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Evaluation of the Basic Science Pre-Clerkship Curriculum in Medicine at Western University

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Abstract

Basic sciences are a cornerstone of undergraduate medical education (UME), upon which the clinical sciences are built, however, research indicates that students' basic science knowledge is not well retained. Additionally, UME curricula vary with respect to which basic science content is delivered, the depth in which it is taught, and the employed instructional methods, which could influence trainees' knowledge retention. Thus, there is a need for an educational model that ensures students are competent in the fundamentals prior to entering a clinical setting. This investigation provides insights into current strengths and potential areas for improvement with respect to basic science pre-clerkship curricula.

The aims of this research were to: i) determine clerkship directors' perceptions of necessary basic science concepts, along with strengths and areas for improvement, with respect to students' basic science knowledge; ii) assess medical students' knowledge retention of the identified basic science concepts; iii) determine where, when, how, or if, the identified basic science concepts were taught during pre-clerkship; and iv) assess medical students' knowledge reinforcement levels of the identified basic science concepts during clerkship.

We established that students are expected to have some knowledge of every basic science prior to clerkship, and the identified concepts mapped to each systems-based pre-clerkship course. Additionally, directors' perceptions of potential areas for improvement outweighed strengths. On average, students retained ≥60% of relevant basic science knowledge from pre-clerkship, and reinforced concepts during each clerkship rotation. Mapping the concepts to curricular content revealed that where, when, how, or if, the concept was delivered during pre-clerkship did not influence students' basic science knowledge, nor did clerkship group or rotation order. Interestingly, even though lower-performing students demonstrated the greatest post-test improvement,

they still left each rotation with knowledge deficits compared to their highest-performing peers. Thus, while they did not catch up to their highest-performing peers, the clinical experience of clerkship appears to be most beneficial for lower-performing students. This may suggest that earlier integration of clinical learning with the basic sciences could foster students' basic science knowledge, thereby ensuring that all trainees are well-equipped with the necessary knowledge prior to clerkship.

Keywords

Undergraduate Medical Education, Pre-Clerkship Education, Basic Science Education, Perceptions of Basic Science Education, Perceptions of Students' Basic Science Knowledge, Basic Science Knowledge Retention, Basic Science Knowledge Reinforcement, Curriculum Mapping, Curriculum Development, Curriculum Design, Curriculum Evaluation

Summary for Lay Audience

Basic sciences are essential in undergraduate medical education (UME), as they provide a framework upon which clinical concepts are built, however, research demonstrates that medical students' basic science knowledge is not well retained. Additionally, basic science education varies across UME programs, which may influence students' basic science knowledge. With a strong basic science foundation being necessary for the successful practice of medicine, there is a need for an educational model that ensures students are competent in the fundamentals prior to clinical training. Thus, the goal of this research was to provide insights into current strengths and potential areas for improvement with respect to UME basic science education.

During this investigation, clinical educators were interviewed to determine which basic science concepts they expect students to know prior to entering clinical training, along with their perceptions of strengths and areas for improvement, with respect to students' basic science knowledge. Students' knowledge levels of the concepts deemed necessary by clinical educators were analyzed prior to (pre-test) and at the completion (post-test) of each clinical rotation. The timing in which the content was delivered and the instructional methods used were also evaluated to determine if they impacted students' knowledge levels.

Students are expected to have knowledge of every basic science prior to clinical training, and clinical educators' perceptions of potential areas for improvement outweighed strengths. Students, on average, retained ≥60% of their basic science knowledge, and reinforced concepts during each clinical rotation. Additionally, students' knowledge levels were not influenced by the timing of content delivery nor the instructional methods used. Interestingly, even though students who achieved lower scores on the pre-test demonstrated the greatest improvement on the post-test, they still left each rotation with knowledge deficits compared to their higher-performing peers. Therefore, while clinical experience

does benefit students' learning, it is not sufficient to enable lower-performing students to catch up to higher-performing students. With the basic sciences underpinning the clinical sciences, these findings may suggest that earlier integration of clinical learning could help foster students' basic science knowledge levels, and help ensure that all trainees are confident in the fundamentals prior to clinical training.

Co-Authorship Statement

The material in this thesis is the original work of the author. Madeleine Norris participated in all aspects of the work contained within this thesis including study design, data collection, data analysis, and preparation of the manuscripts.

Kem Rogers, Charys Martin, Marjorie Johnson, and Mark Cachia all made contributions to the study design, and/or data analysis, and/or data interpretation. All authors were also involved in drafting and/or editing manuscripts. The first manuscript has been published: Norris et al. 2020. Expectations and Perceptions of Students' Basic Science Knowledge: Through the Lens of Clerkship Directors. Medical Science Educator, 1-11. The second manuscript has been submitted for publication in Medical Science Educator: Are clerks proficient in the basic sciences? Assessment of third-year medical students' basic science knowledge prior to and at the completion of core clerkship rotations.

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Chapter 1

1 INTRODUCTION TO THE STUDY

Basic sciences education is an essential component of undergraduate medical education (UME), as it creates a necessary foundation upon which the clinical sciences can be built (Flexner 1910; Custers and ten Cate 2002; Harris et al. 2004; de Bruin et al. 2005; Miles 2005; Woods et al. 2005; Norman 2007; Finnerty et al. 2010; McColl et al. 2012; Prober and Khan 2013). During their medical training, students must rely on their basic science foundation in order to develop mental representations of diseases and comprehend relevant clinical concepts (Boshuizen and Schmidt 1992; Woods et al. 2005; Custers and ten Cate 2011; McColl et al. 2012; Nouns et al. 2012). Not only is basic science knowledge fundamental for the development of clinical sciences knowledge, but a strong basic science foundation has also been associated with enhanced clinical reasoning skills and improved diagnostic accuracy in a clinical setting (Barrows and Feltovich 1987; Woods et al. 2007; Spencer et al. 2008; Finnerty et al. 2010; McColl et al. 2012). Regardless of the necessity of this knowledge, the specific basic science concepts that students must be knowledgeable in, and the best instructional methods for delivering basic science content, has yet to be determined (Cottam 1999; Marcel 2006; McColl et al. 2012; Samarakoon et al. 2013; Weggemans et al. 2017). As a result, it is unclear if current students learn and retain the most clinically relevant basic science concepts prior to entering a clinical setting (Harris et al. 2003; Ling et al. 2008; Spencer et al. 2008; Tokuda et al. 2010; Schneid et al. 2018).

Based on these factors, there is a demand for an educational model that ensures all students are proficient in the necessary basic science concepts prior to entering a clinical setting. Thus, we set out to investigate clerkship directors' and students' perceptions, along with students' knowledge levels, with respect to basic sciences education at the UME level. By combining the analysis of these metrics, we can provide insights into curricular strengths, and potential areas of improvement which can be used to modify the integration of the basic sciences with the clinical sciences during pre-clerkship, with the overarching goal of ensuring all trainees are proficient in the fundamental basic sciences as they progress through their training. In this thesis, we developed an evidence-based feedback tool that enabled us to critically evaluate the effectiveness of pre-clerkship basic science education at the UME level, according to the concepts deemed necessary by UME clerkship directors. This tool can be used as a template by educators for assessing the effectiveness of basic sciences education in undergraduate, graduate, and professional program curricula.

1.1 Undergraduate Medical Education

Undergraduate medical education (UME) is designed to train future physicians, and to equip all medical graduates with the knowledge and skills necessary to keep up with evolving health care demands (Chen et al. 2015; Vogel and Harendza 2016). Health care needs are dynamic and multifactorial, and thus it is essential that all medical students are trained in the necessary basic, social, and clinical sciences that are required for treating and managing complex conditions (van Zanten et al. 2008). Regardless of UME curricula sharing a common goal of effectively training future physicians, there is considerable variation among North American UME programs due to differences among learners, educators, cultures, and disease prevalence in different regions (van Zanten et al. 2008; Malau-Aduli et al. 2013; Briggs et al. 2015; Starr et al. 2017).

