Examining Curricular Integration Strategies To Optimize Learning Of The Anatomical Sciences

by

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy
Rehabilitation Sciences Institute
University of Toronto

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2016

Abstract

**Background:** Integration of basic and clinical science knowledge is essential to clinical practice. Although the importance of these two knowledge domains is well-recognized, successfully supporting the development of learners’ integrated basic and clinical science knowledge, remains an educational challenge. In this dissertation, I examine curricular integration strategies to optimize learning of the anatomical sciences.

**Objectives:** The studies were designed to achieve the following research aims: 1) to objectively identify clinically relevant content for an integrated musculoskeletal anatomy curriculum; 2) to examine the value of integrated anatomy and clinical science instruction compared to clinical science instruction alone on novices’ diagnostic accuracy and diagnostic reasoning process; 3) to compare the effect of integrating and segregating anatomy and clinical science instruction along with a learning strategy (self-explanation) on novices’ diagnostic accuracy. **Methods:** A modified Delphi was used to objectively select clinically relevant content for an integrated musculoskeletal anatomy curriculum. Two experimental studies were created to compare different instructional strategies to optimize learning of the curricular content. In both of these studies, novice
learners were taught the clinical features of musculoskeletal pathologies using different learning approaches. Diagnostic performance was measured immediately after instruction and one-week later. **Results:** The results show that the Delphi method is an effective strategy to select clinically relevant content for integrated anatomy curricula. The findings also demonstrate that novices who were explicitly taught the clinical features of musculoskeletal diseases using causal basic science descriptions had superior diagnostic accuracy and a better understanding of the relative importance of key clinical features for disease categories. **Conclusions:** This research demonstrates how integration strategies can be applied at multiple levels of the curriculum. Further, this work shows the value of cognitive integration of anatomy and clinical science and it emphasizes the importance of purposefully linking the anatomical and clinical sciences in day-to-day teaching.
Acknowledgments

I have been privileged to work under the supervision of two incredible women in science, Drs. Anne Agur and Nicole Woods.

To Anne, thank you for being an incredible role model and mentor. Throughout this entire process you have been one of my biggest supporters and toughest critics and I am indebted to you for the time you have spent helping me work through this PhD. Your love for anatomy and teaching has been inspirational.

To Nikki, I have so much gratitude for the time you have spent sharing your expertise with me. You are one of the smartest people I have ever worked with and I know this PhD would not happened without you. Thank you for continually challenging me and for providing me with so many opportunities to grow as a researcher. Your mentorship has been invaluable.

To my committee members, Drs. Denyse Richardson and John Flannery, thank you for your continued feedback and for connecting me to your clinical networks. This research would not have been possible without your support.

I must also extend my thanks to the entire Wilson Centre community. My understanding and awareness of the breadth of health professions education research has grown immensely by being a part of this community. A special thank you to my lab group including: Mahan, Mariam, Ryan, Julian, Jeff, Kinga, David, and Jean-Marie. I greatly appreciate the feedback, support, and insight that each of you have provided.

To the entire leadership team and my colleagues at Humber - thank you for supporting me and for making this professional development opportunity possible.

Lastly, to my loving husband Adam, I thank you for patiently supporting me and for always encouraging me when I needed it most. Everyday you have shown me with
grace what it means to be a true, equal partner and for that I am incredibly thankful. And to my little Nora, thank you for reminding me each day that there is so much in life to be grateful for. My hope for you is that one-day you dream of something and that you set goals and persevere until your dream becomes a reality – as this is what my PhD has been.
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1.1 Value of Basic Science in Health Professions Education

Knowledge of basic science, such as anatomy, physiology, and biochemistry is essential to clinical practice across the health professions. As such, basic science training plays an important role in the development of healthcare professionals. Collectively, experts in health professions education suggest that knowledge of basic science is fundamental for clinical application and foundational to the development of learners’ effective thinking skills that are necessary for successful clinical reasoning and decision-making.

The value of basic science has also been captured in several experimental studies that have examined the role of basic and clinical science knowledge in learning medical diagnoses. Explicit evidence for the value of basic science knowledge in clinical reasoning was first established in a study that compared the effect of two different approaches to learning neurological diseases using rank novices. In the first approach, participants were taught the underlying causal basic science mechanisms for the clinical features of each disease and in the second approach, participants were taught the clinical features of each disease using conditional probabilities. Participants completed a diagnostic accuracy test immediately after learning and again one-week later. The results of the diagnostic tests showed that immediately after learning there was no difference in performance between the two groups. However, one-week later, those who were taught using conditional probabilities showed a reduction in diagnostic accuracy whereas those who were taught using basic science descriptions maintained their initial performance. The authors of this study suggested that the basic science provided learners with a framework to reorganize and reconstruct the feature lists associated with each disease, and thus enabled them to maintain their diagnostic
performance over time\textsuperscript{2}. These findings were later replicated in a larger study using first and second year medical students studying rheumatic and neurologic diseases\textsuperscript{4}. Similar to the previous study, the learning materials for both groups included the clinical features of each disease. In one group the features were accompanied by simple basic science explanations and in the other group the features were accompanied with epidemiological information regarding each disease. Again, diagnostic performance between the two groups of students was identical immediately following completion of the learning materials, but after a one-week time delay students who were taught using causal basic science descriptions had superior diagnostic accuracy\textsuperscript{4}.

Woods argued that the findings of these two studies provide evidence to show that basic science knowledge provides a coherent conceptual framework for anchoring clinical knowledge\textsuperscript{2,4}. More specifically, Woods theorized that causal basic science explanations essentially act as glue that molds the clinical features of a disease into a coherent mental representation\textsuperscript{6}. It was also speculated that the benefits of conceptual coherence were not observed until after a time delay since immediately after learning novices could simply rely on their memory of the clinical features to arrive at a correct diagnosis. However, after the passage of time, as a learners’ memory decayed their reasoning strategy shifts to rely on the coherent relationship between features in order to maintain diagnostic performance\textsuperscript{4}. These speculations were further investigated in a follow up experiment that directly compared the effect of learning four artificial endocrine diseases using either basic science explanations or a clinical feature list\textsuperscript{6}. In this experiment, participants in the causal learning condition were taught about the clinical features of each disease using simple basic science explanations and those in the feature learning condition learned the clinical features without any causal explanations. Diagnostic tests were completed immediately after learning and one-week later. A recognition memory test was also administered one-week after initial learning to measure participants’ recall of diagnostic features associated with each disease. Similar to Woods’ previous work, the results showed that the causal learning condition outperformed the feature list condition on the diagnostic test after the time delay. The results of the memory test revealed no difference between the two learning conditions.
The authors concluded that the pattern of performance observed suggests that learners who were taught the causal connections between the signs and symptoms of a disease were able to develop a coherent mental representation that could be maintained over time. Further, since no difference was observed on the memory test between the two learning conditions it was clear that the benefits of the causal learning condition were independent of participants’ explicit memory of the individual features associated with each disease. Thus, although participants in the causal learning condition could rely on their memory of the clinical features immediately after learning, as their memory decayed their reasoning strategy shifted to rely on their coherent understanding of each disease to select a diagnosis. Together, the results of these studies provide evidence to show that causal basic science knowledge for clinical features of a disease has substantial value to novice diagnosticians.

Although Woods and colleagues’ experimental work has clearly delineated a value for basic science knowledge to novice learners, others have previously argued that basic science knowledge is rarely articulated during routine clinical problem solving. Patel and Groen demonstrated this phenomenon in an empirical study that involved expert cardiologists solving a typical case of acute bacterial endocarditis. In this study, cardiologists were asked to read the clinical case and then describe in writing the underlying pathophysiology. The analysis of clinicians’ responses revealed that their explanations consisted primarily of clinical knowledge and that virtually no reference to basic science was provided in their pathophysiological explanations. Based on this finding, the authors suggested that clinicians’ knowledge of basic science does not contribute directly to reasoning in expert clinical problem solving. This effect was later replicated in a different study that required participants with varying levels of clinical experience to think aloud as they reasoned through a clinical problem. The results of this study revealed that in comparison to medical students with little clinical experience, an expert clinician made significantly fewer biomedical propositions during clinical problem solving. The authors suggested that as students progress through their medical training and gain more practical experience their application of clinical knowledge becomes more predominant during clinical reasoning. Experimental work
by Patel and colleagues\textsuperscript{10} has also demonstrated that when medical students were provided relevant basic science information in addition to a clinical problem that they rarely made use of this information when providing a written diagnostic explanation for the clinical case. Further, when students did provide basic science information in their pathophysiological explanations they often used it incorrectly and as a result it had a negative impact on diagnostic reasoning\textsuperscript{10}.

The studies previously described by Patel\textsuperscript{10} and Boshuizen and Schmidt\textsuperscript{8} have sometimes been taken as evidence of the limited impact of basic science knowledge in expert clinical reasoning. However, an alternative explanation for the pattern of performance observed in these studies is that basic science knowledge while impactful it is not explicitly articulated or necessary during routine clinical problem solving. Schmidt and colleagues\textsuperscript{11} have theorized that experts’ basic science knowledge becomes encapsulated or subsumed under clinical concepts as a result of repeated exposure with patients. More specifically, as students are exposed to patient problems their “networks of detailed, causal, pathophysiological knowledge become encapsulated into diagnostic labels or high-level, simplified causal models that explain signs and symptoms.”\textsuperscript{12} The theory of encapsulation suggests that when experts are faced with a routine clinical problem they do not explicitly engage in deep pathophysiological reasoning since this knowledge is encapsulated within their clinical knowledge. Thus, during routine clinical problem solving experts can rely solely on their clinical knowledge or pattern recognition against previously encountered cases to arrive at a correct diagnosis, but when an expert is faced with a challenging or complex case their basic science knowledge is available and can be used to support their diagnostic reasoning process\textsuperscript{11}. The findings of several experimental studies support the theory of encapsulation\textsuperscript{13-17}. For example, Joseph and Patel\textsuperscript{13} showed that when endocrinologists and cardiologists were asked to reason aloud through complex clinical cases within and outside of their discipline, reference to underlying pathophysiological mechanisms were frequently made when the clinicians reasoned through the most difficult clinical cases. Using a different approach, Rikers and colleagues have also examined the role of encapsulated basic science knowledge in routine clinical problem
solving using experienced family physicians and medical students. In this experiment participants were instructed to study simple clinical case descriptions followed by judging the relatedness of different target items to the clinical case. The target items consisted of related and unrelated diagnostic and biomedical items. More specifically, the related diagnostic items were diagnoses that encapsulated the signs and symptoms of a clinical case and the related biomedical items referred to the underlying disease processes of one or more clinical features described in the case description. The results showed that physicians were faster at correctly identifying related biomedical and diagnostic items compared to unrelated items and that they made fewer errors than students. These findings, unlike previous studies that have used think aloud protocols, importantly demonstrate that basic science knowledge is still activated when physicians process routine clinical cases. Thus, based on encapsulation theory, although physicians’ basic science knowledge may become encapsulated under clinical concepts this knowledge still plays a role in physicians’ mental representation of a disease.

To further explore the direct role of basic science knowledge in expert clinical reasoning Woods and colleagues completed two experimental studies using rank novices. In these experiments students were taught four artificial disease categories using either a list of clinical features or clinical features along with causal basic science explanations. In one experiment a recognition memory task was administered and in another experiment students completed a diagnostic task under both speed-focused and accuracy-focused conditions. The results showed that students who learned the causal basic science explanations were able to more accurately recognize novel clinical features and encapsulations that were consistent with the underlying disease process. In addition, under speeded conditions, when students were asked to make a diagnostic decision as quickly as possible, those in the causal basic science group were able to avoid errors and showed improved diagnostic performance, whereas performance of the clinical features group dropped. These findings demonstrate that novices display expert-like behavior, such as, superior diagnostic accuracy under speeded conditions and more automatic processing, when they are taught the underlying basic science mechanisms for disease categories. Moreover, these findings support the model of
conceptual coherence and demonstrate the direct value of basic science in learning medical diagnoses. Furthermore, they also highlight the role of causal basic science knowledge in the development of expert diagnosticians. 

In summary, basic science knowledge plays a critical role in expert clinical reasoning. Although experts may not explicitly articulate basic science knowledge during routine clinical problem solving, research has shown that experts' basic science knowledge is still activated when processing both routine and complex cases. There is also a growing body of experimental evidence that demonstrates that understanding basic science mechanisms is essential to creating a coherent mental representation or conceptual coherence of disease categories in novices. Moreover, based on the research discussed, it appears that the key to optimizing the value of basic science instruction is to purposefully link the basic and clinical sciences during training.

1.2 Current Curricula

Although the importance of basic and clinical science training in medical education is well recognized, curricula are often not structured in a way that optimizes the value of basic science training nor supports the development of conceptual coherence. Since the release of the notable Flexner report in 1910, medical education has typically consisted of two years of basic science training with laboratory experiences followed by two years of clinical training. This 2+2 curriculum model is still used in the majority of medical schools today; however, for decades there has been a growing concern that this traditional model fails to integrate the basic and clinical sciences. In addition, over time, several important advancements within the biomedical sciences have been added to the preclinical curriculum and thus, as a result, the number of curricular hours dedicated to each individual basic science has substantially declined. As an example, with respect to gross anatomy education, it has been reported that since the mid-1950’s there has been 55% reduction in the total number of hours dedicated to teaching gross anatomy within medical curricula.
Beginning in the 1980s, basic science instruction was also commonly criticized for lacking clinical relevance, focusing primarily on rote learning of large volumes of scientific facts, and inattention to the practical application of basic science knowledge to clinical situations. In response to these criticisms and concerns, medical schools began to transition from the traditional, discipline-based basic science curriculum to a more integrated approach in which the basic sciences were taught in the context of clinical medicine. Further, many medical schools began to restructure their preclinical curriculum around organ systems in effort to support integration of basic and clinical science knowledge. As an example, some schools adopted the two-pass organ system-based approach, where each organ system was essentially taught twice. During the first year of this type of integrated curriculum students were taught normal structure and function, and during year two the emphasis switched to focus on pathological structure and function. However, despite these curricular changes, several studies by the National Board of Medical Examiners (NBME) consistently reported that medical students' knowledge of basic science, including anatomy, declined as they progressed through their medical training. As such, better integration of basic science remains a strategic priority and continues to be a recurring theme in calls for reform in medical education. In the most recent report on medical education put forth by the Carnegie Foundation for Advancement of Teaching, it is suggested that “medical students should be provided early clinical immersion and residents should have more intense exposure to the sciences and best evidence underlying their practices” in effort to support better integration between formal learning and clinical experiences.

As institutions continue to address issues of curricular integration, educators are presented with the opportunity and task of designing and modifying learning experiences to meet the expectations of curricular reform. Based on the current literature, the process of curricular reform involves several steps or phases; however, there is no specific curricular framework that is consistently used to guide this process.
A six-step approach, proposed by Kern, suggests that this process involve completing a general and targeted needs assessment, writing specific goals and objectives for the curriculum, selecting curricular content and educational methods, implementing educational interventions and their evaluations, and assessing both individuals and the curriculum \(^{31}\). In Canada and the US, these curricular reform efforts have been reported to be coordinated by a single office, such as the vice dean for education \(^{27}\); however, based on several descriptive reports it is often not clear who is specifically involved in each step or phase of the curriculum reform process. For example, in a recent paper that described the design and implementation of a new integrated, first year medical curriculum, it stated that an institutional Curriculum Committee oversaw the entire restructuring process, but then it also mentioned that all reorganization, planning, and implementation were the responsibility of individual faculty members teaching the first year courses \(^{34}\). Further, while reports on curricular integration of the basic sciences commonly describe or identify components of the curriculum development process, such as, the need for reform, the main goals of new curricula, and educational strategies for implementation, a critical component of the curriculum design process that is often not well described is how specific content for new integrated courses is selected \(^{21,34-37}\). In general, two commonly reported approaches used to identify core basic science content involve using either a top down approach, where experts determine the educational objectives and disseminate these decisions to teachers, or a bottom up approach, where teachers, students, and other stakeholders are involved in making the curricular decisions \(^{38}\). These approaches often rely on small expert group opinion, convenience samples, and individual preferences \(^{39-41}\). Furthermore, research suggests that the content of medical curricula, rather than delivery method, plays a critical role in the development and retention of integrated basic science knowledge \(^{42}\). Thus, I argue that its selection should be carefully considered using a well thought out methodological process. In addition, since there is evidence that there can be disparity between clinicians, scientists, and students on the breadth and depth of basic science training necessary for medical practice \(^{43-45}\), careful consideration should also be given to who is actually involved in the process of selecting the curricular content.
1.3 Strategies to Optimize Integration of the Basic and Clinical Sciences

Although integration has been a key component of ongoing curricular reform efforts for many decades, there continues to be much discussion on how best to structure curricula to optimize learning of the basic and clinical sciences. Two common methods often described to support integration of knowledge include horizontal integration and vertical integration. Horizontal integration refers to integration across disciplines within a finite period of time. As an example, at Morehouse School of Medicine, four first-year basic science courses were reorganized to align the subject matter presented in each course. During this restructuring process the anatomy curriculum served as the foundation and thus, as result of this reorganization, the content for each course was organized around both a regional cadaver dissection and the body's organ systems. While the goals of this restructuring process were multiple, at the forefront was to promote the discovery of links between different subject areas in an effort to model the increasingly integrative nature of the Step 1 of the United States Medical Licensing Examination. Yet, the authors reported that despite their reorganization efforts the class average on each of the NBME subject examinations was comparable to previous years. In contrast to horizontal integration, vertical integration occurs across time and involves disrupting the traditional divide between the basic and clinical sciences. Examples of such curricular innovations include introducing clinical experiences during the traditional pre-clinical years and revisiting the basic sciences during clerkship. It has been suggested that vertical integration promotes a better understanding of both the basic and clinical sciences and encourages students to achieve deeper learning; however, evidence to support these claims is lacking. Spiral integration is another curricular model that supports learning of both basic and clinical sciences across both disciplines and time. This approach involves revisiting basic and clinical science topics at increasing levels of complexity throughout the curriculum and requires students to build upon pre-existing knowledge as they progress from one year to the next. Now while all of these curricular integration efforts have been lauded, there remains limited evidence to suggest that common curricular integration
efforts, such as those described above, result in any significant changes to learners’ integrated basic and clinical science knowledge\textsuperscript{53-55}. Goldman and Schroth have proposed that part of the challenge of realizing the benefits of integration results from the failure to recognize that often “integration is a strategy of curriculum development and not a goal in itself”\textsuperscript{56}. Further, each of these models of integration described focuses on organizational changes to curricula and thus it is inherently difficult to evaluate how these macro-level changes impact learners’ integrated basic and clinical science knowledge\textsuperscript{55}. Based on these findings, it is clear that we need to find better ways to support and promote the development of integrated basic and clinical science knowledge.

