Abnormal area of bone formation in response to inflammatory mediators.

**Displacement of teeth is a feature of:**

a. dysplastic lesions

b. fast growing lesions

c. inflammatory lesions

d. slow growing lesions

**On a radiographic image, a well-defined cortical boundary is typically a characteristic of:**

a. a fast growing lesion

b. a slow growing lesion

c. bony inflammation

d. bony hyperplasia.

**A sclerotic bone reaction is seen with:**

a. Periapical cemental dysplasia and sclerosing osteitis

b. Dense bone island and sclerosing osteitis

c. Compound odontoma and sclerosing osteitis

d. Periapical cemental dysplasia and dense bone island
Appendix #7: The training passages used for the study group after the learning phased in the test enhanced learning study:

**Periapical cemental dysplasia** is a localized change in normal bone metabolism, where normal bone is replaced by fibrous tissue and abnormal bone. Associated teeth remain vital. Radiographically the lesion appears to mature from the center outwards with the most mature and radiopaque part of the lesion in the center and a radiolucent border the represents fibrous tissue. The lamina dura around the affected teeth is lost due to normal bone being resorbed and replaced with fibrous tissue. This radiolucent area is surrounded by an area of sclerotic bone reaction. PCD does not cause tooth displacement.

**Complex odontomas** are benign hamartomas of the jaws. Hamartomas can be defined as overgrowths of disorganized normal tissue that have limited growth potential. Odontomas originate from the dental lamina. These entities form disorganized masses of radiopaque dental tissue and is surrounded by a radiolucent fibrous capsule. Because of the slow growing nature of the lesion it is usually surrounded by a uniform radiopaque line that represents bone reaction and it has the ability to displace teeth.

**Sclerosing ostietis** is an abnormal area of bone formation in response to inflammatory mediators. The source of infection is usually necrotic pulp involved with a non vital tooth. In the early stages of periapical inflammatory disease widening of the periodontal membrane space at the apex of the tooth is due to The presence of toxic metabolites at the tooth apex. The bone reacts to this initially by resorbing bone then gradually forming new bone (sclerosisising osteitis). Radiographically, there is a gradual transition to normal appearing bone at the periphery of sclerosising osteitis is due to the gradual decrease in the amount of inflammatory exudate at the periphery.
Dense bone islands are considered to be bony hyperplasias. Hyperplasia in bone can be defined as an increase in the number of normal cells in bone with normal arrangement of the tissue. Dense bone islands also have limited growth potential. Because of the nature of dense bone islands, all of the following are correct: They have no fibrous tissue capsule, the involved teeth remain vital and the radiodensity resembles normal cortical bone.