Abraham Flexner was a pioneer of UME and is responsible for the foundation on which many medical schools built their curriculum (Flexner 1910; Finnerty 2010). Most notably, Flexner was responsible for the 20th century reform of medical education. Based on his beliefs, Flexner created an educational model in which he proposed the first two years of study, commonly known as pre-clerkship, should be comprised of basic science education. Following their pre-clerkship training, students are then immersed in a series of clinical rotations (clerkship) and clinical electives during their last two years of study (Woods et al. 2005; Finnerty 2010). This curricular model has withstood the test of time in most Canadian medical schools as many curricula still follow an adapted Flexnerian model of education at the UME level where the basic and clinical sciences are integrated into the pre-clerkship curriculum (Flexner 1910; Spencer et al. 2008; Pawlina 2009; Prober and Khan 2013). However, due to the time constraints of this educational model (Weston 2018), many curricula are not equipped to ensure that all students demonstrate proficiency in all domains of practice prior to entering a clinical setting, and as a result, there is an increasing number of supporters for UME curricular revisions (Irby et al. 2010; Prober and Heath 2012; Street at al. 2014).

1.1.1 What is Considered Basic Science Education?

Basic science education in pre-clerkship curricula primarily focuses on the disciplines of anatomy, biochemistry, microbiology, pathology, pharmacology, and physiology, all of which are fundamental for effectively preparing trainees for clinical practice (Woods et al. 2005; Spencer et al. 2008; Pawlina 2009; McColl et al. 2012; Prober and Khan 2013). Topics of nutrition and imaging are often integrated with the basic sciences in pre-clerkship as they are fundamental for effectively diagnosing and managing certain clinical conditions (Pascual et al. 2011; Kris-Etherton et al. 2014). In agreement with Flexner, the importance of basic science rigor at the pre-clerkship level and prior to entering a clinical setting continues to be supported by present-day educators and learners (Custers and ten Cate 2002; Woods et al. 2005; Cooke et al. 2006; Spencer et al. 2008; Nouns 2012; Sivapragasam 2016).

1.1.2 Necessity of Basic Science Education

Many educators believe that basic science, specifically anatomy and physiology, are a cornerstone within medical education as they provide the framework upon which the clinical sciences are constructed (Flexner 1910; Custers and ten Cate 2002; Cooke et al. 2006; Harris et al. 2004; Miles 2005; Woods et al. 2005; Norman 2007; Finnerty et al. 2010; McColl et al. 2012; Prober and Khan 2013). There is a common misconception associated with basic science education that it is essentially a collection of facts which students need to memorize and recall, when in actuality, basic science knowledge is fundamental for students when reconstructing characteristics of a disease during clinical practice. In order to be proficient in a clinical setting, students must first master 'normal' structure and function through the basic sciences, following which they can start to create mental representations of the signs and symptoms of a differential diagnosis and conceptualize the relevant clinical concepts (Boshuizen and Schmidt 1992; Woods et al. 2005; Custers and ten Cate 2011; McColl et al. 2012; Nouns et al. 2012).

1.1.3 Basic Science Education & Clinical Proficiency

A strong basic science foundation is also vital for fostering trainees' proficiency in a clinical setting. More specifically, basic science knowledge is fundamental for the development of students' clinical reasoning skills, which are essential for the problem-solving process physicians rely on to construct differential diagnoses and reach a clinical decision, and ultimately, achieve overall proficiency in the field (Barrows and Feltovich 1987; Woods et al. 2007; Regehr and Mylopoulos 2008; Mylopoulos and Regehr 2009; Finnerty et al. 2010; Cutrer et al. 2018). When trainees are evaluating patient signs and symptoms, they are relying on their basic science foundations to determine the most probable diagnosis (Woods et al. 2007). Further evidence suggests that novices, such as clerks and junior physicians, actively rely on their foundational basic science knowledge more so than experts in the field, whereas more senior physicians may be unaware that they are utilizing their basic science knowledge in order to interpret patient signs and symptoms (Norman 2007; Woods et al. 2007; Pangaro 2010). Thus, the importance of a strong basic science foundation holds true even for practicing physicians, as basic science knowledge has been shown to be a vital element for experts in the field (Pawlina 2009; Malau-Aduli et al. 2013; Kulasegaram et al. 2017). For example, research indicates that, for complex clinical cases and diseases, senior physicians must more actively rely on basic science concepts during the clinical reasoning process (Norman et al. 1994). Further to this, a strong basic science foundation has also been associated with enhanced diagnostic accuracy in the clinic (Woods et al. 2007; Spencer et al. 2008; McColl et al. 2012). When patients present with complex signs and symptoms that are not easily diagnosable, trainees must rely on their basic science foundation in order to navigate and interpret the clinical condition and ultimately reach a conclusion (Smith 2010; Custers and ten Cate 2011; McColl et al. 2012). This suggests that comprehension and retention of basic science knowledge, which underpins all clinical conditions and diseases, is fundamental for the development of clinical science knowledge, clinical reasoning skills and diagnostic accuracy, all of which are essential for achieving overall competence as a physician (Norman 2007; Woods et al. 2007; Finnerty et al. 2010).

The importance of strong basic science knowledge holds true as trainees are transitioning into their specialty of choice at the post-graduate level, as a lack of proficiency in basic science knowledge has been shown to also be strongly correlated with failure rates on board examinations (Hojat et al. 1993; Lazić et al. 2006; Malau-Aduli et al. 2013; West et al. 2014). Board examinations are comprised of clinical-vignette style questions, and as described earlier, trainees must rely on their basic science foundations in order to build their clinical science knowledge, comprehend clinical signs and symptoms, and reach the most probable diagnosis (Woods et al. 2005), all of which would be necessary for interpreting the clinical questions.

With basic science providing the language for the field of medicine, trainees must be proficient in the necessary fundamentals in order to navigate the exponentially increasing body of medical research in both basic and clinical science (McColl et al. 2012; Sivapragasam 2016), and to ultimately keep up with today's dynamic health care demands (Mylopoulos and Woods 2014; Cutrer et al. 2017). In order to help foster trainees' clinical reasoning and expertise, and promote their success on board examinations, educators must ensure that medical students are proficient in the fundamental basic science concepts prior to entering the clinical setting of clerkship, and as they transition into residency.

1.1.4 Basic Science Curricular Content

The literature shows that pre-clerkship curricula are important for building fundamental knowledge in the basic and clinical sciences to effectively prepare trainees for medical practice (Pawlina 2009; McColl et al. 2012); however, the specific basic science concepts that students are expected to know, and the depth in which they are expected to learn them has yet to be determined (Denny et al. 2005; McColl et al. 2012). Curricular content often gets recycled through the years, and has been pre-determined either by tradition, or educators and clinicians with their own agenda. As a result, there is no core syllabus or basic science curriculum that is standard across UME curricula which, consequently, leads to basic science education developing and evolving independently at each institution (Prober and Khan 2013). Further to this, although many curricula integrate basic and clinical science disciplines within an individual course, each basic science discipline is often taught in isolation from the others, simply due to the specializations of instructors (Grande 2009). This siloed approached can translate to disconnect between basic and clinical science disciplines, which could lead to knowledge gaps for trainees.

In medical curricula, the social and behavioral sciences that medical students are expected to learn during pre-clerkship has increased, but with a finite number of curriculum hours, the time devoted to teaching the basic sciences has been compromised in many UME programs (Weston 2018). Curriculum planners also want to ensure that medical students are not overloaded, which can contribute to a decreased amount of time set aside for basic science education (Weston 2018). Further to this, it has been reported that many students feel that their basic science education lacks clinical relevance, and their basic science knowledge is not transferable to a clinical setting (Eyal and Cohen 2006; Jalili et al. 2008). As discussed so far, pre-clerkship basic science education should prepare students for the next stage of their medical training (Pawlina 2009; McColl et al. 2012); however, with the time dedicated to teaching and learning basic science, and the curriculum in which the basic science disciplines are delivered, remaining highly variable across UME (Cottam 1999), there is a lack of consistency in basic science curricular content across institutions (Prober and Khan 2013). As a result, there is a need to determine which basic science content, and the detail to which it should be taught, is integral for enhancing student outcomes.