Another way of understanding integration of basic and clinical sciences is as a cognitive activity that occurs within the learner’s mind\textsuperscript{55}. A series of experimental studies have shown that this type of integration can be supported through micro-level teaching activities that present the basic and clinical sciences in a causal network\textsuperscript{6,57}. For example, Baghdady and colleagues demonstrated that pre-doctoral dental students were able to more accurately diagnose radiographic pathologies when they were taught the radiologic features integrated with causal basic science descriptions compared to those who were taught the basic science segregated from the radiologic features\textsuperscript{58}. Thus, although both groups of students received the same information for each disease (clinical features and underlying causal mechanisms) those who were taught using a segregated approach were not able to fully utilize the basic sciences. It is suggested that learners develop a more coherent mental representation of a disease when they are explicitly provided the causal connections between clinical features and the basic sciences, since these causal relationships help them to understand that features of a disease go together for a reason\textsuperscript{59}. This cause and effect relationship was further explored in a different study that examined how presentation and organization of basic science content impacts diagnostic reasoning in novices\textsuperscript{60}. Participants in this study were given explanations for diagnosing neurologic or rheumatic disorders using causal explanations linking basic science to clinical to features, clinical features followed by basic science, basic science followed by clinical features, or clinical features only.
Diagnostic testing revealed no difference between groups immediately after learning but follow up testing one-week later showed that the causal basic science group had superior diagnostic performance relative to the other three groups. These findings provide additional evidence to suggest that explicitly providing the causal connections between the basic and clinical sciences enables learners to develop a coherent understanding that can be maintained over time. These findings support the model of conceptual coherence that suggests that when learners understand the causal mechanisms that govern why clinical features are associated with a disease, they can make diagnostic decisions based on what “makes sense” rather than on the memorization of isolated features. Importantly, the results of this study also provide empirical evidence to demonstrate that simply creating proximity between the basic and clinical sciences may not facilitate or support the development of integrated basic and clinical science knowledge. Thus, although common integration efforts, such as rearranging curricula to have basic science and clinical concepts presented back-to-back or revisiting the basic sciences during clerkship, may create opportunities for integration within the curriculum, simply improving the proximity between the basic and clinical sciences does not guarantee cognitive integration.

The experimental work by Woods and colleagues has clearly shown that cognitive integration of basic and clinical sciences supports diagnostic reasoning in novices. To date, an area that has received limited exploration is ways in which educators can translate this mental activity into sound instructional strategies. Since cognitive integration occurs within the learner’s mind, I hypothesize that a potential strategy that may promote and support the development of integrated knowledge would be to encourage the learner to elaborate on the causal relationships between clinical features and basic science mechanisms while they learn about novel disease categories. Self-explanation is a specific learning strategy that may foster such elaborations.
1.4 Self-explanation as a Learning Strategy

Self-explanation is defined as “a constructive or generative learning activity that facilitates deep and robust learning and, like other cognitive skills, improves over time” \(^{61}\). Generally, self-explanations are characterized as any content-relevant articulations made by the learner after reading a line of text \(^{62}\). A unit of self-explanation may include inferences, paraphrases, monitoring statements, and nonsensical statements \(^{62}\).

Research has shown that not all learners spontaneously engage in effective self-explanation \(^{63,64}\); however, several studies from a variety of domains demonstrate that prompting learners to self-explain while learning, positively impacts the development of both conceptual and procedural knowledge \(^{64-66}\).

Although the mechanisms driving the underlying effects of self-explanation are not well understood there are several proposed cognitive processes involved \(^{67}\). According to Chi \(^{62}\), as learners generate inferences to themselves they may identify gaps in their current understanding and fill in missing information from the instructional material. Similarly, it is suggested that as learners generate inferences while learning in a new domain without any prior knowledge, the process of inference generation allows them to connect and make sense of information presented across different sentences \(^{62}\). An alternate mechanism proposed by Chi \(^{62}\) suggests that learners repair or reconstruct their existing mental representation, as they perceive conflicts between their own mental model and the learning material. Since each individual learner has a unique mental model, this metacognitive mechanism of ‘self-repair’ also helps to explain why some learners produce more self-explanations than others. It has also been proposed that self-explanation exerts constraints on processing, by driving learners to discover patterns or regularities within the material being studied \(^{68}\). More specifically, this account suggests that good explanations show how what is being explained is an instance of a general pattern and explicit discovery of such generalizations that underlie what is being explained facilitates learning \(^{68}\).

As previously mentioned, the self-explanation principle has been applied in a variety of ways and across a number of different instructional contexts. For example, in one of the seminal studies by Chi and colleagues \(^{64}\) learners were prompted using open-ended
self-explanation prompts while they learned about the circulatory system using an expository text. In this form, the self-explanation prompt encouraged learners to make connections between their existing knowledge and the newly presented information in the text, while not placing any limits or expectations on the type of explanation required by the learner. As a result of eliciting such self-explanations, learners developed a better understanding of the circulatory system in comparison to students who simply read the text passage twice \(^64\). In contrast, Atkinson et al. \(^69\) used menu-based explanations while students learned to solve probability word problems using worked-out examples on a computer. As such, students were prompted to self-explain by selecting a probability principle from a dropdown menu as they observed individual solution steps for each worked-out example. The results of this study showed that students performed significantly better on both near and far transfer tasks when they self-explained using menu-based explanations in comparison to those who did not self-explain while learning \(^69\). Thus, while these two studies used radically different forms of self-explanation (open-ended versus menu-based prompts) and different instructional contexts (text versus work-out examples), both demonstrated that prompting students to self-explain while they worked with instructional materials had a positive impact on learning \(^64,69\). More recent research on self-explanation has also found that specific forms of self-explanation are more optimal than others in different learning contexts \(^61\). Specifically, within multimedia learning environments, it has been shown that focused self-explanation prompts, which provide explicit instruction regarding the type of content to include in the explanation, are more effective than the open-ended approach \(^70\). This research suggests that within multimedia environments, where multiple sources of information are present (pictures, text, videos), learners benefit when they are explicitly instructed to make connections between the different sources of information while they self-explain.

The effect of self-explanation during clinical problem solving has also recently been explored in medical education \(^71-75\). In the first of a series of studies, Chamberland and colleagues investigated the value of third-year clerks generating self-explanations aloud while reasoning through familiar and less familiar clinical cases \(^71\). Prior to reasoning
through these clinical cases, students in the self-explanation group were provided with a definition of self-explanation along with an audio example of the procedure. The results showed that students who generated self-explanations during clinical problem solving had superior diagnostic performance on less familiar transfer cases one-week later, in comparison to students who did not self-explain 71. Further analysis of students’ self-explanation protocols revealed that they generated more self-explanation segments and a higher number of biomedical inferences when they reasoned through less familiar clinical cases 72. These findings suggest that as students self-explain while reasoning through novel clinical cases they actively attempt to understand the signs and symptoms of a disease using their basic science knowledge 72. Moreover, the authors proposed that self-explanation promotes deep and meaningful learning that thereby supports the development of better clinical reasoning skills and a more coherent mental representation of unfamiliar disease categories 71,72.

More recently, the value of combining self-explanation and models of self-explanation from peers and experts on medical students’ diagnostic abilities has also been examined 73. In this study, participants solved four clinical cases twice, once after generating inferences to themselves while reasoning through clinical cases and again after listening to an example self-explanation (by a peer or expert) or after solving a word puzzle (control group). During the assessment phase, one-week later, all participants solved the same four cases used during the training phase along with four new, more difficult transfer cases. The results showed that for the training cases students’ diagnostic accuracy and diagnostic performance significantly improved over time. For the control group, an improvement in diagnostic accuracy was not observed until one-week following the initial self-explanation exercise. These results importantly demonstrate that self-explanation alone is an effective strategy for improving students’ clinical reasoning skills 73. Furthermore, these findings suggest that self-explanation involves deep processing and a refinement of students’ mental model, as the positive effects of self-explanation were not observed until after a one-week delay of time.
Based on the literature on cognitive integration and self-explanation during clinical problem solving, it seems plausible to expect that prompting students to self-explain while they learn from instructional materials that foster the development of integrated basic and clinical science knowledge would have a positive impact on learning. Thus, self-explanation may be a potential strategy that educators can support and encourage the use of in order to help facilitate learners’ integrated basic and clinical science knowledge.

1.5 Summary
In conclusion, knowledge of basic science plays a critical role in development of expert diagnosticians. Although collectively experts agree that basic science training is important, the traditional 2+2 structure of medical curricula does not capitalize on the value of basic science teaching. Experimentally, Woods and colleagues have shown that a way to optimize the value of basic science instruction is to purposefully integrate the basic and clinical sciences during training. It is suggested that when learners understand the causal mechanisms that govern why clinical features are associated with a disease they develop a coherent mental representation or conceptual coherence of a disease that thereby enables them to find meaning in clinical problems. Further, when the basic and clinical sciences are explicitly integrated during teaching, novices exhibit expert-like behavior during clinical problem solving, including more automatic and holistic processing. Thus, in an effort to support the development of conceptual coherence and to optimize the value of basic science teaching, curricular strategies should focus on explicitly integrating the basic and clinical sciences throughout training.
Chapter 2
A Rationale for the Methodological Process

2.1 Integration as a Strategy for Curriculum Development

The integration framework proposed by Goldman and Schroth\(^ {56} \) is used as a lens to understand the rationale for the design and order of three studies described in this dissertation. This framework applies integration as a guiding strategy for achieving curricular goals in medical education. To optimize the benefits of integration, the framework recommends that curriculum and integration decisions occur in three successive stages; first at the program level, next at the course level, followed by the session level. The purpose of making decisions in this order helps to ensure that a coherent rationale for integration is carried forward into the instructional design of courses and into the selection of specific teaching strategies for each session. Within each level of the curriculum, the framework proposes that curricular design decisions should be clearly defined prior to conceptualizing and adopting integration strategies. Although it appears that the integration framework fosters only a linear decision making process, Goldman and Schroth do acknowledge that there may be iterations of decision making within each level as certain integration decisions may also inform or impact the design of curricula.

According to this integration framework\(^ {56} \), program level curricular decisions, such as; the overall goals of a medical program, measurable objectives, and educational requirements should be clearly established prior to selecting or implementing program level integration strategies. These established curricular design decisions can then be used as a rationale for program level integration. As such, specific integration strategies can be selected and developed to ensure that their purpose and underlying organization principles align with the specific goals of the program. Together, curriculum and integration program level decisions, then form a rational foundation on
which to build the curriculum structure at the course level. Similarly, at the course level, curricular decisions, such as; defining course objectives and determining course content should be considered before selecting specific course level integration activities. The framework suggests that making curricular decisions in this hierarchal manner ensures that appropriate types of integration activities are selected to help achieve the specified course objectives. Finally at the session level, curricular decisions focus on establishing the objectives and content for individual teaching sessions, followed by selecting teaching strategies that will promote and support the development of learners’ integrated knowledge. In summary, in an effort to maximize the potential of integration strategies, the integration framework proposed by Goldman and Schroth suggests that curricular development decisions should be considered prior to conceptualizing integration strategies, in order to ensure that integration strategies at all levels of the curriculum align with the overall goals in which they are intended to achieve.

2.2 Applying Goldman and Schroth’s Integration Framework

In Canada, the Royal College of Physicians and Surgeons of Canada (RCPSC) has established accreditation standards for Physical Medicine and Rehabilitation (PM&R) training. The Objectives of Training in PM&R describe the goals of PM&R training and also outline specific key and enabling competencies expected of physiatry specialists, including those related to the basic sciences. For example, physiatrists are required to “demonstrate an understanding of basic sciences relevant to PM&R and the application of basic science principles to clinical care” and “apply knowledge of the clinical, socio-behavioural, and fundamental biomedical sciences relevant to the specialty of physiatry.” In relation to Goldman and Schroth’s integration framework, these competences represent program level curricular decisions. These objectives are used to inform specific educational requirements for PM&R programs and they also provide a rationale for program level integration strategies.
In Canada, the largest PM&R post-graduate medical program is located at the University of Toronto. At this institution, a unique program-level integration strategy implemented to support trainees in achieving competencies related to the basic sciences is the inclusion of integrated clinical anatomy modules into the training program. These modules have been organized to take place during academic half-day sessions, in the human anatomy laboratory, and alternate between musculoskeletal anatomy and neuroanatomy each year. These established program level curricular and integration decisions in the PM&R program form the rationale for subsequent curriculum development at the course and session level.

The first study described in this dissertation proposed to objectively design clinically relevant content for an integrated musculoskeletal anatomy curriculum for PM&R residents at the University of Toronto. As previously mentioned in the introduction, designing content for curricula is an important component of the curriculum design process. Further, since there is limited time within the PM&R curriculum for basic science training it is imperative that content taught in the clinical musculoskeletal anatomy modules is relevant to daily clinical practice. Thus, to objectively design the content for this curriculum, practicing physiatrists from across Canada were engaged in a modified Delphi process. The Delphi method was specifically chosen since it uses a systematic approach to collect experts’ opinions to achieve consensus without bias. In this study, Cronbach’s alpha was selected as the statistical index to determine whether consensus was achieved within the expert population during each Delphi round. As described by Graham et al., internal consistency (Cronbach’s alpha) reflects the extent of consensus within a group by measuring the homogeneity of opinion expressed by a group of individuals. Cronbach’s alpha values between 0.7 and 0.8 are considered satisfactory for research purposes, thus, a priori it was decided that consensus would be achieved once a subscale reached a Cronbach’s alpha ≥ 0.8. A total of two Delphi rounds were required to achieve consensus. According to Goldman and Schroth’s integration framework, this study relates to the course level curriculum design phase and the Delphi method can be considered as a strategy to define the content for the integrated, multidisciplinary curriculum.
Following the identification of clinically relevant content for an integrated musculoskeletal anatomy curriculum for PM&R trainees (Chapter 3), two experimental studies were designed to compare different instructional strategies to optimize learning of the curricular content. As such, the instructional materials for the experimental studies described in Chapters 4 and 5 were developed using clinically relevant items identified during the modified Delphi process. In both of these studies, novice learners were taught about the clinical features of four confusable musculoskeletal pathologies using different instructional approaches. Novice allied health students were chosen as participants for these research studies as they were assumed to have an understanding of basic anatomical terminology, but minimal experience with the musculoskeletal pathologies selected for the learning materials. More specifically, the purpose of the first experimental study (Chapter 4) was to investigate the value of integrating basic and clinical science instruction compared to clinical science instruction alone on novices' diagnostic accuracy and diagnostic reasoning process. Further, the purpose of the second experimental study (Chapter 5) was to compare the effects of integrating and segregating basic and clinical science instruction, and a learning strategy (self-explanation) on novices' diagnostic accuracy. A flow chart outlining the general protocol used in these studies is shown in Figure 1.
Figure 1: Diagrammatic representation of the protocol used in the studies described in Chapters 4 and 5

- **Session 1**
  - Learning phase
  - Diagnostic accuracy test
  - Memory test
  - One-week later

- **Session 2**
  - Diagnostic accuracy test
  - Memory test
As shown in Figure 1, participants completed a prior knowledge test and basic hand anatomy tutorial and quiz before starting the learning phase in each study. The purpose of the anatomy tutorial and quiz was to review basic anatomical terms and structures that were relevant to the learning materials, such as anatomical position, bones and joints of the hand, and movements permitted by joints in the hand. The tutorial consisted of written descriptions along with images/video clips that were accompanied by audio recordings (Appendix 1) and the quiz consisted of 7 multiple-choice questions on basic hand anatomy (Appendix 2).