1.1.5 Instructional Methods for Delivering the Basic Sciences in Undergraduate Medical Education

Not only are the hours dedicated to basic science education variable, but the employed instructional methods also vary widely across UME curricula, and are constantly undergoing revisions (Cottam 1999; Searle et al. 2003; Marcel 2006; Samarakoon et al. 2013; Weggemans et al. 2017). Furthermore, there is evidence to suggest that there is a sense of dissatisfaction with basic science instruction from both students and educators (McLaren 1980; Drake et al. 2009; Pawlina 2009), and some medical students have indicated that they are unhappy with traditional teaching techniques (Badyal and Singh 2018). The literature has also indicated that some instructional methods currently employed in UME are inadequate at providing students with the necessary fundamentals that are required for improved student outcomes and overall success (Nandi et al. 2000). As a result, it has yet to be determined which instructional method(s) are most effective for delivering basic science content and fostering students’ learning.

There are three main overarching instructional methods that are currently employed by most UME programs to teach basic science: large group learning, small group learning, and independent learning. It has been reported in the literature that students’ basic science knowledge retention can be influenced by the instructional method(s) in which the content is delivered. However, it has yet to be determined which instructional method(s) have the most positive influence on students' basic science knowledge acquisition and retention (Costa et al. 2007; Freeman et al. 2014; Wolff et al. 2015)

1.1.5.1 Large Group Learning

Large group learning, which is primarily presented as didactic lectures, has long been the standard instructional method not only in UME, but in many other curricula and educational contexts (Drake 1998; Prober and Khan 2013; Freeman et al. 2014; Datta et al. 2015; Raman and Raju 2015). Didactic lectures are predominantly a passive learning method, which focuses on presenting relevant content to students with the goal of facilitating knowledge acquisition (Miller et al. 2013; Wolff et al. 2015). However, there is a finite amount of time dedicated to these learning sessions, which limits the amount of information educators can deliver, and can lead to an inability to encompass the constantly increasing amount and complexity of knowledge that students are expected to acquire (Nii and Chin 1996; Eyal and Cohen 2006; Prober and Khan 2013; Samarakoon et al. 2013). Large group learning has been associated with lower knowledge retention rates of the presented material when it is compared to other instructional methods, such as active learning strategies (Costa et al. 2007; Subramanian et al. 2012; Street et al. 2014; Wolff et al. 2014). In contrast to these negative findings, there is evidence to suggest that large group, didactic lectures are still an effective instructional method in UME curricula (Freeman et al. 2014; Wolff et al. 2015). A study conducted by Fischer et al. (2004), which focused on students completing obstetrics and gynaecology (OB/GYN) training, demonstrated no significant differences in performance scores when comparing students who learned via didactic lectures to students who learned via small group learning. Similar results were found in another study which demonstrated that there were no differences between students' performance when comparing large group learning to small group learning during trauma and orthopaedics training (Bulstrode et al. 2003), suggesting that large group learning remains an effective instructional method in medical education.

1.1.5.2 Small Group Learning

Small group learning, which is typically associated with active learning methods such as laboratory sessions, problem-based learning (PBL), team-based learning, or small group discussions, have come to the forefront of UME curricular design (Haidet et al. 2002; Prince 2004; Graffam 2007; Thompson et al. 2007; Littlewood et al. 2013; Emke et al. 2016). These sessions follow a learner-centered approach which relies on students actively participating, engaging, and interacting with their learning, thereby enabling them to help guide their own education (DeNeve and Heppner 1997; Michel et al. 2009; Miller et al. 2013; Wolff et al. 2015). Small group learning can enhance student engagement, and increase students' knowledge acquisition and retention (Kvam 2000; McConnel et al. 2003; Searle et al. 2003; Koles et al. 2005; Costa et al. 2007; Koles et al. 2010; Subramanian et al. 2012; Lucas et al. 2013; Roehl et al, 2013; Freeman et al, 2014; Wolff et al, 2015; Levine et al. 2016), which has been shown in courses focusing on engineering statistics (Kvam 2000), geology (McConnel et al. 2003), and pharmacotherapy (Lucas et al. 2013). In the field of medical education, evidence suggests small group learning can help foster students' understanding of the subject matter resulting in enhanced knowledge retention when compared to traditional large group learning (Subramanian et al. 2012; Wolff et al. 2014), and as a result, many medical educators are incorporating more small group learning sessions to improve education (Spencer and Jordan 1999; Haidet et al. 2002; Searle et al. 2003; Koles et al. 2005; Lucey 2013; Roehl et al, 2013; Samarakoon et al. 2013; Freeman et al, 2014; Emke et al. 2016; Levine et al. 2016).

In a 2011 study, Thomas and Bowen demonstrated that students performed better on clinical assessments when taught via small group learning methods, compared to large group learning methods, in their ambulatory medicine rotation, and a study by Costa et al. (2007) demonstrated that fourth-year medical students who learned via small group learning methods performed better on their assessments at the end of their 3-week orthopaedic and trauma placement, compared to their peers learning via large group learning. Interestingly, the studies which demonstrate that medical students have improved performance when learning via small group, active learning sessions were in a clinical curriculum as opposed to a pre-clerkship curriculum (Costa et al. 2007; Thomas and Bowen 2011), which may indicate that the effectiveness of teaching modalities may be dependent on the stage of training and the curriculum in which they are delivered. However, the proliferative evidence on the proven effectiveness of small group learning methods on students' knowledge acquisition and retention outside of pre-clerkship curricula may suggest that there is a place for this instructional method in basic science education at the UME level.

1.1.5.3 Independent Learning

With independent learning, the acquisition and conceptualization of knowledge is strictly guided by the student, enabling them to have greater control and flexibility over their learning (Spencer and Jordan 1999; Brookfield 2009; Prunuske et al. 2016; Huynh 2017). Many higher education programs and UME curricula are now employing this instructional method to deliver content to students (Levett-Jones 2005; Simon and Aschenbrener 2005), and typically utilize online platforms to facilitate self-directed learning modules (Ruiz et al. 2006; Masters and Gibbs 2007; Prunuske et al. 2016; Huynh 2017). Independent learning has been associated with increasing student confidence, and with the development of the knowledge and skills that are required for learning outside of the classroom (Nolan and Nolan 1997; Mahler et al. 2011). However, success with this instructional method is largely dependent on students' self-motivation and self-regulation, as students must be cognizant of their learning process and know when they need to seek help or ask for feedback (Murdoch and Wilson 2006;

Mahler et al. 2011). When independent learning is used in conjunction with large group learning methods, students have demonstrated a greater satisfaction, compared to traditional didactic sessions alone (Levett-Jones, 2005; Blissit 2016). Additional studies have shown that independent learning can be as effective as large group learning, or in some cases even more effective, when studying community medicine, dermatology, and electrocardiography (Fasce and Ibanez 1994; Jenkins et al. 2008; Prunuske 2016). However, there are some stated drawbacks of this instructional method as the lack of instructor-student and student-student interaction can negatively impact students' comprehension of the subject matter (Prunuske et al. 2016). Further to this, a study found that students' assessment scores were significantly lower when learning how to interpret electrocardiograms via independent learning compared to large group and small group learning methods (Mahler et al. 2011). Interestingly, in Mahler's (2011) study, students were learning about electrocardiograms via a text-based manual, whereas in Fasce and Ibanez's (1994) study on the same topic, demonstrated positive student outcomes with independent learning, students were using interactive learning methods. This indicates that student outcomes may be dependent on the design and implementation of the independent learning module.