To support the development of integrated basic and clinical science knowledge, the common teaching strategy used in both of these studies was presenting the basic and clinical sciences in a causal network. As such, participants in one learning condition were taught the clinical features of each disease using causal basic science explanations. In the other learning conditions, participants were either taught only the clinical features of each disease or the clinical features segregated from the basic science explanations. Diagnostic accuracy and memory tests were completed immediately after the learning phase and one-week later (Appendix 3 and 4). For the purpose of counterbalancing (to avoid practice and order effects), two versions the diagnostic accuracy test were created and matched for difficulty. Participants who completed version A immediately after learning were given version B one-week later, and vice versa. A diagnostic justification test was also completed one-week after initial learning in the study described in Chapter 4 (Appendix 5). In relation to Goldman and Schroth’s integration framework, these experimental studies represent session-level integration strategies, as they are both examples of micro-level teaching activities that are carried out during an individual teaching session to teach content.

In conclusion, this chapter has summarized how Goldman and Schroth’s integration framework can be used a lens to understand the rationale for the design and order of the three studies described in this dissertation.
Chapter 3
Determination of Clinically Relevant Content for a Musculoskeletal Anatomy Curriculum for Physical Medicine and Rehabilitation Residents


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3.1 Introduction

Postgraduate medical education in Canada is guided by the CanMEDS framework “that sets clear and high standards for essential competencies” expected of physician specialists. This integrated framework includes the central physician role of the Medical Expert which encompasses the ability to “apply knowledge of….fundamental biomedical sciences relevant to the physician’s specialty.” As such, each specialty has identified specific key and enabling competencies for their discipline including those in the biomedical sciences. Educators have the task of designing and modifying learning experiences to align with these competencies.

Traditionally, the fundamental basic sciences are taught during the preclinical years of medical education. In North America, few medical schools have published descriptions of basic sciences courses beyond the first two years of medical training. McGill University in Canada was one of the first to publish a description of a basic science curriculum for fourth-year medical students. The purpose of this curriculum
after clerkship was to provide students with an opportunity to integrate basic and clinical sciences at a time when they could better appreciate the relevance of basic sciences given their clinical experiences. Only four (24%) Canadian and 24 (19%) U.S. medical schools formally reported a basic science course during the third or fourth year of medical school. For educators involved in postgraduate specialties that rely heavily on anatomical knowledge, the lack of basic science education throughout undergraduate medical training is concerning.

Undergraduate anatomy curriculums generally focus on the basic principles common to all areas of medical practice and do not cover the breadth and depth of clinical anatomy knowledge necessary for specialty training. In 1999, Cootam surveyed postgraduate residency programs in the U.S. and found that 57% felt that residents needed a refresher in anatomy and 86% reported that anatomy was either extremely or very important to the mastery of their discipline. Despite its recognized importance, in North America the number of curriculum hours dedicated to anatomy during medical training has substantially declined. In addition, research indicates that medical students' and residents' basic science knowledge significantly declines throughout their medical training. In 2006, D'Eon compared test scores of second-year medical students re-taking test questions from three first-year basic science courses (neuroanatomy, physiology and immunology). The results indicate that there was substantial knowledge loss for all three of the basic science courses; however, the most significant knowledge loss (52.7%) was reported in the neuroanatomy course. In a different study that included basic science questions from the United States Medical Licensing Examination (USMLE) Step 1 test on the USMLE Step 2 Clinical Knowledge test found that students' anatomical knowledge declined by 7.9%. Similarly, Hamilton and Nagy reported that emergency medicine residents' average test scores on a clinically oriented anatomy exam developed from a first-year medical course was 40% compared to a score of 75% attained by first-year medical students on the same questions. In three separate studies, it has also been shown that the majority (>79%) of medical students and residents fail to demonstrate competency on an examination of fundamental musculoskeletal (MSK) medicine concepts. In Canada, mandatory
MSK education represents only 2.3% of the average medical school curriculum and only 31% of the schools include mandatory exposure to MSK education in a clinical setting. Combined, these studies suggest that medical graduates entering residency may have a limited working knowledge of important anatomical concepts.

To address this issue, some postgraduate training programs have augmented their curriculum to include structured clinical anatomy training specific to their discipline, and have found it to be successful in improving residents’ understanding of anatomical knowledge relevant to their practice. High satisfaction amongst residents has also been reported as an outcome of gross anatomy based curriculum in residency training. Together these studies demonstrate how structured anatomy courses in postgraduate medical training improve trainees’ anatomical knowledge and also subsequently emphasize vertical integration of basic science knowledge with clinical practice.

In Physical Medicine and Rehabilitation (PM&R), the diagnosis and management of MSK conditions and neurological disorders represent the major areas of practice. Thus, an understanding of the clinical anatomy related to these two systems plays an integral role in physiatrists’ competence. Surveys of PM&R residents and practicing physiatrists have reported that the number one topic that they would like to learn more about is MSK medicine. The identified need for more training in MSK/soft tissue disorders is the result of a perceived deficiency of this topic during residency training. To date, there have been PM&R education papers published on MSK examination, ultrasound, injection skills and neuromuscular medicine. Although all of these PM&R educational activities involve an understanding of clinical anatomy none thoroughly address or review the MSK anatomy of the body as a whole.

It appears that there is a need in postgraduate PM&R education for MSK anatomy curricula that address the needs of learners at the postgraduate level. A critical first step in this process is selecting the appropriate content for such a curriculum. Despite
differences in the views between basic and clinical science teachers regarding the depth of knowledge to include in a curriculum \(^{43}\), it is not unusual for basic science training to be developed largely by in-house basic science teachers \(^{38}\). Reported methods used to develop content for postgraduate curricula range from small expert group opinion to individual preferences \(^{39,106}\). In papers describing postgraduate anatomy curricula few report how content was generated for the curriculum. Thus, it is assumed that the individual authors reporting the curriculum determined the content. Based on our literature review, we found no specific papers describing the development of content for a PM&R clinical MSK anatomy curriculum. The scope of this paper is to describe the use of the Delphi method to identify clinically relevant content to incorporate in an MSK anatomy curriculum for PM&R residents. The structure of a current PM&R anatomy program will be discussed first to contextualize the framework for which the new curriculum content will be implemented.

### 3.2 Description of University of Toronto PM&R Modules

In 2001 the PM&R residency program at the University of Toronto implemented clinical anatomy modules into its training program. Residents do not receive a formal credit for their participation in these sessions; however, attendance is a mandatory component of the program (PGY 1-5, \(n=18\)-20). The modules consist of four academic half-day sessions each year, alternating between MSK anatomy and neuroanatomy. Each session is four hours in length and utilizes teaching methodologies that encourage resident participation, such as group discussions, peer teaching, instructor-student teaching, and case presentations. The sessions are lead by a clinical anatomist and at least one PM&R clinical educator.

Prior to the modules, residents are given anatomy and clinical readings to complete along with clinical cases/questions that will be discussed during each session. In the first three hours of each session, residents work in small groups (4 residents/group) in the cadaver lab and review anatomical structures using cadaveric prosections. For reference, each lab table has access to a dissection guide and an anatomy atlas.
Residents locate anatomical structures on the prosections and a senior resident in each group leads a discussion of related clinical applications. In the last hour, residents work through clinical cases that relate directly to anatomical structures that were reviewed in the cadaver lab. A senior resident prepares and presents the clinical cases to the group and leads the discussion amongst their colleagues. Different residents are in charge of preparing and presenting the clinical cases during each session. The discussion of the clinical cases is interactive and informally takes place in a classroom setting beside the cadaver lab. The clinical anatomist and PM&R clinical educators are present during the entire session and are also involved in enhancing the discussion throughout.

In each MSK session, the emphasis is on the clinical relevance of bones, joints, muscles, and nerves within specific regions. The topics of the MSK sessions are: 1) lumbosacral spine, lumbar/sacral plexus, and gluteal region; 2) lower limb; 3) neck and cervical region, brachial plexus, and superficial and deep back; and 4) upper limb. At this time, no objective evaluation specific to these modules has been completed; however, feedback from many residents indicates that they find these sessions valuable and that their participation in the gross lab is time well spent. However, because of time constraints some topics are covered very quickly or in some cases not covered at all. In addition, the specific content that is covered in each session is sometimes dependent on the present clinical educator's expertise and experience.

The curriculum for the MSK anatomy module has been developed primarily by one clinical anatomist appointed to the Division of Physiatry and one PM&R residency program director. Senior residents are also involved in determining the clinical cases/questions that are discussed in each session. Over the years, refinements have been made to the curriculum content, but to date, no agreement exists on the specific content and level of detail of the content that should be included in the anatomy sessions. Due to time and resource constraints within the PM&R residency program, we seek to determine the most clinically relevant content to incorporate in an MSK anatomy curriculum by using a national consensus method. The Delphi method was chosen as the methodological approach to achieve consensus and it is based on the
assumption that “group opinion is considered more valid and reliable than individual opinion” ¹⁰⁷.

3.3 Delphi Method

The Delphi method is an established approach used in health professions education research for curriculum and competency development ⁷⁹,¹⁰⁸-¹¹⁰. As Jones and Hunter ¹¹¹ describe, the Delphi method attempts “to assess the extent of agreement (consensus measurement) and to resolve disagreement (consensus development)” where there is either a lack of scientific evidence or contradictory evidence on a specific topic. The Delphi method has been shown to be an effective approach to systematically collect experts’ opinions and achieve consensus on curricular topics without bias ⁷⁹.

Additional distinguishing features of the Delphi method are: 1) expert panelists can provide anonymous opinions that are not influenced by peer pressure or other extrinsic factors; 2) expert panelists can be from geographically distinct areas; 3) feedback can be shared in a controlled manner and; 4) the exchange of information can be obtained easily using electronic resources ¹⁰⁷,¹¹². Experts for a Delphi are defined by having expert knowledge on the specific topic under study. To achieve consensus on expert opinion, the Delphi method uses an iterative, multi-step process involving a series of questionnaires known as rounds ¹⁰⁷,¹¹¹. Typically, in the first round, the expert panel completes open-ended questions on an issue or topic. Responses are then analyzed by the researcher and sent back to the expert panel in the form of statements. In the second round, experts rate their level of agreement for each statement on a numerical scale. Again, the researcher analyzes these responses and the statements along with the results from this round are sent back to the expert panel for reconsideration. In the third round, experts have the opportunity to re-rank their agreement for each statement in view of the overall group’s response ¹⁰⁷,¹¹¹. There is no set rule on the number of rounds that a Delphi should consist of; however, many use two or three rounds ¹¹³. As described by Graham et al. ⁸⁰ internal consistency (Cronbach’s alpha) is used to determine consensus at the end of each Delphi round. It is reported in the literature that an alpha of 0.7 is satisfactory for research purposes, whereas a minimum alpha of 0.9 is
needed for direct clinical applications\textsuperscript{81}. Once consensus has been achieved agreement scores are calculated. An agreement score of 80\% is reported as a realistic achievement in consensus seeking-methodologies\textsuperscript{113}.

3.4 Development of Content for a PM\&R MSK Anatomy Curriculum

A two round modified Delphi method was used to establish the content for the MSK anatomy curriculum. The modification to the Delphi involved replacing the first round of open-ended questions with a structured questionnaire. This modification is an accepted approach and is often used in Delphi studies\textsuperscript{114}. The clinical MSK anatomy curricular items were compiled by the principal investigator (PI) from multiple sources: 1) the current clinical MSK anatomy cases used in the PM\&R residency program at the University of Toronto; 2) consultation with five PM\&R experts in community and academic practice and; 3) clinical MSK anatomy and PM\&R textbooks. Anatomical structures (bones, joints, muscles, nerves) and associated clinical MSK conditions were presented in parallel using an online questionnaire\textsuperscript{115}. The questionnaire was pilot-tested for face and content validity by three physiatrists and one clinical anatomist, and modifications were made to the curricular lists accordingly. The Research Ethics Board at the University of Toronto approved ethics for this study and informed consent was obtained from each participant.

To recruit expert participants this study was presented at the PM\&R Royal College specialty committee meeting. The specialty committee consists of PM\&R Program Directors (n=13) and physiatrists involved in both community and academic practice (n=5) from across Canada. Following the presentation, an invitation email was sent to all members of the specialty committee. The snowball method\textsuperscript{116} was used to recruit additional expert participants. As such, each specialty committee member who voluntarily agreed to participate was asked to identify two additional PM\&R experts and to provide their name and contact information to the PI. The PI then contacted these individuals by email to invite them to participate. An MSK medicine expert in this study was defined as a “physical medicine and rehabilitation medical specialist involved in
either academic or community practice in Canada.” These individuals were chosen as experts for this study as physiatrists have extensive training in MSK medicine and they are directly involved in the interdisciplinary care of MSK disorders in Canadian practice.

In the first Delphi round, experts were asked demographic information, such as practice location, specific areas of PM&R practice and years of experience as a physiatrist. In addition, each expert was asked to rate the importance of each proposed curricular item (n=361) to PM&R residency education using a five-point Likert scale (Table 1). The five-point Likert scale ranged from 1 (unimportant or not applicable to PM&R residency education) to 5 (essential to PM&R residency education). Experts also had the opportunity to add additional anatomical structures, clinical MSK conditions and comments. At the end of round one, the mean rating and standard deviation for each item was calculated. Internal consistency (Cronbach’s alpha) for each subscale and for the overall questionnaire was also calculated. Prior to the study, it was decided that all subscales that reached a Cronbach’s alpha ≥ 0.8 after the first iteration would not be included in round two of the Delphi. The remaining subscales, along with the mean and standard deviation for each item within the subscale, were sent back to the experts and they were asked to reconsider their judgments based on the opinions of others using the same five-point Likert scale. In addition, new curricular items suggested in round one were also included in round two. Agreement scores were used as an outcome measure to determine the content to include in the curriculum. The items where ≥80% of the experts responded 4 or 5 on the Likert scale were recommended to be included in the curriculum.

3.5 Results

3.5.1 Demographics

Fifty-seven experts from across Canada were approached to participate in the Delphi questionnaire. A total of 37 physiatrists participated and the overall response rate over two rounds was 97%. Current practice locations for the expert population included: academic-based hospital (73%), community-based hospital (11%) and community
practice (24%). Experts represented all subspecialty areas of PM&R practice as described by the American Academy of PM&R except for hospice and palliative medicine, cancer rehabilitation and occupational and environmental medicine. The range of experience as a physiatrist for the expert population was as follows: 1-5 years (37.8%), 6-10 years (10.8%), 10-15 years (18.9%), 15-20 years (13.5%) and greater than 20 years (18.9%)

3.5.2 Curricular Content
The initial list of anatomical structures and clinical MSK conditions consisted of 361 items that were organized into 47 subscales. The overall internal consistency for the first round of the Delphi was 0.99. After the first iteration, 40 of the 47 subscales had a Cronbach’s alpha ≥ 0.8 and thus the items in these subscales were not included in round two. The 7 subscales that did not reach a Cronbach’s alpha ≥ 0.8 included the shoulder complex, scapulothoracic joint, scapulohumeral muscles, distal radio-ulnar and wrist joints, joints of the hand, fascia of the hand and fascia of the leg and foot. The curricular list presented to the expert panel in round two consisted of 45 items, 13 of which were additional items suggested by the expert panel in round one. The overall internal consistency for round two of the Delphi was 0.99.

After the second iteration, agreement scores were calculated. For 208 of the 374 items, at least 80% of experts agreed that the items were either very important or essential to PM&R residency education. These 208 items are recommended for inclusion in a clinical MSK anatomy curriculum for PM&R residency training (Table 2).

3.6 Discussion
The modified Delphi method is an effective process to develop content for a clinical MSK anatomy curriculum for PM&R residents. The top-down approach using physiatrists in practice from across the country resulted in the identification of 208 relevant anatomical structures and clinical MSK conditions important in Canadian
PM&R practice. This represents a 44% reduction of the initial curricular items. Consensus on the items to include in the curriculum was reached without the expert participants ever having to meet in person, and on average, it took each participant 68 minutes to complete both Delphi rounds. It is important to note that this average time is likely above the actual time it took, as some participants opened the questionnaire and then returned hours later to complete it. Some argue that the Delphi method requires too much investment of clinicians’ time; however, based on our experience an approximate investment of 68 minutes and a high response rate (97%) does not support this argument.

The face-to-face introduction of this study at the Royal College PM&R specialty committee meeting was a successful way to engage those with a vested interest in postgraduate PM&R medical education. Similar to Penciner et al. the use of the snowball technique enabled us to recruit and maintain expert participants from across the country for the Delphi process. The use of this technique resulted in the participation of 37 physiatrists representing a range of years of experience and also a high response rate of 97% over two rounds, both of which enhance the validity of this study. Other studies that have used the Delphi method for competency and curriculum development have reported the involvement of 10-31 experts to establish consensus. Thus, the participation of 37 physiatrists in this study represents an above-average sample size.

When designing training programs it is imperative that content included in the curriculum is relevant to daily clinical practice. The process of developing content for postgraduate anatomy curricula is not commonly described in the literature. Reported methods that have been mentioned for determining content for postgraduate anatomy curricula include individual preferences and small convenience samples. In the U.S., some PM&R educational activities have reported using guidelines established by educational committees, departments’ billing data and informal surveys to establish content. While there are focused efforts on postgraduate PM&R education in Canada there are no established guidelines for PM&R anatomy education. Although
developing content for curricula can be a complex task \textsuperscript{121}, we found the Delphi method to be a straightforward process in establishing relevant and necessary curricular content. In addition, the use of the Delphi method allowed for representation of physiatrists from across the country, and thus, the content for the curriculum reflects clinical practice of physiatrists nationally and not within a limited region. In comparison to other PM&R education activities \textsuperscript{100-103,105}, this is the first comprehensive description of content for a MSK anatomy curriculum for PM&R residents.

This study also had limitations that should be noted. Similar to other Delphi studies, the items included in the modified Delphi may be biased since they were pre-determined by the PI. To minimize this bias, the PI did consult with physiatrists in both academic and community practice along with clinical anatomy and PM&R textbooks to obtain additional items for the initial curricular lists. The participants were also able to suggest additional curricular items in the first round of the Delphi. A selection bias may also exist in this study since 20 of the 57 physiatrists approached to complete the questionnaire did not participate. The authors do not believe this to be too concerning since the experts that did participate represented almost all subspecialty areas of PM&R practice as described by the American Academy of PM&R.

3.7 Conclusion
This research supports using evidenced-based content in postgraduate anatomy curricula. The results clearly define the key anatomical concepts that have an essential application to PM&R practice. The identified content will be organized and implemented into the existing MSK anatomy sessions in the PM&R training program at the University of Toronto. The authors acknowledge that establishing clinically relevant content is only one component of curriculum development process \textsuperscript{31}. Once the new curricular content has been implemented, its effectiveness will be tested. It seems reasonable to assume that a reduction (44\%) of content will allow for more time to be spent on vertically integrating relevant anatomical concepts and clinical conditions important in the practice of physiatry.
This MSK anatomy content will be shared with all PM&R residency programs across the country to standardize MSK anatomy education for PM&R residents. The established content will also be used to develop a list of core competencies relevant to MSK anatomy that can be used to guide the development of and preparation for clinical examinations. The content of this MSK anatomy curriculum may also be useful to overlapping medical specialties (rheumatology, orthopedics, plastics, emergency medicine, family medicine and sports medicine). Finally, the Delphi methodology employed in this study serves as a guideline for the development of future evidence-based clinical anatomy content for postgraduate residency training. Future research will explore how to effectively deliver and assess the effectiveness of this clinical anatomy curriculum to postgraduate trainees.
Table 1: Structure of Delphi questionnaire

Please rate the importance of understanding the anatomical structures and clinical MSK conditions as core knowledge for PM&R residents using the Likert scale below.

1 - Unimportant or not applicable to PM&R residency education  
2 - Moderately important to PM&R residency education  
3 - Important to PM&R residency education  
4 - Very important to PM&R residency education  
5 - Essential to PM&R residency education

<table>
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<th>Anatomical structures</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Clinical MSK Correlation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>Deltoid, Teres Major, Rotator cuff muscles</td>
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<td></td>
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<td>Rotator cuff tendinopathy/tears</td>
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</tbody>
</table>
Table 2: Recommended items to be included in a clinical MSK anatomy curriculum for PM&R residents

*Note: All individual muscles were included in the questionnaire, but for brevity only muscle groups are listed. Attachments, actions, and innervation for all muscles within the muscle groups listed should be discussed.

**MSK Anatomy of the Upper Limb**

<table>
<thead>
<tr>
<th>Anatomical Structures</th>
<th>Clinical MSK Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bones of shoulder</td>
<td>Clavicle, scapula, sternum, 1st rib &amp; humerus</td>
</tr>
<tr>
<td>Bones of forearm</td>
<td>Radius, ulna, carpals, metacarpals &amp; phalanges</td>
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<tr>
<td></td>
<td>Ligaments: acromioclavicular &amp; coracoclavicular (conoid &amp; trapezoid)</td>
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<tr>
<td>Acromioclavicular joint</td>
<td>Location &amp; movements/arthrokinematics</td>
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<td>Scapulothoracic joint</td>
<td>Articular surfaces, movements/arthrokinematics, bursae</td>
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<td></td>
<td>Ligaments: coracohumeral,</td>
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<td>Glenohumeral joint</td>
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<td>Joint Group</td>
<td>Relevant Joints &amp; Movements</td>
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<td>transverse humeral, glenohumeral</td>
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<td>Osteoarthritis &amp; rheumatoid arthritis</td>
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<td>Subacromial bursitis/injection sites</td>
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<td>Elbow joint</td>
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<td>Subcutaneous olecranon &amp; subtendinous bursitis/injection sites</td>
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<td>Ligaments: collateral ligaments (ulnar &amp; radial) &amp; annular</td>
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<td>Distal radio-ulnar joint (DRUJ) &amp; wrist joint</td>
<td>Articular surfaces &amp; movements/arthrokinematics of DRUJ &amp; wrist joint</td>
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<td>Ligaments: radiocarpal ligaments (palmar &amp; dorsal), collateral (ulnar &amp; radial), articular disc of DRUJ (triangular ligament)</td>
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<td>Joints of hand</td>
<td>Intercarpal, carpometacarpal, metacarpalphalangeal &amp; interphalangeal joints</td>
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<td>Axioappendicular</td>
<td>Anterior &amp; posterior</td>
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<td>&amp; scapulohumeral muscles</td>
<td>axioappendicular (trunk) muscles</td>
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<td>Deltoid, teres major, rotator cuff muscles</td>
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<td>Distal biceps tendonitis &amp; rupture</td>
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<td>Anatomical snuff box</td>
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<td>Types of palmar grasps/pinches</td>
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<td>Thenar &amp; hypothenar muscles</td>
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<td>Lumbricals &amp; interossei (palmar &amp; dorsal)</td>
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| Fascia of hand | | Dupuytren's contracture |
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<thead>
<tr>
<th>Nerves of upper limb</th>
<th>Roots, trunks, divisions &amp; cords of brachial plexus</th>
<th>C5-T1 root impingement &amp; idiopathic brachial neuritis</th>
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<td>Supravcavicular &amp; infraclavicular part of brachial plexus</td>
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<td>Cutaneous nerves of arm, forearm &amp; hand</td>
<td>Brachial plexopathy</td>
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<td>Entrapment neuropathies &amp;</td>
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<tr>
<td>Dermatomes &amp; myotomes</td>
<td>nerve entrapments</td>
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<tr>
<td>Ulnar, radial, &amp; median neuropathies</td>
<td>Mechanical vs. infectious/inflammatory</td>
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<tr>
<td>radiculopathy &amp; plexopathy</td>
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**MSK Anatomy of the Lower Limb**

<table>
<thead>
<tr>
<th>Bones of hip &amp; thigh</th>
<th>Hip bone, femur &amp; patella</th>
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</thead>
<tbody>
<tr>
<td>Angle of inclination &amp; torsion angle of femur</td>
<td>Ischial bursitis/injection sites</td>
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<td></td>
<td>Trochanteric bursitis/injection sites</td>
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<table>
<thead>
<tr>
<th>Bones of leg &amp; foot</th>
<th>Tibia, fibula, tarsals, metatarsals &amp; phalanges</th>
<th>Metatarsalgia</th>
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<tbody>
<tr>
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<td>Plantar spurs</td>
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<td>Consequences/levels of amputations of the lower limb</td>
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<td>Pes planus &amp; cavus</td>
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<table>
<thead>
<tr>
<th>Hip joint</th>
<th>Articular surfaces, movements/arthrokinematics &amp; bursae</th>
<th>Hip fractures</th>
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<tbody>
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<td></td>
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<td>Osteoarthritis &amp; AVN (osteonecrosis)</td>
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<td>Subluxation in cerebral palsy</td>
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<td>Slipped capital femoral epiphysis</td>
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<table>
<thead>
<tr>
<th>Knee joint</th>
<th>Articular surfaces, movements/arthrokinematics &amp;</th>
<th>Baker's cyst</th>
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<td>Patello-femoral pain syndrome</td>
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<tr>
<td>Location</td>
<td>Description</td>
<td>Conditions</td>
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<tr>
<td>Bursae</td>
<td>Ligaments: collateral (medial &amp; lateral), oblique popliteal, arcuate popliteal, patellar, cruciate (anterior &amp; posterior) &amp; menisci (medial &amp; lateral)</td>
<td>Genu varum &amp; valga</td>
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<td>Q angle</td>
<td>Osteoarthritis &amp; osteochondritis dissecans</td>
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<td>ACL/PCL/MCL/LCL/Meniscus tears &amp; strains &amp; terrible triad</td>
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<td>Avascular necrosis</td>
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<td>Patellar tendonitis &amp; instability</td>
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<td>Injection sites for the knee joint</td>
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<tr>
<td>Ankle joint</td>
<td>Articular surfaces &amp; movements/arthrokinematics</td>
<td>Inversion &amp; eversion ankle injuries</td>
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<td></td>
<td>Ligaments: talofibular ligament (anterior &amp; posterior), calcaneofibular &amp; medial ligament of ankle</td>
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<tr>
<td>Joints of foot</td>
<td>Subtalar, transverse tarsal, cuneonavicular, tarsometatarsal, intermetatarsal, metatarsophalangeal &amp; interphalangeal joints</td>
<td>Hallux limitus, rigidus, valgus</td>
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<td>Ligaments: spring, long plantar &amp; short plantar</td>
<td>Charcot arthropathy</td>
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<td>Longitudinal &amp; transverse arches of the foot</td>
<td>Osteoarthritis</td>
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<td>Gout</td>
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<td>Gluteal, thigh, leg</td>
<td>Superficial &amp; deep gluteal</td>
<td>Myofascial pain associated with</td>
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<td>&amp; foot muscles</td>
<td>muscles</td>
<td>gluteal muscles</td>
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<td>Anterior, medial &amp; posterior thigh muscles</td>
<td>Piriformis syndrome</td>
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<td>Pes anserinus</td>
<td>Trendelenberg sign &amp; gait</td>
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<td>Anterior, lateral &amp; posterior leg muscles</td>
<td>Gluteus medius bursitis/injection sites</td>
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<td>Muscles on the dorsum of the foot</td>
<td>Snapping hip</td>
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<td>Hip flexor contractures</td>
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<td>Fascia of leg &amp; foot</td>
<td>Flexor/extensor/fibular retinaculum &amp; plantar fascia</td>
<td>Plantar fasciitis</td>
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<td>Nerves of lower limb</td>
<td>Roots to lumbar &amp; sacral plexus &amp; lumbosacral trunk</td>
<td>Bowel/bladder &amp; sexual dysfunction</td>
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<td>Nerves to gluteal region, thigh, leg &amp; foot</td>
<td>Lumbosacral plexopathy</td>
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<td>Cutaneous nerves of the buttocks, thigh (including inguinal region), leg &amp; foot</td>
<td>Entrapment neuropathies</td>
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<td>Dermatomes &amp; myotomes</td>
<td>Neuropathy (sciatic, obturator, femoral, tibial, common fibular/peroneal)</td>
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<td>Meralgia paresthetica</td>
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<td>Diabetic</td>
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<td>Anatomy</td>
<td>Description</td>
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<td>MSK Anatomy of the Neck &amp; Cervical Spine</td>
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<td>Bones of neck &amp; cervical spine</td>
<td>C1-C7 &amp; hyoid</td>
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<td>Stingers &amp; burners</td>
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<td>Mechanical cervical spine pain</td>
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<td>Atlanto-occipital joint</td>
<td>Articular surfaces &amp; movements/arthrokinematics</td>
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<td>Atlanto-axial joint</td>
<td>Atlanto-axial instability</td>
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<td>Cervical vertebrae</td>
<td>Articular surfaces, movements/arthrokinematics &amp; intervertebral discs</td>
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<td>Ligaments of the cervical spine</td>
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<td>Cervical disc herniations</td>
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<td>Hyperextension injury</td>
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<td>Cervical spondylosis including central &amp; foramina stenosis</td>
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<td>Cervical facet syndrome</td>
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<td>Sternoclidomastoid</td>
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<td>Myofascial pain associated with the head &amp; neck muscles</td>
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<td>Whiplash injury &amp; neck spasms</td>
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<td>Nerves of neck</td>
<td>C1-C8 spinal nerves</td>
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<td>Dermatomes &amp; myotomes</td>
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<td>Radiculopathy &amp; plexopathy</td>
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<td>Greater occipital nerve blocks &amp; occipital neuralgias</td>
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<td>Clinical MSK Anatomy of the Trunk</td>
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<td>Bones of trunk</td>
<td>T1-L5, sacrum, coccyx &amp; thoracic cage (ribs &amp; sternum)</td>
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<td>Scoliosis, excessive kyphosis &amp; lordosis</td>
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<td>Condition</td>
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<td>Mechanical thoracic spine pain</td>
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<td>Compression &amp; stress fractures of vertebra</td>
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<td>Spina bifida</td>
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<td>Joints of thoracic &amp; lumbar vertebrae</td>
<td>Articular surfaces, movements/arthrokinematics &amp; intervertebral discs</td>
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<td>Ligaments associated with the thoracic &amp; lumbar spine</td>
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<td>Lumbosacral facet joint syndrome/osteoarthritis of facets</td>
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<td>Degenerative disc disease (DDD) &amp; disc herniations</td>
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<td>Spondylolisthesis &amp; spondylosis of thoracic &amp; lumbar spine</td>
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<td>Sacro-iliac joint</td>
<td>Articular surfaces &amp; movements/arthrokinematics</td>
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<td>Sacro-iliac joint dysfunction &amp; sacroiliitis</td>
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<tr>
<td>Nerves of trunk</td>
<td>Spinal nerves (T1-S4)</td>
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<td></td>
<td>Dermatomes &amp; myotomes of trunk (thorax &amp; abdomen)</td>
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Chapter 4
Exploring Cognitive Integration of Basic Science and its Effect on Diagnostic Reasoning in Novices


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4.1 Introduction
Integration of basic science is increasingly being recognized as important for practice in the health professions. As such, better integration of basic science disciplines with clinical content has become a central characteristic of curriculum reform. Common integration strategies include problem-based learning, early exposure to real and simulated clinical experiences, rearrangement of basic science and clinical curricula, and shared teaching. While there is limited empirical evidence for the value of many of these curricular integration efforts, learners have been found to benefit when learning is based on the concept of ‘cognitive integration.’ In contrast to the more common horizontal or vertical integration, ‘cognitive integration’ captures the understanding that the integration of basic and clinical sciences is a cognitive activity that occurs within the learner, not in the curriculum. Cognitive integration is supported through day-to-day micro-level teaching and involves specific pedagogical strategies that purposefully link the basic and clinical sciences.

There is considerable laboratory evidence that cognitive integration supports diagnostic reasoning in novices. For example, when compared with students who
learned only clinical signs and symptoms, students who learned neurological and rheumatological diseases through integrated basic science descriptions had superior diagnostic accuracy 1-week after learning. By understanding the causal mechanisms that govern why clinical features are associated with a specific disease, students’ diagnostic decisions can be based on what ‘makes sense’ rather than on the memorization of isolated features \[^{57,59}\]. The purposeful and explicit integration of basic and clinical sciences during teaching essentially allows the learner to develop a coherent mental representation of the disease category \[^{4,57}\].

Experimental findings demonstrating the value of this conceptual coherence have been consistent with undergraduate populations from a number of areas of medicine and other health disciplines, including dentistry, neurology, and rheumatology \[^{4,58}\]. The results of these studies suggest that immediately after learning novices may rely on an analytical feature counting strategy to arrive at a diagnosis, but after the passage of time their reasoning strategy shifts to rely on a more holistic understanding of disease categories in order to maintain diagnostic performance \[^{4}\]. While this model of reasoning is supported in the pattern of performance across studies, it has been difficult to provide an explicit measure of how students use their coherent mental representation to arrive at the correct diagnosis. This is because the model of conceptual coherence does not necessitate the overt application of basic science knowledge in diagnosis. Rather, the model suggests that novice diagnosticians use basic science knowledge unconsciously and automatically to reorganize and reconstruct diagnostic feature lists associated with abnormal functioning when solving clinical problems \[^{59}\]. This cognitive process is evident by learners’ ability to arrive at a correct diagnosis but might not be easily expressed. Thus, directly asking learners how or if they used their basic science knowledge to solve a case might not lead to greater insights regarding cognitive integration or conceptual coherence.