1.1.5.4 Summary of Instructional Methods

Despite the studies analyzing the efficacy of large group learning, small group learning, and independent learning methods on students' basic science knowledge acquisition and retention, it has yet to be determined which instructional method(s), along with other curricular components such as timing of delivery and reinforcement, are most effective for promoting medical students' basic science knowledge acquisition and retention during their pre-clerkship training (Koles et al. 2005; Samarakoon et al. 2013).

1.1.5.5 Basic Science Knowledge Retention

Many studies demonstrate that current undergraduate medical students' knowledge of fundamental basic science concepts is not well retained, and they continue to lose their basic science knowledge as they progress through their training and into their post-graduate training program, which unfortunately can translate to compromised quality of patient care (Harris et al. 2003; Ling et al. 2008; Spencer et al. 2008; Tokuda et al. 2010; Schneid et al. 2019). When evaluating basic science content learned in the first year of study, medical students' knowledge of some basic science concepts can drop as low as 46% after a period of 8-10 months after initial exposure (Weggemans et al. 2017). Other research demonstrates that, for 85% of students, their knowledge of first year content declined below the minimal level of competency of 65% within 5-11 months (Schneid et al. 2018). More specifically, when assessing specific basic science disciplines, medical students' knowledge dropped to an average of 61.7% and 67.1% after a period of 10-11 months in the topics of immunology and physiology, respectively, however, their knowledge fell to 41.5% in the subject of neuroanatomy, which may suggest that the extent to which students retain their basic science knowledge could be influenced by the subject material (D'Eon 2006). This decrease in knowledge retention we see in current trainees is likely multifactorial, however, some potential factors may be: i) a lack of integration between relevant basic and clinical science concepts (Norman 2009), ii) a lack of reinforcement of the material throughout the curriculum (Custers 2010), iii) presenting so much detail that it overshadows the fundamental concepts students should know (DiCarlo 2009), or perhaps iv) the employed instructional methods are not appropriate for fostering students' knowledge retention in the basic sciences (Costa et al. 2007). Regardless of the source, the knowledge deficits that many trainees display may be contributing to the lack of proficiency they tend to demonstrate in a clinical setting (Sanson-Fisher et al. 2005; Schneid et al. 2018).

1.1.5.6 Basic Science Knowledge Reinforcement

There is very little research focusing solely on students' basic science knowledge reinforcement during their clinical training (Rosenbaum and Axelson 2013; Steven et al. 2014; Han et al. 2015), however, some complimentary literature does indicate that the integration of the basic and clinical sciences can enhance students' understanding of these two sciences and help foster their knowledge levels (Dahle et al. 2002). Further to this, it has been shown that experiential learning, such as the clinical experiences that students are immersed in, can help foster students' basic science knowledge, and some educators believe that this experiential learning should be occurring throughout all of UME (Wilkinson et al. 2002; Cooke et al. 2010; Gonzalo et al. 2017). Studies have demonstrated that clinical experiences integrated early on in UME can enhance students' learning of the subject matter, clinical skill proficiency, and their understanding of student-patient relationships, compared to students without early clinical experiences (Kossoff et al. 1999; Dyrebye et al. 2007). Therefore, when traditional instructional methods for delivering the basic sciences, such as large group and small group learning, are paired up with relevant clinical learning sessions, students' learning is more relevant, and enables them to reinforce their basic sciences knowledge, which can ultimately make their learning more relevant and better prepare them for their future career as a health care professional (Wilkinson et al. 2002; Dahle et al. 2002; Norman 2007; Finnerty et al. 2010; Brauer and Ferguson 2015).

Based on the information presented above, we know that a strong basic science foundation is necessary for the successful practice of medicine, and early integration of clinical experiences may aid students' reinforcement of fundamental basic science concepts. However, with clinical directors and medical students being key stakeholders in medical education (Dennis et al. 2014; Girotto et al. 2019), what are both parties' perceptions of trainees' basic science knowledge?

1.2 Perceptions of Undergraduate Medical Education Trainees

1.2.1 Clerkship Directors' Perceptions of Trainees

The literature indicates that clinical directors perceive most medical students to be lacking basic science knowledge after completing their pre-clerkship training (D'Eon 2006; Spencer et al. 2008; Nouns et al. 2012; Weggemans et al. 2017). As a result, clerkship directors may perceive students as lacking confidence and proficiency at the beginning of clerkship, which may be, in part, due to a weak basic science foundation (Windish et al. 2004). While there is variability among institutions and graduating cohorts, research indicates that clerkship directors perceive students to be ill-prepared when they are entering a clinical setting, and demonstrate weaknesses with their clinical skills and reasoning through patient signs and symptoms (Windish et al. 2004; Sanson-Fisher et al. 2005; O'Brien et al. 2007).

1.2.2 Trainees' Self Perceptions

From the students' perspective, studies show that some undergraduate medical students indicate that they do not understand how a strong basic science foundation is relevant to their future clinical practice (Fincher et al. 2009). Furthermore, research indicates that many newly minted medical graduates feel as though their undergraduate medical training did not prepare them well for clinical practice, and feel ill-prepared with respect to their basic science knowledge (Jungbauer et al. 2003; Cave et al. 2009; Tokuda et al. 2010; Goldacre et al. 2010; Chen et al. 2015; Oschsmann et al. 2011). More specifically, there is evidence to suggest that students perceive their pre-clerkship education to be a source of their shortcomings in a clinical setting (O'Brien et al. 2007), and these shortcomings can unfortunately remain unaddressed as trainees transition into their post-graduate training program (Tokuda et al. 2010; Chen et al. 2015). When surveying first year medical residents, only 29% of respondents indicated that they felt prepared in their basic science knowledge that underpins the common clinical conditions that they are presented with (Tokuda et al. 2010). Consequently, this lack of basic science knowledge retention, identified in many medical trainees and graduates, can unfortunately result in a lack of overall competence in medical training (Tokuda et al. 2010). One way in which we can better prepare tomorrow's physicians is to review curricular content, identify areas in need of improvement with respect to students' basic science knowledge, and effectively address these potential knowledge deficits, thereby ensuring all students are well-equipped with the knowledge that is necessary to for a successful transition to clerkship.

1.3 Creating Continuity Throughout the Stages of Medical Training

The lack of proficiency and readiness for clinical practice we see in current trainees may, in part, be stemming from a disconnect among medical educators within the various stages of medical training, such as pre-clerkship and clerkship, and this discontinuity can extend beyond UME and stretch into post-graduate medical education (Aschenbrener et al. 2015). However, ideally, each stage of medical training should be on a continuum of learning (Teunissen and Westerman 2011; Nousiainen et al. 2017). Discontinuity throughout one's medical training can result in disjointed delivery of content and leave students with some deficits in their knowledge. For example, research indicates that the transition from pre-clerkship to clerkship can be stressful for undergraduate medical students (Radcliffe and Lester 2003; Poncelet and O'Brien 2008). Furthermore, trainees often feel unprepared for their subsequent stages of medical training, and struggle with the transitions, suggesting a discontinuity between the stages of training (Small et al. 2008; Cave et al. 2009). Therefore, by creating a seamless continuum across all stages of medical training, we can promote knowledge integration for students, aid with the development of their critical thinking skills, and ultimately foster trainees' overall competence in the field of medicine (Hirsh et al. 2007; Aschenbrener et al. 2015). To help ease the transition to subsequent stages of medical training, some medical curricula have increased the vertical integration within their curricula (Wijnen-Meijer et al. 2010). With vertical integration, there is enhanced integration between the basic and clinical sciences, and some medical curricula are also introducing earlier clinical experiences for students, both of which have been shown to enhance students' preparedness for their transition to their next stage of training (Wijnen-Meijer et al. 2010; Cameron et al. 2014). Thus, increasing communication between educators across the spectrum of medical training can hopefully translate to increased consistency across the medical education continuum, and ultimately enhance students' outcomes as they progress through the various stages of medical training.