An explanation consistent with conceptual coherence is that, while impactful, basic science knowledge is less likely to be articulated in a think aloud protocol unless the cases are particularly complex. Schmidt et al. \[^{11}\] theorized that experts’ basic science
knowledge becomes encapsulated under clinical concepts as a result of repeated clinical exposure. However, when experts are faced with a challenging clinical problem they revert to their basic science knowledge for an explanation. This is supported in studies that have compared think aloud protocols from novices and experts as they reason through difficult clinical problems \(^{17,124}\). For example, a study that compared reasoning strategies of junior residents to experienced clinicians as they worked through complex nephrology problems found that increased experience was associated with superior diagnostic performance and more extensive use of causal explanations \(^{17}\).

Recently, Williams and Klamen \(^{125}\) have described a written diagnostic justification task, intended to make students’ diagnostic strategy explicit. In this task, students were asked to identify their diagnostic strategy by explaining how they used patient and laboratory data to move from initial differential diagnoses to a final diagnostic decision. It was found that students’ diagnostic justification scores were highly correlated to the final comprehensive exam score \(^{125}\). Moreover, the relative contribution of biomedical knowledge and clinical cognition on students’ diagnostic strategy has been investigated using structural equation modelling. This structural equation modelling study revealed a small correlation between biomedical and clinical knowledge in the first two years of training, but found that both constructs demonstrated a moderate relationship with diagnostic justification ability of fourth year students \(^{126}\). These findings suggest that the diagnostic justification task appears to capture the use of basic science knowledge in clinical diagnosis. Based on these findings, it is plausible that a diagnostic justification task could provide a way to explicitly capture the impact of integrated basic science knowledge on novices’ diagnostic reasoning process.

In the present study, we aimed to extend previous work on cognitive integration using new learning materials teaching musculoskeletal pathologies with allied health students. In addition, we aimed to further our understanding of cognitive integration and conceptual coherence by using a diagnostic justification task to investigate the impact of integrated basic science instruction on novices’ diagnostic reasoning process. We hypothesized that students who are taught musculoskeletal conditions using basic
science descriptions would have superior diagnostic accuracy after a time delay compared with those who are only taught the clinical features. It was expected that this effect would be present even though learners’ memory of clinical features associated with each musculoskeletal condition may decline over time. Furthermore, we anticipated that the diagnostic justification task would allow for explicit measurement of the impact cognitive integration has on novices’ diagnostic reasoning process, allowing for the possibility that students would use their basic science knowledge, without necessitating its articulation.

4.2 Methods

4.2.1 Participants

Forty-five first and second year massage therapy students from Humber College, Toronto participated in this study. All students had completed the same introductory musculoskeletal anatomy course. The students were assumed to have a basic understanding of the bones, joints, and muscles of the hand but had minimal, if any, prior experience with the musculoskeletal pathologies selected for the learning materials. Students received a $30 Campus Bookstore gift card for participating. Human research ethics approval was obtained from Humber College and participation was completely voluntary.

4.2.2 Learning materials

Two learning conditions were created for the purpose of this study; an integrated basic science (BaSci) condition and a clinical science only (CS) condition. Participants in both learning conditions were taught the clinical features of four confusable musculoskeletal pathologies: Dupuytren’s contracture, carpal tunnel syndrome, Guyon’s canal syndrome, and pronator teres syndrome. The learning material for each of the pathologies in the BaSci group included an integrated review of relevant anatomical structures, clinical features, and the underlying causal mechanisms (anatomical
pathology) of each feature. The learning material for the CS group used the same descriptions and images/video clips for the clinical features of each pathology; however, the anatomy and underlying causal mechanisms were excluded. To equalize the learning time between the two conditions, the CS group was taught epidemiology and potential treatment options for each of the four pathologies. In both learning conditions participants were not told explicitly which clinical features were key to making a correct diagnosis. An example of learning material for both groups is shown in Table 3. The learning materials consisted of images and video clips accompanied by audio recordings (19 minutes in length) that narrated the written material on each slide. Participants were given an unlimited amount of time to study each slide but were not permitted to click backwards through the learning materials. This was done in an effort to control the time on task between the groups. Two textbooks, the Anatomical Basis of Neurologic Diagnosis \textsuperscript{127} and Clinically Oriented Anatomy \textsuperscript{128} were content references for the learning materials. Both learning conditions were reviewed for clarity and accuracy by an experienced physical medicine and rehabilitation clinician and a clinical anatomist.

4.2.3 Testing materials

Three tests were used in this study.

1. Diagnostic accuracy test: To test diagnostic accuracy, participants were presented with 15 clinical cases and were asked to choose the correct diagnosis from a list of four pathologies. Each case description included the age, sex, a minimum of three clinical features, and an image or video clip of the patient’s hand presentation. For counterbalancing purposes, two versions (A and B) were created and matched for difficulty. Both tests were reviewed for accuracy by a clinical anatomist and piloted by 22 undergraduate students. Analysis of the pilot data revealed no difference between test A and B.
2. Memory test: To measure participants' recall of clinical features they were asked to choose the correct features for each of the pathologies from a list of 16 features. The same list was provided for all four musculoskeletal pathologies.

3. Diagnostic justification test: This test aimed to explicitly capture the participants' diagnostic reasoning process when explaining a correct diagnosis. Participants were provided with an image of a patient’s hand presentation and were told the correct diagnosis. Participants were then asked to provide the patient with a written explanation of their diagnosis, being as specific as possible. These explanations were typed into a text box located below the image of the patient’s hand presentation. All four pathologies were tested in the same manner with participants having no time or word count restrictions to provide their response. This simplified diagnostic justification measure was specifically developed for this study and was considered to be appropriate for this context. The prompt used for each question on this test was deliberately left vague in an effort not to influence participants' responses and to avoid intentional learning instructions. Further, unlike the diagnostic justification task used by Williams & Klamen, we did not require students to provide a diagnosis or a differential diagnosis nor were students prompted to list key clinical findings (positive or negative).

The learning and testing materials were presented using a customized software programme which enabled us to control the minimum amount of learning time for each participant, record reaction times, and track participant responses.

4.2.4 Protocol

Upon consent, participants were randomly allocated 1:1 into the BaSci or the CS group. This study was completed in cohorts up to six participants at a time. Each participant was seated at an individual table and was provided with a laptop computer, headphones, and instructions for viewing and testing. Before starting the learning materials participants completed a prior knowledge test and a basic hand anatomy tutorial and quiz. The prior knowledge test consisted of five clinical cases and used the
same format as described for the diagnostic accuracy test. The basic hand anatomy tutorial and quiz were created to review anatomical terminology and the bones, joints, and joint movements of the hand. At the end of the tutorial participants completed seven multiple-choice questions on basic hand anatomy. The computer programme scored the quiz and required participants to achieve a minimum of 86% (6 out of 7) in order to proceed to the learning phase of the study. Participants who did not achieve 86% on their first attempt were redirected to the beginning of the tutorial and were instructed to review the material. Following the second attempt on the quiz all participants were directed to the learning phase. Immediately after the learning phase, participants completed the diagnostic accuracy test (test A or B) followed by the memory test. One week later, participants returned to complete the diagnostic accuracy test (test A or B), followed by the diagnostic justification test, and the memory test. Participants who had taken diagnostic accuracy test A the previous week were given test B, and vice versa. On both immediate and delayed testing, all test items were presented one at a time, in random order, and no time restrictions were imposed.

4.2.5 Analysis

An independent samples t-test was used to compare the prior knowledge test scores of the BaSci and CS group. For each participant, the number of correct responses on the diagnostic accuracy and memory tests was calculated. The results on these two tests were analyzed separately using a 2x2 repeated measures ANOVA, with the learning group (BaSci and CS) as the between-subject variable and time (immediate vs. delayed) as the within-subject variable. A series of planned t-tests were also performed. The same analysis was used to compare the amount of time it took participants to complete the diagnostic test on immediate and delayed testing. Based on pilot data, a seven-point Likert scale was created by the research team to score participants’ diagnostic justification responses (Figure 2). The scale ranged from one (identifies incorrect sign/symptoms) to seven (identifies more than one key sign/symptoms for the pathology and provides a correct rationale for each sign/symptom). Two independent, blinded raters used the scale to score all responses. To assist with grading, raters were
provided with a list of clinical features associated with each of the pathologies with the key clinical features highlighted. Intra-class correlation was calculated to measure agreement between the raters. The average of the raters’ scores for each participant was subject to an independent samples t-test to compare the type of information participants used to justify their diagnosis. Pearson’s correlations were calculated for both learning groups to measure the relationship between participants’ diagnostic accuracy and diagnostic justification scores and diagnostic accuracy and time to complete the diagnostic tests.

4.3 Results

A priori it was decided that participants would be excluded from the final analysis if they did not complete testing at both time points or if they were identified as an outlier on either the diagnostic or recall test. One participant did not return to complete follow-up testing and a box plot analysis identified one participant as an outlier on the first recall test. A total of 43 participants were included in the final analysis.

The BaSci group (n = 22) scored 48% and the CS group (n = 21) 39% on the prior knowledge test. A comparison of these scores revealed no difference (p = 0.12).

On the diagnostic accuracy test, participants in the BaSci group more accurately diagnosed the musculoskeletal pathologies on both immediate and delayed testing compared with the CS group (Table 4). The ANOVA showed a significant main effect of time, \( F_{1, 42} = 12.3, p = 0.001, \eta_p^2 = 0.23 \) and learning group, \( F_{1, 42} = 11.2, p = 0.002, \eta_p^2 = 0.21 \). The effect size of the difference for the learning groups was in the large effect range (d = 0.82).
Time taken to complete the diagnostic accuracy test immediately after learning and one week later differed between the BaSci (8.5/8.1 min) and CS (7.6/6.4) groups. The ANOVA showed a significant main effect of group, $F_{1,42} = 4.8$, $p = 0.03$, but there was no significant correlation between diagnostic performance and time to complete the diagnostic tests.

On the memory test, the BaSci group outperformed the CS group (Table 4). The ANOVA showed a significant main effect of learning group, $F_{1,42} = 12.4$, $p = 0.001$, $\eta_p^2 = 0.23$, and a significant interaction between time and learning group, $F_{1,42} = 6.3$, $p = 0.02$, $\eta_p^2 = 0.13$. To determine what was driving the interaction, a series of planned t-tests were performed. An independent samples t-test revealed the BaSci group did significantly better than the CS group on immediate testing only ($p < 0.01$).

As shown in Table 4, the BaSci group also outperformed the CS group on the diagnostic justification test ($p = 0.01$). The effect size of the difference for the learning groups was in the moderate to large effect range (0.74). Explanations provided by the BaSci group included one key feature for each disease category along with an incorrect feature(s). In contrast, the explanations by the CS group included the identification of one correct feature; however, the feature was common to more than one disease category. Agreement between the two independent raters was high (ICC = 0.90). A significant correlation was found between students' diagnostic justification and diagnostic accuracy scores one week after initial learning for both the BaSci ($r = 0.70$, $n = 22$, $p < 0.001$) and CS groups ($r = 0.51$, $n = 21$, $p < 0.02$). These data provide some validity evidence for the simplified diagnostic justification test used in this study.

4.4 Discussion

The BaSci group outperformed the CS group on the diagnostic accuracy tests. One week after initial learning, both groups experienced a drop in performance; however, the
smallest decline was observed in the BaSci group. Students who received integrated instruction also outperformed students who were only taught the clinical features of the pathologies on the basic memory test. However, this difference was no longer evident one week later. Thus, as predicted, students in the BaSci group were able to maintain superior diagnostic performance after a time delay, despite showing no advantage of remembering the clinical features for the pathologies learned. These results support the model of conceptual coherence and provide converging evidence for the value of basic science in clinical reasoning 57,59.

Students who were taught using integrated basic science also outperformed those who were only taught the clinical features on the diagnostic justification test. Both groups identified correct features on the test, but those who received integrated instruction identified key diagnostic features rather than features that were common across disease categories. As hypothesized, the BaSci group was able to more accurately justify the pathologies learned without overtly using their basic science knowledge. These results provide insight on how learners’ integrated basic science knowledge is used to make more accurate clinical decisions. This finding also furthers our understanding of conceptual coherence by providing explicit evidence of specific changes that occur in clinical reasoning when instruction supports the integration of basic and clinical science knowledge.

Previous work in clinical reasoning has shown that better conceptual coherence results in novices exhibiting expert-like behaviour when solving clinical problems, including more automatic and holistic processing 3,59. The findings of the current study suggest this may be due to the learners’ greater understanding of the relative importance of key clinical features as evidenced by the students’ explanations on the diagnostic justification test. Furthermore, the strong correlation found between the BaSci group’s diagnostic accuracy and diagnostic justification scores are consistent with predictions made by a recent structural equation modelling study 126, thereby providing evidence
that diagnostic justification can indirectly capture the use of learners’ integrated basic science knowledge in clinical diagnosis.

This study has limitations that should be noted. The simple diagnostic justification test used in this study was created specifically for this experiment and these learning materials. The results of the test cannot be taken as a generalizable measure of the participants’ justification abilities. We cannot conclude that integrated basic science instruction leads to better diagnostic justification in all settings or for all cases. Further, the diagnostic justification test was completed one week following initial instruction, immediately after the diagnostic accuracy test. Studies on non-analytical reasoning have demonstrated that novice problem solving is influenced to some degree by similarity to exemplars in memory. Thus, it is possible that exposure to the clinical descriptions and pictures on the diagnostic accuracy test influenced students’ explanations on the justification task. Students were also incentivized to participate and it is unknown whether the same results would be observed in a general setting. In addition, all aspects of this study took place in an artificial learning environment and the learning materials were tightly controlled using customized software. These learning conditions and materials may not reflect how learning would occur in a classroom setting.

The importance of integrating basic science instruction with clinical training throughout undergraduate curricula is well recognized and several strategies that aim to integrate these two knowledge domains have been described. However, curricular innovations that merely create proximity between the basic and clinical sciences have not been found to significantly improve learners’ integrated knowledge. In contrast, the current study shows that when basic and clinical science knowledge is cognitively integrated, learners develop better conceptual coherence and as a result have superior diagnostic abilities. Further, by teaching students the causal basic science mechanisms they understood the relative importance of key clinical features for disease categories and we suggest that they use this knowledge to make more accurate clinical decisions.
This highlights the utility of integrated basic science knowledge and emphasizes the importance of purposefully linking basic and clinical science instruction in day-to-day teaching. Moreover, a simple diagnostic justification task has been identified as an additional measure that educators can use to assess learners’ grasp of integrated instructional materials without reliance on explicit articulation.

4.5 Conclusion

This study demonstrates the positive impact of integrating basic anatomical education and clinical science instruction on students’ diagnostic reasoning ability in addition to diagnostic accuracy. The findings of this study further our understanding of conceptual coherence by providing explicit evidence of the advantage learners have when basic science knowledge is cognitively integrated. Future research should explore potential learning strategies that will promote the development of integrated basic science knowledge.
Table 3: Sample explanations for Dupuytren contracture explained in the two learning conditions

**INTEGRATED BASIC SCIENCE GROUP (BaSci)**

Dupuytren contracture presents as painless nodular thickenings of the palmar aponeurosis that adheres to the skin. No pain is associated with the disease since the nerves of the hand which transmit pain information to the brain are not affected. Gradually, thickening and progressive shortening (contracture) of the longitudinal bands produces raised ridges in the palm of the hand. Fibrosis degeneration and shortening of the longitudinal bands causes partial flexion of the affected fingers at the metacarpophalangeal (MP) and proximal interphalangeal (PIP) joints.

With progressive disease, a flexion deformity will develop and as a result the patient will report an inability to fully extend the affected fingers at the MP and PIP joints. The flexion deformity is caused by the shortening of the longitudinal bands of the palmar aponeurosis. The flexion deformity limits the person’s ability to fully open their hand, making it difficult to grasp large objects. In Dupuytren contracture there are no sensory changes observed in the hand. This is because the contracture does not affect the nerves of the hand that are responsible for supplying sensory information to the skin.

**CLINICAL SCIENCE ONLY GROUP (CS)**

Dupuytren contracture presents as painless nodular thickenings that adhere to the skin. Gradually, patients present with raised ridges in the palmar skin that extend from the proximal part of the hand to the base of the fingers. In patients’ affected fingers, partial flexion occurs at the metacarpophalangeal (MP) and proximal interphalangeal (PIP) joints. With progressive disease, a flexion deformity can develop and patients will report an inability to fully extend the affected fingers at the MP and PIP joints.