1.4 Overview of Undergraduate Medical Education at Schulich

The UME curriculum at the Schulich School of Medicine and Dentistry is a four-year training program. During pre-clerkship (years one and two), the basic and clinical sciences are integrated throughout pre-clerkship into systems-based courses, all of which incorporate a blend of instructional methods including large group learning, small groups learning, and independent learning modules. In year one, students study the basic, clinical, and social sciences in the following courses: Introduction to Medicine, Blood, Infection & Immunity, Skin, Heart & Circulation, Respiration & Airways, Genitourinary System, Physician as Leader, Population Health, Epidemiology, Medical Ethics & Humanities, Professional Portfolio, and Patient Centered Clinical Methods. In the second year of study, the basic, clinical, and social sciences are incorporated into Digestion & Nutrition, Endocrine & Metabolism, Reproduction, Key Topics in Family Medicine, Musculoskeletal System, Emergency Care, Neurosciences, Eye & Ear, Psychiatry & the Behavioral Sciences, Healthcare Systems, Medical Ethics &

Humanities, Professional Portfolio, and Patient Centered Clinical Methods (**Table 1**). Following the first two years of study, students begin clerkship year, in which there are six different core rotations: Paediatrics, Obstetrics and Gynaecology (OB/GYN), Internal Medicine, Family Medicine, Psychiatry, and Surgery. Students are also required to participate in an emergency medicine and an anesthesia rotation, which are mandatory sub-rotations of internal medicine and surgery, respectively. Following the clinical year of clerkship, students complete clinical electives, the post-graduate matching process (Canadian Resident Matching Service (CARMs)), and a course that focuses on the transition to their post-graduate training (Integration & Transition).

Table 1: Current Schulich School of Medicine & Dentistry Undergraduate Medical Education sample academic calendar for the basic science pre-clerkship curriculum (Year one and two), clerkship (Year three), and Year four.

<table>
<tr><th colspan="9">Schulich UME Academic Calendar</th></tr>
<tr><td rowspan="2">Year 1</td><td colspan="3">Term 1</td><td colspan="4">Term 2</td></tr>
<tr><td>Introduction to Medicine</td><td>Blood</td><td>Infection & Immunity</td><td>Skin</td><td>Heart & Circulation</td><td>Respiration & Airways</td><td>Genitourinary</td></tr>
<tr><td rowspan="2">Year 2</td><td colspan="3">Term 3</td><td colspan="5">Term 4</td></tr>
<tr><td>Digestion & Nutrition</td><td>Endocrine & Metabolism</td><td>Reproductive System</td><td>Family Medicine</td><td>Musculoskeletal System</td><td>Emergency Medicine</td><td>Neuroscience, Eye, & Ear</td><td>Psychiatry & Behavior</td></tr>
<tr><td rowspan="2">Year 3</td><td rowspan="2">Paediatrics</td><td rowspan="2">OB/GYN</td><td>Internal Medicine</td><td rowspan="2">Family Medicine</td><td rowspan="2">Psychiatry</td><td>Surgery</td></tr>
<tr><td>Emergency Medicine</td><td>Anesthesia</td></tr>
<tr><td>Year 4</td><td colspan="3">Clinical Electives</td><td colspan="2">CARMs</td><td>Integration & Transition</td></tr>
</table>

1.4.1 Call for an Evidence-Based UME Curriculum

As outlined above, basic science education is essential in UME to train and equip all students with the basic science knowledge that is required to build their clinical science knowledge upon, ultimately enabling them to treat and manage patient demands (Woods et al. 2005; Spencer et al. 2008; Pawlina 2009; McColl et al. 2012; Prober and Khan 2013). More than just knowing the material, knowledge in the basic science disciplines has been shown to improve clinical reasoning skills and the accuracy of various diagnoses in a clinical setting (Barrows and Feltovich 1987; Woods et al. 2007; Spencer et al. 2008; Finnerty et al. 2010; McColl et al. 2012). Regardless of the necessity of a strong basic science foundation, multiple studies demonstrate that medical students' basic science knowledge is not well retained, and it is not uncommon for them to continue to lose their knowledge as they progress through their training (Ling et al. 2008; Spencer et al. 2008; Tokuda et al. 2010; Schneid et al. 2018). However, some factors that may positively influence students' basic science knowledge acquisition and retention is the instructional method(s) employed to deliver the relevant content, and the integration of early clinical experiences (Cottam 1999; Kossoff et al. 1999; Costa et al. 2007; Dyrebye et al. 2007; Cooke et al. 2010; Samarakoon et al. 2013; Freeman et al. 2014; Wolff et al. 2015)

Based on the inconsistencies among UME curricula, and the current reported basic science knowledge levels, there is a need for a UME training program that ensures all students are proficient in the necessary basic science fundamentals throughout their medical training. The Schulich School of Medicine & Dentistry is undergoing a curriculum renewal at the UME level, and as a result, the basic science pre-clerkship curriculum has been revised (Doctor of Medicine Curriculum Renewal, Schulich School of Medicine & Dentistry, 2019). However, currently, there is limited research on how to best integrate the basic sciences into UME, with the overarching goal of enhancing student outcomes. Therefore, by creating a curricular evaluation tool we can consistently monitor the influence of curricular changes on student outcomes in the basic sciences to ensure that the high-yield basic science concepts are effectively integrated into pre-clerkship.

1.4.2 Research Aims

To ensure medical students are competent in the basic science fundamentals, an evidence-based approach for determining which high yield foundational basic science concepts students should be proficient in after completing pre-clerkship is essential. By establishing which basic science content is integral to student success, analyzing current curricular content, and evaluating students' knowledge levels of fundamental basic science content, we can provide insights into the effectiveness of the basic science pre-clerkship curriculum, and inform curricular re-design and delivery of basic science content in UME. Thus, the specific aims of this research were to:

1. Determine UME clerkship directors' perceptions of necessary basic science concepts, along with current student strengths and areas in need of improvement, with respect to students' basic science knowledge.
2. Assess current third-year medical students' knowledge retention of the basic science concepts deemed necessary by clerkship directors.
3. Determine where, when, how, or if, the identified basic science concepts are taught in Schulich's (2017-2018) basic science curriculum to elucidate areas of strengths and potential areas of improvement.
4. Assess current third-year medical students' knowledge reinforcement levels of the basic science concepts deemed necessary by clerkship directors.

1.5 Study Significance

Currently there is limited evidence on how to effectively integrate the basic sciences into a pre-clerkship curriculum within UME, and whether basic science curricula are effective for fostering medical students' basic science knowledge. Thus, there is a need for an evidence-based curriculum that ensures students are proficient in high-yield basic science concepts prior to entering a clinical setting, and ultimately, prior to graduation. Therefore, by determining which basic science concepts students are expected to know, evaluating current student's knowledge levels of fundamental basic science concepts, and elucidating how and when these concepts are delivered in UME, we will provide insights into potential strengths and areas of improvement of the basic science pre-clerkship curriculum. Through the use of an evidence-based approach, we can create a feedback loop to critically evaluate the overall efficacy of the basic science pre-clerkship curriculum and collected data can be fed forward to help inform changes to the UME basic science curriculum. This evidence-based feedback tool can be used as a template by faculty and educators for assessing the effectiveness of basic sciences education in undergraduate, graduate, and professional program curricula.

The overarching goal of this research was to create an evidence-based curriculum evaluation tool to evaluate the efficacy of basic science education in pre-clerkship curricula. The development, implementation, and findings of the curriculum evaluation tool will be explored throughout this thesis. Chapter 2 will describe the methods that were employed for assessing clerkship directors' and students' perceptions, evaluating students' basic science knowledge levels, mapping identified basic science concepts to current curricular content, and all together, creating an evidence-based curriculum evaluation tool. The data collected from this research will be thoroughly explored throughout Chapter 3, and Chapter 4 will delve into the research findings to elucidate areas of strength, and potential areas in need of improvement, with respect to basic science pre-clerkship curricula. Lastly, the main conclusions drawn from this research will be summarized in Chapter 5, along with suggestions for curricular revision to enhance students' learning in the basic sciences during their pre-clerkship training.

Chapter 2

2 METHODS & ANALYSIS

2.1 Overview of Methodology

The overarching goal of this research was to create an evidence-based curriculum feedback loop to critically evaluate the UME curriculum (**Figure 1**). To begin this feedback loop, we first set out to evaluate which basic science concepts clerkship directors deem necessary for students to know prior to entering each rotation. We also assessed clerkship directors' perceptions of medical students' basic science knowledge, along with students' self-perceptions of their knowledge. Using the concepts deemed necessary by clerkship directors, we built a custom basic science assessment to evaluate medical students' basic science knowledge retention of the identified basic science concepts. The assessed concepts were then mapped to current curricular content to determine where, when, how, or if, the concepts were delivered in the pre-clerkship curriculum. Students' reinforcement levels of the identified basic science concepts were also measured to reveal if clinical learning had any influence on students' basic science knowledge levels. Analyzing these metrics enabled us to highlight areas of strength, and potential areas of improvement, which can then be directly used to critically evaluate the basic science pre-clerkship curriculum and inform future curricular design.

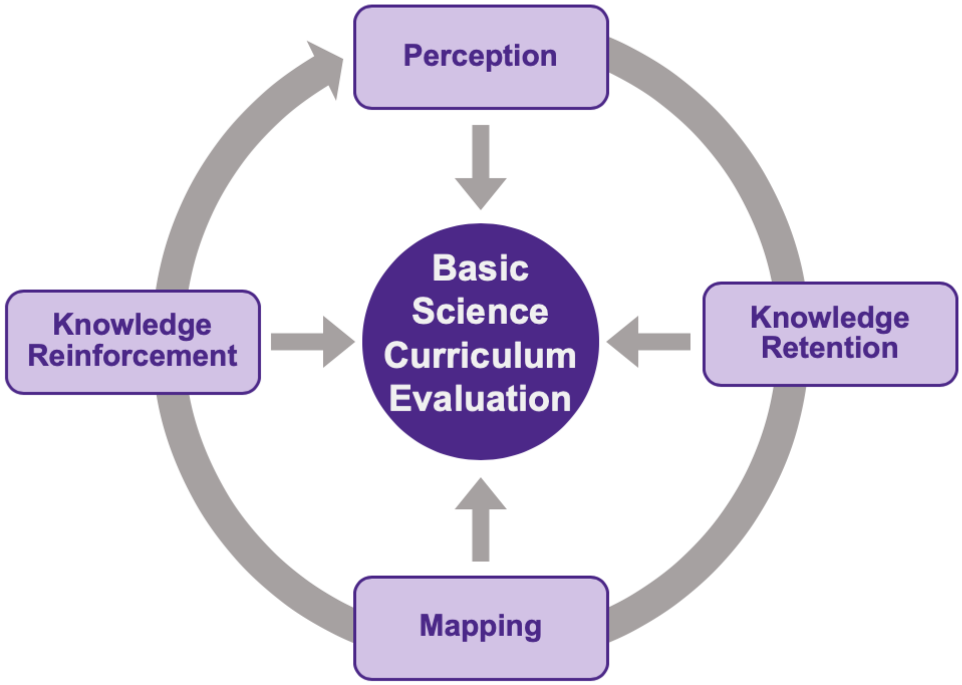


Figure 1: Evidence-based curriculum evaluation tool designed to critically evaluate the effectiveness of the basic science pre-clerkship curriculum through assessing clerkship directors' and students' perceptions of trainees' basic science knowledge, along with students' basic science knowledge levels, and mapping those metrics to current curricular content to elucidate areas of strength and potential areas in need of improvement within the basic science pre-clerkship curriculum.

This research was conducted at the Schulich School of Medicine & Dentistry in Undergraduate Medical Education (UME), which has two campuses located in London, Ontario, Canada, and Windsor, Ontario, Canada.

2.2 Ethics

This study was deemed Quality Improvement/Quality Assurance by Western Research Ethics (**Appendix A**).

2.3 Perceptions

2.3.1 Clerkship Director Interviews

Schulich's basic science pre-clerkship UME curriculum course objectives were reviewed by two authors including a UME assistant professor and a doctoral student. The objectives were used as a framework to create an interview questionnaire comprised of inquiries that assessed clerkship director's expectations of students' basic science knowledge, along with clerkship director's perceptions of current student strengths and weaknesses (**Appendix B**). For the purpose of this study anatomy, biochemistry, imaging, microbiology, nutrition, pathology, pharmacology, and physiology were classified as basic sciences. The questionnaire included inquiries such as "*Which basic science concepts are students expected to know coming into this clerkship rotation?",* along with more targeted questions such as, "*Which, if any, specific developmental conditions, fetal or embryonic, are students expected to have the fundamental knowledge of, in terms of identifying and explaining the anatomical basis, prior to entering the rotation?"*. Depending on the clerkship director's answers, follow up questions, such as "*Which developmental conditions do you feel students struggle with the most?*" were asked. Prior to implementation, the questionnaire was reviewed by Ken Meadows, PhD, an educational researcher at Western University, to ensure the questions were impartial and targeted towards the basic science pre-clerkship curriculum.

Using the questionnaires as a guide, 1-hour interviews were conducted with UME clerkship directors from both London and Windsor campuses for the six core clerkship rotations and the two core sub-rotations (**Table 1**). Each campus has 1-2 clerkship directors per rotation; thus, the number of clerkship directors present at each interview varied, and consent was received from all interviewees (**Table 2; Appendix C**). Interviews were audio-recorded (using QuickTime Player – Audio Version 10.4), following which the interviews were transcribed. A code table based on the six core basic sciences was created and used as a template

(**Table 3**). During the interview process, certain basic science themes emerged, such as genetics and immunology, and these themes were included in the codebook as subcomponents; however, the subcomponents were not part of the interview questionnaire and so not all clerkship directors were asked about these subcomponents.

Table 2: The number of clerkship directors at each Schulich campus (London, Ontario and Windsor, Ontario) who were interviewed, according to clerkship rotation.

	Paediatrics	OB/GYN	Internal	Family	Psychiatry	Surgery
London, Ontario	2	2	1	1	2	1
Windsor, Ontario	1	1	1	1	1	1

Table 3: Code table of the six core basic sciences and sub-components that were discussed with clerkship directors, which was used a template to code the six interview transcripts.

Core Basic Science	Component of Core Basic Science
Anatomy	Gross Anatomy Embryology/Fetal Development Histology Imaging Neuroanatomy
Biochemistry	Biochemistry Immunology
Microbiology	Microbiology
Pathology	Pathology Imaging Immunology
Pharmacology	Pharmacology Immunology
Physiology	Physiology Genetics Immunology

2.3.2 Coding

The interview transcripts were then coded by two researchers (using ATLAS.ti software Version 1.6.0; Berlin, Germany) according to the template in **Table 3**, and into the following categories: i) which basic science concepts clerkship directors deemed to be necessary (**Figure 2**), and ii) perceived student strengths or iii) perceived areas requiring improvement with respect to students' basic science knowledge.

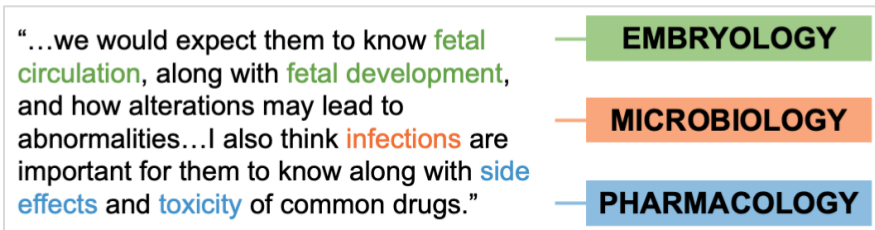


Figure 2: Excerpt of the interview with paediatrics clerkship directors demonstrating how each interview was coded according to the basic sciences that the clerkship directors deemed necessary for students to know prior to entering the paediatrics rotation.