The disease can occur in both hands but is generally not symmetric in severity. The ring finger is most commonly involved followed by the little finger. Patients typically have a difficult time grasping large objects. There are no sensory changes observed in this disease.
Figure 2: Likert scale used to score the diagnostic justification test

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Chapter 5
The Effect of Self-Explanation and Cognitive Integration of Basic and Clinical Sciences in Novices

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To be submitted to Advances in Health Sciences Education

5.1 Introduction

Integrated basic and clinical science knowledge is essential for practice in the health professions. Although the importance of these two knowledge domains is well-recognized, successfully supporting the development of learners’ integrated basic and clinical science knowledge and achieving integration in the classroom specifically, remains an educational challenge. There is, however, a growing body of experimental evidence that has shown that learners can benefit when integration is based on the concept of cognitive integration. In contrast to the more common horizontal or vertical integration, cognitive integration is based on the premise that integration occurs within the learner’s mind rather than within the curriculum.

Cognitive integration is supported through micro-level teaching activities and involves specific educational strategies that purposefully expose the relationships between the basic and clinical sciences. It is suggested that training which explicitly exposes learners to the causal mechanisms underlying why clinical features are associated with a disease aids in the development of a coherent mental representation of the disease category. The value of this conceptual coherence has been captured in a series of studies that have shown that learners demonstrate superior diagnostic abilities and a better understanding of the relative importance of key clinical features for disease categories when instruction fosters cognitive integration. However, although studies have shown that cognitive integration of basic and clinical science improves
learners’ conceptual understanding of a disease, there has been limited exploration of the ways in which educators can translate this theoretical model of mental processes and structures into sound instructional strategies.

Since cognitive integration must occur within the learner’s mind, a potential strategy to promote and support the development of integrated knowledge would be to encourage the learner to explicitly elaborate on the causal relationship between clinical features and basic science mechanisms through self-explanations. Generally, self-explaining is a constructive learning activity that fosters deep learning by encouraging students to generate inferences to themselves while they engage with the learning material. Several studies from a variety of domains have shown that prompting learners to self-explain while learning, positively impacts the development of both conceptual and procedural knowledge. It is proposed that as learners generate inferences to themselves they actively integrate new knowledge within their existing mental representations. Furthermore, while learners explicitly try to make sense of new material they may identify misconceptions within their current understanding which may result in restructuring of their existing mental model over time. It has also been suggested that through self-explanation learners discover unifying patterns within the material being studied and that these generalizations help to facilitate learning.

Based on the proposed mechanisms driving the self-explanation effect, it seems plausible to expect that having learners self-explain the underlying causal mechanisms of a disease may aid in their development of a coherent mental representation of a disease category.

Recent work in medical education on self-explanation and clinical problem solving also lends support to the suggestion that elaborating on causal mechanisms while learning with integrated basic science materials may benefit learners. As an example, Chamberland et al. (2011) investigated the value of third year medical students generating self-explanations aloud while reasoning through familiar and less familiar clinical cases. The findings of this study showed that in comparison to students who did
not self-explain, those who explicitly generated inferences to themselves while reasoning through clinical problems had superior diagnostic performance on less familiar transfer cases one-week later\textsuperscript{71}. This positive effect was observed despite students not receiving any feedback on the accuracy or quality of their explanations \textsuperscript{71}. Further analysis of the self-explanations revealed that students generated a higher number of self-explanation segments and more biomedical inferences when they worked through less familiar clinical problems \textsuperscript{72}. These results suggest that when students self-explain while reasoning through novel clinical problems they actively attempt to understand the clinical features of a disease using their basic science knowledge. Thus, by generating inferences, students elaborate on new information and also integrate new knowledge within their existing mental model. It is proposed that these cognitive processes promote deep and meaningful learning that thereby result in students developing a more coherent understanding of unfamiliar disease conditions and better clinical reasoning skills over time\textsuperscript{71-73}.

In summary, it appears that prompted self-explanation may be an effective strategy that can support learners’ development of integrated basic and clinical science knowledge. Thus, in the current study we aimed to determine whether self-explanation promotes conceptual coherence and, as a result, impacts novices’ diagnostic ability over time. We compared diagnostic efficacy of teaching students the clinical features of musculoskeletal (MSK) pathologies integrated with causal basic science descriptions (integrated basic science approach) versus teaching using an integrated basic science approach combined with self-explanation. A segregated basic science group, who were taught the clinical features and basic science mechanisms separately, was also included to serve as a control. It was hypothesized that novices who self-explain while learning novel disease categories, using an integrated basic science approach, would have superior diagnostic ability over time compared to those who received integrated or segregated basic science instruction alone.
5.2 Methods

5.2.1 Participants

Massage therapy (n = 6), undergraduate kinesiology (n = 36), and first-year postgraduate exercise science (n = 18) and physical therapy (n = 18) students from Humber College, University of Guelph-Humber, and University of Toronto were recruited for this study. This population was specifically chosen to ensure that participants had an understanding of basic anatomical terminology, but minimal, if any, experience with the MSK pathologies selected for the learning materials. Students were recruited by email and in-class announcements and received a $10 gift card as an honorarium for participating. The research ethics boards at Humber College and University of Toronto approved this study.

5.2.2 Learning and Testing Materials

The learning and testing materials were adapted from a previous study that used a similar population and protocol. Participants learned about the clinical features of four confusable MSK pathologies: Dupuytren contracture, carpal tunnel syndrome, pronator teres syndrome, and Guyon’s canal syndrome. The learning materials consisted of images and video-clips presented on laptop computers by a customized computer program, accompanied by audio recordings that narrated the written material on each slide.

Three learning groups were used in this study. In the integrated basic science group (BaSci), participants were taught relevant anatomical structures and were explicitly told the relationship between each clinical feature and its underlying causal mechanism (anatomical pathology) (Table 5). Participants in the self-explanation group (SE) received the same learning material as those in BaSci group, but in addition, after each MSK pathology was taught they were shown a clinical case example and were prompted to self-explain in writing why certain features were present. Each case
A diagnostic accuracy and a basic memory test developed and used in a previous experiment were slightly modified for clarity and used in this study. The diagnostic accuracy test consisted of 15 clinical cases. Participants were asked to choose the correct diagnosis from a list of the four pathologies learned. Each case description included the age, sex, a minimum of 3 clinical features and an image or video clip of the patients MSK condition. For the purpose of counterbalancing, two versions (A and B) of the test were created and matched for difficulty. The basic memory test aimed to measure participants’ recall of the correct clinical features associated with each MSK pathology. All participants were provided with the same list of 16 clinical features and were asked to select the correct features associated with each of the pathologies. All test items were presented on screen one at a time, in random order. No time
restrictions were imposed.

The learning and testing materials were presented using a customized software program which enabled us to track the amount of learning time for each participant, record reaction times, and collect participant responses.

5.2.3 Procedure
Participants were allocated to one of the three learning groups by block randomization using a random numbers table generated by Research Randomizer\textsuperscript{131}. Each participant was seated at an individual desk and was provided with a laptop computer, headphones, and instructions for viewing and testing. Prior to the learning phase of the study, participants completed a prior knowledge test that consisted of 5 multiple-choice clinical case questions. All participants then completed an introductory tutorial and quiz on hand anatomy. The tutorial reviewed anatomical terminology and the bones, joints, and joint movements of the hand. The quiz consisted of 7 multiple-choice questions on basic hand anatomy. Participants who did not score 86\% (6 out of 7) on their first attempt were redirected to the beginning of the tutorial and were instructed to review the material. All participants proceeded to the learning phase following either achieving 86\% or completing their second attempt on the quiz. Immediately after the learning phase participants completed the diagnostic accuracy test followed by the memory test. One-week later participants returned and again completed the diagnostic accuracy test followed by the memory test. Those who had taken diagnostic accuracy test A during the previous week took test B and vice versa.

5.2.4 Analyses
For each participant, the number of correct responses on the prior knowledge, diagnostic accuracy, and memory tests were calculated. A one-way ANOVA was used to compare prior knowledge test scores and total learning time between groups.
Participants’ scores on the diagnostic accuracy and memory were analyzed separately using a 3x2 repeated measures ANOVA, with the learning group (BaSci, SE, SG) as the between-subject variable and time (immediate and delayed) as the within-subject variable. A series of planned post-hoc tests were completed using the least significant difference method.

To evaluate participants’ self-explanation responses, the research team developed a scoring grid for each question. A correct answer was given a score of 2, a partially correct answer 1, and an incorrect answer 0. Two independent raters (KL and AMR) used the scoring grid to score each self-explanation response. Intra-class correlation was calculated to measure agreement between the raters. Descriptive statistics of the self-explanation questions were calculated using the average of the raters’ scores for each participant. Pearson’s correlations were calculated to measure the relationship between participants’ self-explanation and diagnostic accuracy scores.

5.3 Results

A priori it was decided that participants would be excluded from the final analysis if they did not complete testing at both time points or if they were identified as a statistical outlier on either the first diagnostic accuracy or recall test. One participant from the SE group did not return to complete follow-up testing and a box plot analysis identified 4 participants as outliers on the first diagnostic test (2 from BaSci group, 2 from SE group) and 2 outliers on the first recall test (1 from BaSci group, 1 from SG group). A total of 71 participants were included in the final analysis; 25 in the BaSci, 21 in the SE, and 25 in the SG groups.

For the prior knowledge test the BaSci, SE, and SG groups scored on average 36%, 28%, and 34%, respectively. A comparison of these scores revealed no difference $p = 0.49$. 
The SE and SG groups spent more time on the learning materials compared to the BaSci group. On average it took the BaSci, SE, and SG groups [mean, (SD)], 19 min (2.0 min), 33 min (7.8 min), and 27 min (5.6 min) to complete the learning materials, respectively. The ANOVA revealed a main effect of learning group $F_{2,68} = 39.6$, $p < 0.01$. Further post-hoc analysis revealed that there was significant difference ($p < 0.01$) between the BaSci and SE, BaSci and SG, and SE and SG groups. In comparison to the BaSci group the SE and SG groups spent an additional 14.3 minutes and 8.6 minutes on the learning materials, respectively. The difference between time spent on the learning material for SE and SG groups was 5.7 minutes.

The results for the diagnostic accuracy tests are shown in Table 7. The ANOVA showed a significant main effect of time, $F_{2,68} = 10.4$, $p = 0.002$, $\eta^2_p = 0.13$ and learning group, $F_{2,68} = 3.83$, $p = 0.026$, $\eta^2_p = 0.10$. The BaSci group outperformed the SE and SG groups on the diagnostic accuracy test immediately after learning and 1-week later. Post-hoc analysis showed that the BaSci group performed significantly better compared to the SE ($p = 0.045$) and SG groups ($p = 0.011$); however, no difference was observed between the SE and SG groups ($p = 0.65$). The effect size of the difference between the BaSci and SE ($d = 0.60$) and BaSci and SG ($d = 0.61$) groups were in moderate to large effect range.

The basic memory (recall) test scores are summarized in Table 7. The ANOVA revealed a significant main effect of time, $F_{2,68} = 10.9$, $p = 0.002$, $\eta^2_p = 0.14$ and learning group, $F_{2,68} = 5.0$, $p = 0.009$, $\eta^2_p = 0.13$. Post-hoc testing revealed a significant difference between the BaSci and SG groups ($p = 0.002$). Unlike the diagnostic accuracy test no difference was detected between the BaSci and SE groups ($p = 0.17$) or SE and SG groups ($p = 0.11$).
The average total score on the self-explanation questions was 79% (15%). Agreement between the 2 independent raters was high (ICC = 0.93). A significant positive correlation was found between participants’ self-explanation and diagnostic accuracy scores immediately after learning ($r = 0.56$, $n = 21$, $p < 0.01$) and 1-week later ($r = 0.57$, $n = 21$, $p < 0.01$).

5.4 Discussion

The purpose of this study was to explore the effect of using self-explanation while learning with integrated basic science materials on novices’ ability to diagnose MSK pathologies. The results showed that integrated basic science instruction alone leads to superior diagnostic performance in comparison to both integrated instruction combined with self-explanation and segregated basic science instruction. While diagnostic performance declined across all three learning groups after a one-week time delay, the largest drop in performance (10%) was observed in the SE group. Similarly, students’ performance on the basic memory test declined over time; however, unlike the diagnostic accuracy test no difference was observed between the BaSci and SE groups on the memory assessment.

Careful consideration of the learning materials used for the SE group may help to explain the results observed. Participants in this condition were first presented integrated learning materials that were designed specifically to foster a holistic understanding of each disease category $^{130}$. Following integrated instruction, the self-explanation task required that students articulate why certain clinical features arose using their anatomical knowledge. Based on previous findings suggesting that explicit inclusion of underlying mechanisms during learning led to more holistic processing and better diagnostic accuracy, the self-explanation task was intended to emphasize the relationship between clinical features and their underlying causal mechanisms $^{6,58,60}$. Students’ scores on the self-explanation questions clearly indicate that these relationships were successfully emphasized during this task; however, we speculate
that the structure of the task itself may have also influenced learners’ subsequent mental processing. Research on analytic and holistic category learning suggests that analytical category learning leads to stimuli being processed as individual parts rather than integral wholes or ‘blobs’. Similar to Tracy et al., we hypothesize that asking students to explain why certain features were present in each disease fostered a more analytic processing of each category. As a result, the holistic coherence created by the integrated learning materials was disrupted leading to inferior performance on the diagnostic accuracy test relative to the BaSci group. In other words, despite students doing well on the self-explanation questions and their overall score on this task being positively correlated with diagnostic performance, it is plausible that the structure of the self-explanation task encouraged a type of processing that did not align with the holistic model of conceptual coherence and consequently did not have an additive or positive impact on learners’ diagnostic ability. Similarly, a study by Baghdady et al. found that when dental students were forced to use an analytic diagnostic strategy, by identifying individual visual features before choosing a diagnosis, the coherence created by integrated basic science instruction was disrupted and as a result a decline in diagnostic accuracy was observed. Both the current study and the findings of Baghdady et al. suggest that integration strategies need to be carefully structured and applied in a way so that they support the holistic story created by integrated basic science instruction in order to foster conceptual coherence and to capitalize on the benefits of cognition integration.

Superior diagnostic performance by the BaSci group relative to the SG group also provides evidence supporting cognitive integration and the model of conceptual coherence. While the content of the instructional materials presented to both learning groups was the same, learners in the SG group were not explicitly provided causal explanations linking the clinical features of each disease to their underlying anatomical pathology. Thus, similar to previous research, these findings suggest that when instruction explicitly exposes the relationship between clinical features and causal mechanisms, learners’ develop a coherent mental representation of the disease and as result are able to make more accurate clinical decisions. Further, we speculate
that as a result of better conceptual coherence, students in the BaSci group were able to more accurately recall the features associated with each of the pathologies compared to those who were taught using segregated basic science materials. This occurred despite students in the SG group being provided an additional activity that reinforced the specific clinical features associated with each disease. These findings emphasize the value of causal explanations in facilitating the benefits of integrated instruction and they also provide supporting evidence \(^{10,58,60}\) to show that presenting the basic and clinical sciences in close proximity does not guarantee cognitive integration. Together, a comparison of the diagnostic scores of the BaSci and SG and the BaSci and SE groups, suggest that the explicit relationship between clinical features and basic science mechanisms are essential and that the strategies used to emphasize these relationships must also align with the model of conceptual coherence in order to foster cognitive integration.

This study makes significant departures from the previous literature on self-explanation that should be noted. First, our study used focused self-explanation prompts that required learners’ to elaborate on causal mechanisms associated with each disease after they completed conceptual learning materials, whereas prior studies on self-explanation and clinical reasoning used open-ended self-explanation prompts throughout clinical problem-solving \(^{71}\). While both of these forms of self-explanation (open-ended and focused) have been found to have a positive impact on learning \(^{64,136}\), the self-explanation literature recognizes that conditions under which self-explanation is most beneficial and the mechanisms underlying its effect are not well understood \(^{66,67}\). Thus, it is possible that the instructional materials and type of self-explanation prompt used in the current study triggered different cognitive processes and consequently did not have the same impact on learning as observed by Chamberland et al. Second, participants in our study were not told the purpose of self-explanation nor were they shown an example of the procedure. Previous studies have shown that self-explanation ‘training’ is beneficial and results in learners applying the strategy more effectively \(^{137}\). Thus, it is unknown whether the same results would have been observed if participants were provided with a model of self-explanation prior to utilizing the strategy themselves.
The findings of this study and others, demonstrate the value of providing instruction that explicitly exposes the relationship between clinical features and basic science mechanisms on the development of knowledge structures that integrate the basic and clinical sciences. While these causal relationships are essential in developing a coherent mental representation of a disease, the results of this current study importantly show that simply having students elaborate on only some of these causal relationships may not necessarily result in better learning. These findings extend our understanding of conceptual coherence, suggesting that learning strategies, such as self-explanation, may need to foster the holistic story created by integrated basic science instruction in order to positively impact learners’ integrated basic science knowledge. Thus, we would argue that educators should carefully consider not only the structure of a learning strategy but also the extent to which any given learning or teaching tool fosters integrated understanding of clinical signs and symptoms with causal mechanisms. Furthermore, while it has been previously recognized that the cognitive mechanisms driving the self-explanation effect are not fully understood, our findings demonstrate a need for more research in this area in order for educators to develop and support effective self-explanation activities. To further explore the effects of self-explanation and conceptual coherence, future studies should examine whether different forms of self-explanation, such as open-ended prompts along with models of self-explanation may be useful in helping learners develop an integrated understanding of basic and clinical sciences.
Table 5: Sample explanations for Dupuytren contracture used in the three learning conditions in the self-explanation study

<table>
<thead>
<tr>
<th>INTEGRATED BASIC SCIENCE (BaSci) &amp; SELF-EXPLANATION (SE) GROUPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dupuytren contracture is a disease that results in progressive shortening, thickening and fibrosis of the palmar aponeurosis. Deep to the skin on the palmar surface of the hand is the palmar aponeurosis. The palmar aponeurosis forms four longitudinal bands that extend into the fingers.</td>
</tr>
<tr>
<td>Dupuytren contracture presents as painless nodular thickenings of the palmar aponeurosis that adheres to the skin. No pain is associated with the disease since the nerves of the hand which transmit pain information to the brain are not affected. Gradually, thickening and progressive shortening (contracture) of the longitudinal bands produces raised ridges in the palm of the hand. Fibrosis degeneration and shortening of the longitudinal bands causes partial flexion of the affected fingers at the metacarpophalangeal (MP) and proximal interphalangeal (PIP) joints. In Dupuytren contracture the ring finger is most commonly involved, followed by the little finger.</td>
</tr>
<tr>
<td>With progressive disease, a flexion deformity will develop and as a result the patient will report an inability to fully extend the affected fingers at the MP and PIP joints. The flexion deformity is caused by the shortening of the longitudinal bands of the palmar aponeurosis. The flexion deformity limits the person’s ability to fully open their hand, making it difficult to grasp large objects. In Dupuytren contracture there are no sensory changes observed in the hand. This is because the contracture does not affect the nerves of the hand that are responsible for supplying sensory information to the skin.</td>
</tr>
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<table>
<thead>
<tr>
<th>SEGREGATED BASIC SCIENCE GROUP (SG)</th>
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<tr>
<td>A thick layer of deep fascia (palmar aponeurosis) lies superficial to the muscles of the central palm. Proximally, the palmar aponeurosis is continuous with the flexor retinaculum and distally forms four longitudinal bands that attach to the proximal phalanges of the medial four fingers. Fibrosis degeneration of the palmar aponeurosis results in gradual thickening and shortening of the longitudinal bands (picture).</td>
</tr>
</tbody>
</table>
Dupuytren contracture presents as painless nodular thickenings that adhere to the skin. Gradually, patients present with raised ridges in the palmar skin that extend from the proximal part of the hand to the base of the fingers. In patients’ affected fingers, partial flexion occurs at the metacarpophalangeal (MP) and proximal interphalangeal (PIP) joints. With progressive disease, a flexion deformity can develop and patients will report an inability to fully extend the affected fingers at the MP and PIP joints.

The disease can occur in both hands but is generally not symmetric in severity. The ring finger is most commonly involved followed by the little finger. Patients typically have a difficult time grasping large objects. There are no sensory changes observed in this disease.
Table 6: Sample self-explanation questions for Dupuytren Contracture

Q1. Based on your understanding of hand anatomy, explain to yourself (in writing) why the patient does not experience pain or sensory changes?

Q2. Based on your understanding of hand anatomy, explain to yourself (in writing) why you think the patient has difficulty extending their little finger.
Table 7: Scores on the diagnostic accuracy and memory (recall) tests immediately after learning and one-week later

<table>
<thead>
<tr>
<th></th>
<th>Immediate</th>
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<th>Delayed</th>
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<tbody>
<tr>
<td></td>
<td>Group</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Diagnostic Accuracy</td>
<td>BaSci (n = 25)</td>
<td>0.83</td>
<td>0.12</td>
<td>0.75</td>
<td>0.18</td>
</tr>
<tr>
<td>Test</td>
<td>SE (n = 21)</td>
<td>0.74</td>
<td>0.12</td>
<td>0.64</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>SG (n = 25)</td>
<td>0.69</td>
<td>0.21</td>
<td>0.64</td>
<td>0.26</td>
</tr>
<tr>
<td>Memory (recall) Test</td>
<td>BaSci (n = 25)</td>
<td>0.77</td>
<td>0.12</td>
<td>0.72</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>SE (n = 21)</td>
<td>0.73</td>
<td>0.10</td>
<td>0.65</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>SG (n = 25)</td>
<td>0.65</td>
<td>0.15</td>
<td>0.60</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Chapter 6
General Discussion

The overall purpose of this dissertation was to examine curricular integration strategies that optimize learning of the anatomical sciences. The rationale of the three studies described in this dissertation can be understood using Goldman and Schroth’s integration framework. As previously outlined, this framework proposes that aspects of integration can be applied at all levels of the curriculum including the program, course, and individual teachings sessions. Further, Goldman and Schroth suggest that in order to optimize the value of integration in medical education, curriculum and integration decisions should occur in three successive stages starting at the program level, followed by the course level, and lastly at the session level.

At the University of Toronto, a specific program level integration strategy targeted to support PM&R trainees in achieving competencies related to the basic sciences is the inclusion of integrated clinical anatomy modules throughout the PM&R residency program. These established program level decisions were used to inform the development of the three research studies described in this dissertation. The results and implications of these studies will be summarized and discussed in the following sections of this chapter.

6.1 Summary of Findings

In the first study (Chapter 3), a modified Delphi was used to objectively establish clinically relevant content for an integrated musculoskeletal anatomy course for PM&R residents. Using a national panel of practicing PM&R specialists, 208 curricular items were identified as very important or essential to PM&R residency education and were recommended to be included in the curriculum (Table 2). Two Delphi rounds were
required to achieve consensus on these items and on average 68 minutes was invested by each expert panelist to complete this process. The use of a modified Delphi was demonstrated to be an effective method to identify clinically relevant content that has an essential application to Canadian PM&R practice. Further, through this systematic approach the opinions of practicing Physiatrists with a variety of subspecialty areas was gathered without these experts ever having to meet face to face.

Following the identification of content for an integrated musculoskeletal anatomy course, two experimental studies were developed to examine the effect of different educational strategies to optimize learning of the curricular content. As such, the instructional materials for these studies (Chapters 4 and 5) were developed using clinically relevant items identified during the Delphi process.

In the first experimental study (Chapter 4), the effects of two different instructional approaches on learning musculoskeletal diseases were compared using a diagnostic accuracy and a diagnostic justification test. The results of this study showed that novices who were taught the clinical features of musculoskeletal diseases using causal basic science descriptions (anatomical pathology) had superior diagnostic accuracy and a better understanding of the relative importance of key clinical features compared to those who were only taught the clinical features. The findings of this study support the model of conceptual coherence that suggests that when the relationship between anatomical concepts and clinical facts is made explicit during training learners develop a more coherent understanding of disease categories. Moreover, the results of the diagnostic justification test further our understanding of the model of conceptual coherence by demonstrating the positive impact of integrating basic anatomical education and clinical science instruction on novices’ diagnostic reasoning process.
In the final experimental study (Chapter 5) we aimed to enhance learners’ integrated basic science knowledge and conceptual coherence of disease categories by encouraging learners to elaborate on the causal relationship between clinical features and basic science mechanisms through self-explanation. More specifically, in this study we examined the relative impact of two basic science instructional approaches (integrated basic and clinical science instruction and segregated basic and clinical science instruction) and self-explanation on novices’ diagnostic accuracy over time. It was hypothesized that having learners self-explain the underlying anatomical pathology for certain clinical features of each disease would result in better conceptual coherence and consequently superior diagnostic accuracy. The findings showed that integrated instruction alone resulted in superior diagnostic performance in comparison to both integrated instruction combined with self-explanation and segregated basic science instruction. It is suggested that since the self-explanation task only required learners to elaborate on certain clinical features of each of the pathologies, that the task itself likely fostered a more analytic approach to understanding each disease and as a result disrupted the holistic coherence initially created by the integrated learning materials. Further, the findings of this study provide converging evidence\textsuperscript{10,58,60} to demonstrate that presenting the basic and clinical sciences in segregation, but in close proximity, does not optimize the value of basic science teaching. Thus, based on these findings it is suggested that session level integration strategies need to be carefully structured and applied in ways that foster the holistic story created by integrated basic science teaching in order to support the development of conceptual coherence and to positively impact learners’ integrated basic science knowledge.

Combined, these three studies demonstrate how integration strategies can be applied at multiple levels of the curriculum and highlight the significance of examining integration at each level of the curriculum in order to optimize the benefits of integration. To gain further insight on the implications of this research and how it has advanced our understanding of the model of conceptual coherence the findings of these studies will be discussed in the greater context of the health professions education literature.
6.2 Strategy to Develop Course Content

Integration of basic and clinical science training is an ongoing theme within calls for reform within medical education \(^{25,27,28}\). As such, curriculum designers and front-line teachers are often tasked with designing and modifying learning experiences in order to better facilitate integration of the basic and clinical sciences throughout their training programs. As previously discussed, the process of reforming curriculum can be complex and may involve several steps including completing a needs assessment, writing specific goals and objectives, selecting curricular content and educational methods, and evaluating the new curriculum \(^{31,140}\). To date, there have been several reports that describe curriculum reform efforts including those related to the anatomical sciences \(^{34-37}\); however, a critical component of the curriculum design process that is often not well described in the literature is how specific content for these new integrated courses is selected. Further, specifically within postgraduate anatomical education, the identification of content is often selected subjectively by small expert group opinion, convenience samples, and individual preferences \(^{39-41,93-95}\). I argue that since time devoted to basic science training may be limited during residency training it is critical that content of integrated basic science curricula be relevant to daily clinical practice. This is consistent with the suggestion that medical curricula should not merely be ‘stuffed’ with scientific facts, but should consist of training that will inevitably support learners in becoming more effective thinkers and better clinicians \(^{141}\). Further, there is evidence to suggest that content of medical curricula, rather than instructional method, plays a significant role in the development of learner’s integrated basic and clinical science knowledge and thus selection of content for curricula should be carefully considered \(^{42}\).

The use of a modified Delphi (Chapter 3) provides an example of a systematic approach to gathering the opinions of clinical experts and achieving consensus on clinically relevant curricular content for a postgraduate integrated anatomy curriculum. Studies of medical school faculty have shown that basic scientists often advocate for a deeper
level of biomedical content to be included in medical curricula in comparison to clinicians. Accordingly, the selection of practicing Physiatrists as ‘experts’ in this study was intentional to ensure that the identified content represented curricular items that were directly relevant to clinical practice. Further, as a result of including PM&R specialists (n = 37) from across the country, this curriculum reflects musculoskeletal conditions and their related anatomical structures that have an essential application to Physiatrists nationally and across subspecialty areas. The completion of this study using relatively few resources suggests that the Delphi process is a feasible and effective approach to designing curricular content. The entire process required on average one hour from each clinical expert. Further, it only required the principal investigator to generate a comprehensive list of potential curricular items along with calculate internal consistency and agreement scores at the end of each Delphi round. The initial curricular list was generated by compiling items from existing clinical cases used in the PM&R training program, reviewing clinical anatomy and PM&R textbooks, and consulting with a small group of Physiatry experts. Administration and collection of all data was completed using Survey Monkey. Similar to previous research, the use of the Delphi method also enabled experts to provide their opinions anonymously without bias and allowed for controlled feedback to be shared with experts. Moreover, this consensus building process was straightforward and resulted in a considerable reduction (44%) in the number of curricular items that were initially recommended for inclusion. Thus, in addition to identifying clinically relevant content, this approach has also helped to ensure that the curriculum is not simply ‘stuffed’ with anatomical facts and disease conditions, but rather content that has a direct application to clinical practice. In summary, this study supports the use of a systematic approach to developing curricular content for postgraduate clinical anatomy training. Further, the Delphi method appears to be an effective strategy that educators can use to design clinically relevant content for integrated basic science curricula.
6.3 Instructional Strategies to Optimize Learning of the Anatomical Sciences

Researchers and education scholars generally agree that basic science training, including anatomy, plays an important role in the development of clinical expertise; however, there are different theoretical perspectives on how and when learners use their integrated basic science knowledge during clinical reasoning. The model of conceptual coherence proposed by Woods suggests that understanding causal basic science mechanisms is key to developing a coherent mental representation or conceptual coherence of disease categories \cite{6,59}. This mental activity is accomplished by explicitly using basic science, such as anatomical pathology, to explain the underlying mechanisms for clinical features of a disease. More specifically, the model of conceptual coherence suggests that causal basic knowledge enables learners to make a diagnosis based on what makes sense rather than relying on an analytical strategy that focuses on counting the presence or absence of clinical features \cite{59}. Although this model of reasoning is supported in the pattern of performance observed across a number of experimental studies \cite{4,6,58,60,123}, an explicit measure of how learners use their integrated basic science knowledge to arrive at a correct diagnosis has been difficult to capture. This is because the model of conceptual coherence does not require the overt application of basic science knowledge during diagnostic reasoning. Instead, this theoretical model suggests that novices use their integrated basic science knowledge unconsciously and automatically to understand why certain clinical features of a disease belong together when making a diagnosis.

Alternatively, encapsulation theory suggests that causal basic science knowledge that is acquired early in medical training eventually becomes encapsulated under diagnostic labels or simplified causal models as a result of extensive application and repeated clinical exposure \cite{11}. Schmidt has theorized that as a result of encapsulation, expert diagnosticians focus primarily on the clinical presentation of a disease rather than causal mechanisms during routine clinical problem solving. However, when experts are presented with a challenging or complex clinical case, their basic science knowledge
can be retrieved to support diagnostic reasoning \textsuperscript{11-13}. The theory of encapsulation can be used to explain why think aloud protocols of experts have failed to reveal the explicit use of basic science during routine clinical problem solving \textsuperscript{7}, but it does not explain why novices without any clinical experience demonstrate superior diagnostic performance when they are taught clinical conditions using causal basic science explanations. Encapsulation theory also does not provide an explanation for the ability of novices to use basic science to demonstrate expert like processing or to diagnose difficult clinical cases \textsuperscript{3,5}.

The findings of the experimental studies presented in this thesis better align with and support the model of conceptual coherence. Our results have shown that novice allied health students who were taught musculoskeletal pathologies using an integrated basic science approach maintained superior diagnostic accuracy over a one week time delay despite showing no advantage of being able to recall the clinical features associated with each disease. Thus, when instruction supports the development of cognitive integration of basic and clinical science knowledge, novice learners without any clinical experience were able to demonstrate superior diagnostic performance. These findings provide converging evidence for the model of conceptual coherence \textsuperscript{58-60} by demonstrating that when instruction explicitly exposes the relationship between clinical features and anatomical concepts, learners develop better conceptual coherence, and as a result, are able to make more accurate clinical decisions.

Further, by using a diagnostic justification task we were able to explicitly capture specific changes that occur in clinical reasoning when instruction supports the development of integrated basic science knowledge. As predicted by the model of conceptual coherence \textsuperscript{59}, students who were taught musculoskeletal diseases using integrated basic science descriptions were able to more accurately justify a correct diagnosis without explicitly articulating basic science knowledge in their explanations in comparison to those who were only taught the clinical features. Students who were taught using the holistic, integrated approach identified key diagnostic features rather
than features that were common across disease categories. These findings extend our understanding of the model conceptual coherence and suggest that integrated basic science knowledge enables learners to understand the relative importance of key features during diagnostic reasoning.

The findings of this research also highlight the value of causal explanations in facilitating the benefits of integrated instruction and provide supporting evidence\(^{10,58,60}\) to show that merely creating proximity between basic and clinical science instruction does not guarantee cognitive integration. As an example, research by Baghdady et al.\(^ {58}\) has shown that when the basic sciences were taught before radiographic features, students were not able to optimize the value of basic science teaching as demonstrated by their low diagnostic scores. However, when the same basic science information was integrated with the radiographic features as causal explanations students developed a better understanding of the radiographic abnormalities and as result demonstrated superior diagnostic performance\(^ {58}\). Thus, based on the research findings presented in this dissertation and those alike, it is suggested that one way educators can optimize value of anatomical science education is to explicitly link clinical features of a disease using anatomical concepts during teaching. This suggestion deviates from the traditional 2+2 curricular model where the basic and clinical sciences are segregated during training and is also different than current integration strategies, including problem-based learning (PBL) and contextualized teaching.