2.3.3 Students' Perceptions of the Basic Science Pre-Clerkship Curriculum

Students were also evaluated based on their perceptions of the pre-clerkship basic sciences. The survey evaluated students' perceptions on whether they retained knowledge in each basic science from pre-clerkship, or if they perceive their knowledge to be lacking (**Appendix D**). Additionally, the survey assessed whether the students' thought the assessed basic science concepts were covered during their pre-clerkship training.

2.3.4 Statistical Analysis

Using the coding data output from ATLAS.ti (Scientific Software Development GmbH; Berlin, Germany), frequencies of the basic science themes were calculated for each clerkship rotation based on the averages between the two coders. Intraclass correlation coefficients (ICC) were used to assess the inter-rater reliability of codes, and the average measures of the ICC tests were reported. Intraclass correlation coefficient statistical analyses were performed in SPSS using a reliability measures, two-way mixed model with absolute agreement (IBM SPSS Version 21; Armonk, NY, USA). The following ICC intervals were used to define the magnitude of reliability (Fleiss et al. 2013): ICC<0.4 = poor; 0.4<ICC<0.59 =fair; 0.60<ICC<0.74 = good; ICC>0.74 = excellent. A chi-square (X_2) goodness-of-fit test was conducted to determine whether the distribution of students' survey responses was significant ($p \leq 0.05$).

2.4 Students' Basic Science Knowledge Retention

2.4.1 Development of Basic Science Assessments

Using the basic science concepts deemed necessary by clerkship directors during the interviews (**Section 2.3**), a basic science assessment was created for each core clerkship rotation (paediatrics, OB/GYN, internal medicine, family medicine, psychiatry, and surgery). Each assessment was comprised of 45 clinical vignette style, basic science multiple-choice questions (MCQ) (**Figure 3**), which were reflective of the basic science concepts and the frequency of topics that were mentioned in the interviews with clerkship directors (**Section 2.3; Appendix E**). Prior to implementation, each assessment was reviewed by clerkship directors, basic scientists, and a focus group consisting of fourth-year medical students, to ensure the assessments were appropriate.

A 40-year-old woman with ovarian cancer underwent a total hysterectomy, and an extensive lymph node dissection along the right lateral wall of her pelvis. Post-op, she experiences muscle spasms, pain, and numbness along the medial aspect of her right thigh.

Which of the following nerves was damaged during the dissection?

A. Right Femoral Nerve
B. Right Genitofemoral Nerve
C. Right Obturator Nerve
D. Right Pudendal Nerve
E. Right Sciatic Nerve

Figure 3: Example of a clinical-vignette style question, demonstrating the clinical stem and corresponding multiple-choice options, that would be included in the basic science assessments to evaluate students' clinically-relevant basic science knowledge levels.

Eight groups of students (Groups A-H) (**Table 4**) rotated through the six core clerkship rotations, four of which are 6-weeks in length **(Figure 4)**. Surgery and internal medicine are 12-week rotations with two groups of students rotating through each of them simultaneously; both of which have mandatory sub-rotations of anesthesia and emergency medicine, respectively. It is important to note that each group of students (A-H) would follow a different rotation order depending on their clerkship schedule.

Table 4: Distribution of third-year medical students to their clerkship groups (A-H), demonstrating the number of students assigned to each group.

Group	A	B	C	D	E	F	G	H
# of Students	23	22	20	22	22	22	20	21

Prior to implementation, the students were briefed on the formative nature of the assessments, and how the assessment data was going to be used for this investigation. Informed consent was not required from participants as this research was deemed Quality Improvement/Quality Assessment (QI/QA) by Western Research Ethics (**Section 2.1**).

2.4.2 Implementation of Basic Science Assessments Prior to Clerkship

During the 2017-2018 academic year, the basic science assessments were distributed to third-year medical students (n=172) prior to each clerkship rotation to assess students' knowledge retention of concepts deemed necessary by clerkship directors (**Figure 4**). Students completed the pre-tests, which had a time limit of 70 minutes, using the University of Western Ontario's Learning Management System, OWL (Sakai 11.3 – owl3.1). Once all six rotation assessments were completed, an item analysis was conducted on each individual assessment question (n=270) to evaluate student performance, means, and to ensure the questions were of high quality. Assessments were not evaluated for equivalency of difficulty level since the assessment questions were derived from interviews with clerkship directors (**Section 2.3.1**).

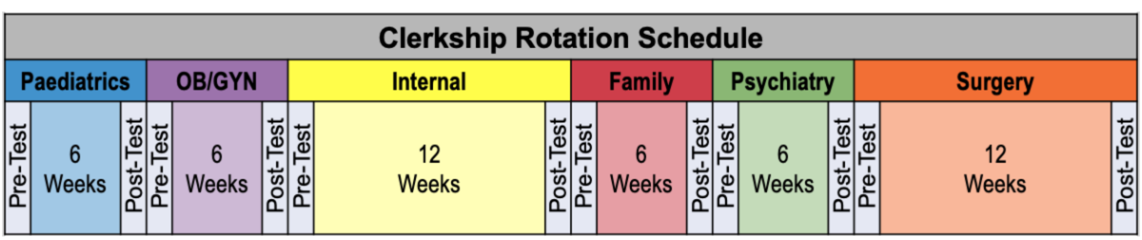


Figure 4: Sample clerkship rotation and basic science assessment schedule for one group of medical students. Four rotations (Paediatrics, OB/GYN, Family Medicine, Psychiatry) are 6-weeks in length, with the remaining two (Internal Medicine, Surgery) are 12-weeks in length. The basic science pre- and post-test assessments were implemented prior to and at the completion of each rotation, respectively, to assess students' basic science knowledge retention and reinforcement.

2.4.2.1 Pre-Test Assessment Feedback

After completing the pre-test, students were provided with general formative feedback on the assessed topics which outlined key points from each assessment question that clerkship directors expected them to be knowledgeable in prior to that rotation (**Appendix F**).

2.4.2.2 Statistical Analysis

Data was analyzed using IBM SPSS Statistics (IBM SPSS Version 21; Armonk, NY, USA). A one-way Analysis of Variance (ANOVA) with an alpha (α) level of 0.05 was used to determine if clerkship rotation, rotation order, or basic science disciplines had any significant effect on students' pre-test performance ($p \leq 0.05$). This was followed by a post-hoc analysis for multiple comparisons (Bonferroni correction) with an alpha (α) level of 0.01 to determine which relationships were significant, and *p* values subjected to the Bonferroni correction will be denoted as p_{bonf} for the purposes of this study ($p_{bonf} \leq 0.01$). Graphs were created using Prism 8 (GraphPad Software, Version 8.3.1; San Diego, CA, USA).

2.5 Mapping

The assessed basic science concepts, which were derived from interviews with clerkship directors (**Section 2.4**), were manually mapped to current pre-clerkship curricular learning objectives using Microsoft Excel (Microsoft Office, Version 16.34; Microsoft Corporation, Redmond, WA, USA). The mapped learning objectives were then linked to the pre-clerkship course(s) in which the learning objectives were delivered (**Figure 5; Table 1**). This process enabled us to determine where, when, or if, the fundamental basic science concepts were being taught during pre-clerkship. The mapped learning objectives were also linked to the employed instructional method to estimate how the objective was delivered during pre-clerkship: large group learning (primarily didactic lecture), small group learning (laboratory sessions, team-based learning, small group discussions), or independent learning modules.