In PBL, students are exposed to the basic sciences through the process of working through clinical cases. Although this approach may be an effective way to demonstrate how the basic and clinical sciences are related in a specific context, there is limited evidence to suggest that PBL results in students developing a better understanding of the basic sciences or superior clinical reasoning skills\(^ {42,142,143}\). Similarly, in contextualized teaching the basic sciences are taught in the context of clinical medicine in effort to demonstrate applicability of basic science concepts to clinical practice\(^ {144,145}\). For example, anatomical concepts can be directly tied to common clinical scenarios by
having students compare normal and abnormal anatomy by utilizing cadaveric specimens and radiographic images\textsuperscript{144}. Contextualized instruction has been found to be an effective strategy for learning and reviewing basic science concepts\textsuperscript{145,146}, however, by simply demonstrating the applicability of basic science to clinical cases does not guarantee that learners will develop an understanding of how knowledge of basic science can be used to solve clinical problems. Thus, it is suggested that a better way to optimize the value of teaching anatomy in a PBL curriculum or in contextualized instruction would be to use anatomical concepts to explain why certain clinical scenarios occur thereby emphasizing the relationship between these two knowledge domains. By making these linkages explicit students will see not only the relevance of basic science to clinical practice, but it will also help foster the development of integrated basic science knowledge.

Finally, the experimental findings of the self-explanation study highlight the importance of considering the model of conceptual coherence when selecting and applying session level integration strategies. Our results demonstrate that although it is key that the basic and clinical sciences are explicitly integrated during teaching simply encouraging learners to elaborate on only some of the causal relationships associated with each disease likely fosters analytic processing which does not align with the holistic model of conceptual coherence. And thus, as a consequence of the self-explanation activity being structured this way, the coherence initially created by integrated learning materials was disrupted. This misalignment is evident by the low diagnostic accuracy scores observed in the self-explanation group. These findings are similar to a previous study that has examined the effect of different diagnostic strategies (analytic and non-analytic) and instructional method on diagnostic accuracy in oral radiology\textsuperscript{135}. In this study, dental students were taught the clinical features of radiographic abnormalities using either basic science explanations or a structured algorithm that did not include basic science information. Students in each learning group were then directed to use an analytic or non-analytic diagnostic strategy while solving a series of clinical cases. The results showed that independent of the type of instruction that was initially provided, students who were forced to identify radiographic features before selecting a diagnosis
(analytic diagnostic strategy) had lower diagnostic accuracy scores in comparison to those who were directed to make a diagnosis first and then identify radiographic features (non-analytic strategy). Based on the findings of the results of our self-explanation study along with those of Baghdady et al.\textsuperscript{135}, it is suggested that educators should carefully consider not only the structure of integrated teaching materials but also the extent to which any given learning or assessment strategy fosters conceptual coherence. As an example, prompting learners to explain the underlying mechanisms for the totality of a disease may promote a more holistic understanding in comparison to having learners explain specific clinical features.

6.4 Contributions to Health Professions Education Research

In conclusion, this research has demonstrated a systematic and effective approach to developing clinically relevant content for integrated anatomy curricula. This work has also shown the value of cognitive integration of anatomy and clinical science knowledge on diagnostic accuracy and it emphasizes the importance of purposefully linking the anatomical and clinical sciences in day-to-day teaching. Further, the findings of this research extend our understanding of the model of conceptual coherence by providing explicit evidence for the positive impact that integrated basic science teaching has on novices’ diagnostic reasoning process. Moreover, this research demonstrates the importance of considering the structure of learning strategies that are used to support the development of conceptual coherence, as strategies that do not foster the holistic story created by integrated basic science instruction may not positively impact learners’ integrated knowledge. Finally, this body of research demonstrates that integration strategies can be applied at multiple levels of the curriculum and it highlights the value and need to examine integration at each level of the curriculum in order to optimize the benefits of integration.
Chapter 7
Limitations

The research completed in this dissertation has potential limitations that should be noted.

The principal investigator generated the items for the initial curricular list that was used in the modified Delphi process and thus, selection of these items may have been inherently biased. There were however several steps taken to minimize this bias and to ensure that the initial curricular list was comprehensive. This included consultation with 5 practicing physiatrists who represented both academic and community practice and reviewing the curricular items with an experienced clinical anatomist. Clinical anatomy and Physical Medicine and Rehabilitation (PM&R) textbooks were also reviewed in effort to ensure all relevant musculoskeletal structures and clinical conditions were included. In addition, during round one of the Delphi process, expert participants were able to suggest additional anatomical structures and clinical conditions to the curricular list. It must also be acknowledged that a selection bias may have existed, as the initial response rate in this study was only 35%. Although it is recognized that this response rate is low, other Delphi studies that have used practicing clinicians as their expert population also report similar completion rates \(^{147}\). Further, the authors were not too concerned about the response rate since the experts who did participate represented almost all subspecialty areas of PM&R practice as described by the American Academy of PM&R, and the number of experts involved represented an above average sample size in comparison to other studies that have used the Delphi method for curriculum development \(^{108,110,118,119}\).
The experimental studies described in Chapters 4 and 5 took place in an artificial learning environment. In addition, the learning materials used in these studies were tightly controlled for using customized computer software that utilized standardized slides accompanied by audio recordings. These learning conditions may limit the ecological validity of the findings of these studies as learning in a classroom or clinical setting may be influenced by a multitude of factors including, interactions with peers, different teachers, and time constraints. Thus, although the findings of these studies advance our understanding of the model of coherence and provide practical principles for supporting the development of cognitive integration the factors mentioned above may lessen the effectiveness of integrated basic science teaching in the classroom or clinic.

Further, the content of the learning and testing materials used in these studies may also limit the ecological validity of this work. The learning materials were carefully constructed using prototypical descriptions, images, and video clips. Thus, while all of the learning material was authentic, patients who have these diseases may also present with other signs and symptoms. In addition, since the purpose of the diagnostic accuracy test was to measure students’ ability to diagnose the pathologies learned, the research team specifically designed each question so that there would be only one correct answer. Each clinical case question included the age, sex, a minimum of 3 clinical features and an image or video clip of the patients’ musculoskeletal disease. These case descriptions do not represent all of the information that may influence a clinicians’ diagnostic reasoning process, such as the patient’s clinical history. Thus, in real life situations, diagnosing these pathologies may be influenced by other factors that were not considered in these studies.

As previously discussed in Chapter 4, the simple diagnostic justification test used in this study was created specifically for this experiment and learning materials. Although the results of this test explicitly demonstrated that learners who were taught the clinical features of each disease using integrated basic descriptions were able to more
accurately justify the pathologies learned compared to those who were only taught the clinical features, these results cannot be taken as a generalizable measure of learners' justification abilities. In addition, we cannot conclude that instruction that uses causal basic mechanisms to describe the clinical features of a disease will lead to better diagnostic justification in all settings or for all cases. It should also be noted that participants completed the diagnostic justification immediately following the diagnostic accuracy, one week after the initial learning activity. Research on non-analytical reasoning in novices has shown that problem solving is influenced to some degree by similarity to previously encountered examples\textsuperscript{129}. Thus, it is possible that participants' responses on the diagnostic justification test may have been influenced by their exposure to clinical case descriptions and images/video clips that were used on the diagnostic accuracy test.

The study that examined the effect of different basic science instructional approaches (integrated and segregated) and self-explanation on diagnostic accuracy (Chapter 5) made significant departures from previous literature on self-explanation during clinical problem solving that should be noted. As previously mentioned, this study used focused self-explanation prompts that required learners to elaborate on the underlying basic science mechanisms of specific clinical features after completing conceptual learning materials, whereas prior studies on self-explanation and clinical reasoning used open-ended prompts throughout a problem solving task\textsuperscript{71}. Although both focused and open-ended self-explanation prompts have been reported to positively impact learning\textsuperscript{64,136}, the general self-explanation literature has acknowledged that conditions under which self-explanation is most beneficial and the mechanisms underlying its effect are not well understood\textsuperscript{66,67}. Thus, it is possible that the instructional materials and type of self-explanation prompt used in this study triggered different cognitive processes and as a result did not have the same impact on learning as observed in previous studies on self-explanation and clinical problem solving. In addition, during the learning phase of this study, participants in the self-explanation group were not told the purpose of the self-explanation activity nor were they provided with an example of the procedure. It is possible that a different effect may have been observed had participants been ‘trained'
on how to apply self-explanation as a learning strategy since previous research has shown that self-explanation training results in learners applying the strategy more effectively.\textsuperscript{137}
Chapter 8
Future Directions

The research presented in this dissertation demonstrates how integration strategies can be applied at multiple levels of the curriculum. Further, we now have explicit evidence that shows how learners’ integrated basic science knowledge positively impacts their diagnostic reasoning process along with a better understanding of the importance of fostering the holistic story created by integrated basic science instruction in day-to-day teaching. The findings of these studies warrant future research on how best to achieve and support integration at all levels of the curriculum.

8.1 Experimental Research

To further examine the effects of educational strategies that aim to support the development of conceptual coherence a future study could combine integrated basic science instruction with a self-explanation activity that focuses on elaborating on the totality of each disease category learned. Similar to the self-explanation study described in Chapter 5, students in one group would be taught four disease categories using an integrated basic science approach, where basic science mechanisms would be used to explain the presence of the clinical features associated with each disease. Another group would receive the same learning materials, but in addition, they would be shown a short clinical vignette followed by a prompt that required them to use their basic science knowledge to explain why they believed the patient presents with the specific disease. Thus, unlike the previous study described in Chapter 5, learners would not be prompted to explain the presence or absence of specific clinical features. Following instruction, both groups would be asked to complete a diagnostic accuracy and memory test. Changing the structure of the self-explanation activity to support more holistic processing may positively impact learners’ integrated basic science knowledge. In a different study the effect of using a holistic self-explanation activity
combined with segregated basic and clinical science training may be explored. The purpose of this study would be to examine whether specific educational strategies, such as holistic self-explanation, can help learners cognitively integrate the basic and clinical sciences. In addition, since explicit training on self-explanation has been found to support learners in applying the learning strategy more effectively \(^{137}\), participants allocated to the self-explanation group in future studies will also be provided with a definition of what self-explanation is along with an example of the procedure prior to starting the learning materials. The self-explanation example will be based on a clinical description of a pathology that is not included in the learning material.

Another educational strategy that has been shown to support the development of novices’ conceptual knowledge is the use of worked out examples \(^{65}\). A future study could examine whether including worked out examples while learning with integrated basic science instructional materials has a positive impact on learners’ development of conceptual coherence. This could also be compared to using self-explanation as a learning strategy. The worked out examples would be similar to the self-explanation activity; however, instead of having learners generate self-explanations for a clinical case, learners would be provided with a written explanation of why a patient presents with a certain disease. These explanations would focus on the underlying causal mechanisms for the clinical features of each disease. It is possible that novices may benefit more from this type of educational strategy since they may have insufficient prior knowledge to explain causal mechanisms for disease categories.

8.2 Applied Research

Future research may also apply the experimental findings presented in this dissertation to real educational contexts. As previously discussed, integration can be applied at all levels of the curriculum; however, we propose that the first logical step would be to create an individual teaching session using the principles of cognitive integration and conceptual coherence. This would involve establishing clear integrated learning
objectives and instructional materials that explicitly integrate the basic and clinical sciences. For example, in an integrated musculoskeletal anatomy session, teaching of specific musculoskeletal conditions would be explicitly integrated with a discussion on relevant anatomical structures and the underlying anatomical pathology for each clinical condition. Within a laboratory environment, cadaveric models could be used to explain and demonstrate normal and abnormal anatomy and could provide an additional opportunity to focus on the explicit relationship between anatomical concepts and the clinical presentation of different disease states. This type of educational intervention should be compared to a similar teaching session that presents the same content using the traditional delivery format. Further, although many integration interventions include measures of satisfaction, attitudes, and recall of facts it is important that learners’ integrated knowledge is assessed to determine the impact an educational intervention has on learning. Thus, outcome measures used in this type of educational intervention would also involve assessing transfer or application of integrated knowledge.

Following this type of study, the next step would be to apply the principles of cognitive integration and conceptual coherence to an entire course and program. This would require a considerable amount of time, resources, and effort to ensure that basic science teaching is optimized throughout the curriculum. Similar to an educational intervention at the session level, learners’ ability to apply and transfer their integrated knowledge should be assessed following completion of such curriculum and should also be compared to a control group. Throughout the process of designing and implementing these applied educational interventions there will likely be a multitude of research questions and opportunities that will arise. Further, optimizing the value of basic science teaching throughout a curriculum is only one way that integration can be supported, there is still much research needed to fully understand how educators and administers can support and achieve integration at all levels of the curriculum.
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Appendices

Appendix #1: Screenshots from the anatomy tutorial used in the studies described in Chapters 4 and 5

Knowledge of basic anatomical terms and structures will help you understand the following tutorial on upper limb conditions.

In order to describe various body parts and their location a common visual reference point is used. This reference point is known as anatomical position (picture). When describing body structures to one another you always refer to this position.

A structure that is closer to the midline of body is said to be medial, whereas a structure that is farther away from the body is said to lateral. Eg. The index finger (2nd finger) is lateral to the little finger.

A structure on the limbs that is closer to the origin of the body is said to be proximal, whereas a structure that is farther from the origin is said to be distal. Eg. The palm of the hand is proximal to the tips of the fingers.

The anterior hand is known as the palmar surface and the posterior hand is known as the dorsal surface (picture).

There are 5 fingers in the hand. From the lateral to medial they are referred to as the: thumb, index, middle, ring and little finger (picture). The bones of the hand are made up of carpals, metacarpals and phalanges (red, purple and green arrows). Each finger except for the thumb has 3 phalanges: proximal, middle and distal (picture).
Appendix #2: Anatomy quiz questions used in the studies described in Chapters 4 and 5

1. The picture to the right depicts which surface of the hand?
   a. Dorsal
   b. Palmar

2. On the following picture, which letter is located on the ring finger.
   a. Z
   b. Y
   c. L
   d. M

3. Which directional term describes finger Z to finger Y.
   a. Proximal
   b. Distal
   c. Lateral
   d. Medial

4. The red arrow is pointing to which of the following joints?
   a. Proximal interphalangeal (PIP) joint
   b. Distal interphalangeal (DIP) joint
   c. Metacarpalphalangeal (MP) joint
   d. Carpometacarpal (CMC) joint

5. When a muscle no longer receives nerve supply we say the muscle is:
   a. Innervated
   b. Deinnervated
6. The black arrow is pointing to which of the following joints?
   a. Proximal interphalangeal (PIP) joint of index finger
   b. Distal interphalangeal (DIP) joint of index finger
   c. Metacarpalphalangeal (MP) joint of index finger
   d. Carpometacarpal (CMC) joint of index finger

7. Which surface of the hand is shown in this picture?
   a. Dorsal
   b. Palmar
Appendix #3: Screenshot of a diagnostic accuracy case question used in the studies described in Chapters 4 and 5

Case 1 of 15

A 38-year-old female experiences an upper limb injury in her left hand. She complains of pain and sensory changes (tingling) along the medial aspect of her hand and in her ring and little fingers. She also has Froment’s sign (weak pinch grip).

Upon physical examination the therapist notes a small amount of intrinsic hand muscle wasting and Wartenberg’s sign (see video).

☐ A Dupuytren contracture
☐ B Carpal tunnel syndrome
☐ C Guyon canal syndrome
☐ D Pronator teres syndrome
Appendix #4: Screenshot of the basic memory test used in the studies described in Chapters 4 and 5

From the list provided, please identify the features present in cases of:

Carpal tunnel syndrome.

Select ALL applicable boxes.

Click SUBMIT when finished.

Submit

- Sensory changes (numbness/tingling) in palmar thumb, index, middle & ring fingers
- Sensory changes (numbness/tingling) in central palm
- Sensory changes (numbness/tingling) in medial palm and ring & little fingers
- No sensory changes
- Pain in the forearm and/or hand
- No pain in the forearm or hand
- Inability to actively straighten (extend) affected fingers
- Loss of strength and coordination in the thumb (difficulty with precision handling grip)
- Loss of strength and coordination in index, middle, ring & little fingers (loss of grip strength)
- Froment's sign (difficulty in pinch grip)
- Wartenberg's sign (abducted little finger)
- Claw hand (hypertendere MP joints & flexed IP joints)
- Benediction sign (difficulty flexing thumb, index & middle fingers)
- Intrinsic hand muscle wasting
- Thenar muscle wasting
- Nodular thickenings & raised ridges in palm
Appendix #5: Screenshot of a diagnostic justification test question used in the study described in Chapter 4

You have diagnosed your patient with Carpal tunnel syndrome.

The patient has now asked you to justify your diagnosis. In the box below, please provide your patient with a detailed explanation for your diagnosis. Be as specific as possible. There is no space limit for this question.