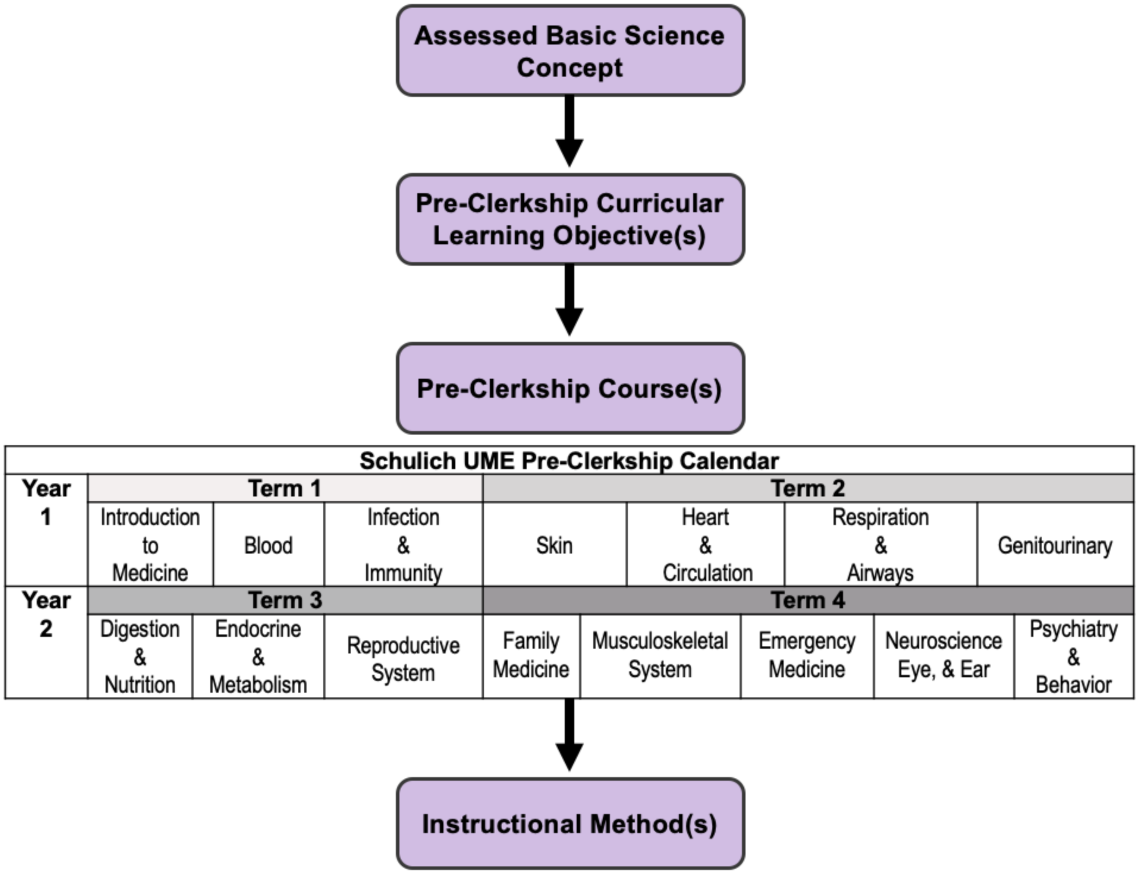


Figure 5: Flowchart of the mapping process to determine where, when, how, or if, the basic science concepts were delivered during pre-clerkship. The assessed basic science concepts were mapped to pre-clerkship curricular learning objectives, which were then linked to the pre-clerkship course in which the concept was delivered. Once the assessed concepts were linked to their respective learning objective(s), the employed instructional methods that were used to deliver the concepts could be estimated.

2.5.1 Mapping Assessment Data to Current Curricular Content

Students' pre-test question scores (**Section 2.4**) were analyzed based on the pre-clerkship course and term in which the concept was delivered, along with the instructional method(s) that were employed to deliver the linked learning objectives. The number of times a concept was linked to more than one pre-clerkship curricular learning objective was also evaluated to determine if content reinforcement during pre-clerkship had any influence on students' basic science knowledge retention.

2.5.2 Statistical Analysis

Students' average pre-test question scores were analyzed using a one-way Analysis of Variance (ANOVA) with an alpha (α) level of 0.05, followed by a post-hoc test for multiple comparisons with an alpha (α) level of 0.01 (Bonferroni correction) ($p_{bonf} \leq 0.01$), to determine if timing of delivery, content repetition, or instructional method had a significant effect on students' basic science knowledge retention levels. Graphs were generated using Prism 8 (GraphPad Software, Version 8.3.1; San Diego, CA, USA).

2.6 Students' Basic Science Knowledge Reinforcement

2.6.1 Basic Science Post-Test Assessments

The basic science assessments that were created for the pre-test (**Section 2.4.1**), were also distributed to students (n=172) as a post-test at the end of each clerkship rotation to assess their learning and reinforcement of fundamental basic science concepts (**Figure 4**). The post-test assessments contained the same questions as the pre-test, however, they were arranged in a scrambled format so students were less likely to rely on their memory to complete the assessment. The online format and settings of the pre-test were replicated for the post-test as students completed the post-test using the University of Western Ontario's Learning Management System, OWL (Sakai 11.3 – owl3.1), and had a time limit of 70 minutes.

2.6.2 Post-Test Assessment Feedback

Following the post-test students received individualized feedback outlining where their basic science knowledge was lacking to help promote their personal development during the clerkship year (**Appendix G**).

2.6.3 Statistical Analysis

Data was analyzed using IBM SPSS Statistics (Version 21; Armonk, NY, USA). Students' pre- and post-test scores were statistically compared using a paired-samples, two-tailed t-test to determine if there were significant differences ($p \leq 0.05$) present between the two assessment scores. Additionally, a one-way Analysis of Variance (ANOVA) was used to assess if rotation order, clerkship group, or student performance quartiles had any significant effect on students' assessment performance, followed by a post hoc test (Bonferroni correction) for multiple comparisons with an alpha (α) level of 0.01 ($p_{bonf} \leq 0.01$). Graphs were generated using Prism 8 (GraphPad Software, Version 8.3.1; San Diego, CA, USA).

2.7 Curriculum Evaluation

The methods described throughout this chapter of the thesis provide the basis to critically evaluate areas of strength and potential areas of improvement within the pre-clerkship basic science curriculum. More specifically, by using the concepts deemed necessary by clerkship directors to build a basic science assessment, we were able to evaluate students' knowledge retention levels of those identified concepts and provide potential insights into why clerkship directors perceived there to be areas in need of improvement, compared to areas of strength, in regard to students' basic science knowledge. Furthermore, when mapping the assessed basic science concepts to where, when, how, and how many times, a concept was delivered, and correlating those concepts with students' assessment scores, we can determine which, if any, curricular components have any impact on students' basic science knowledge levels. Lastly, evaluating students' knowledge reinforcement levels of the identified basic science concepts provides critical insights into the influence of experiential, clinical learning on students' basic science knowledge. These insights could be then fed forward to curriculum committees and course directors to help inform the re-design and delivery of basic science content in pre-clerkship.

Chapter 3

3 STUDY RESULTS

3.1 Perceptions

3.1.1 Clerkship Directors' Perceptions of Basic Science Content

When interviewing the clerkship directors, we evaluated which basic science concepts they expect medical students to know prior to entering their rotation. The themes depicted in **Figure 6** demonstrate the prevalence of each basic science appearing in the transcribed interviews from all six core clerkship rotations and the two sub-rotations of anesthesia and emergency medicine. Overall, data revealed that students were expected to have some knowledge of every basic science prior to entering clerkship year. More specifically, pharmacology was the most prevalent, and biochemistry was the least prevalent, with respect to which basic science concepts third-year medical students are expected to know prior to entering clerkship. The ICC indicated excellent reliability between the two coders of the coding data for each clerkship rotation (ICC values: paediatrics=0.904; OB/GYN=0.930, internal medicine=0.964, emergency medicine=0.935, family medicine=0.965, psychiatry=0.868, surgery=0.932, anesthesia=0.902).

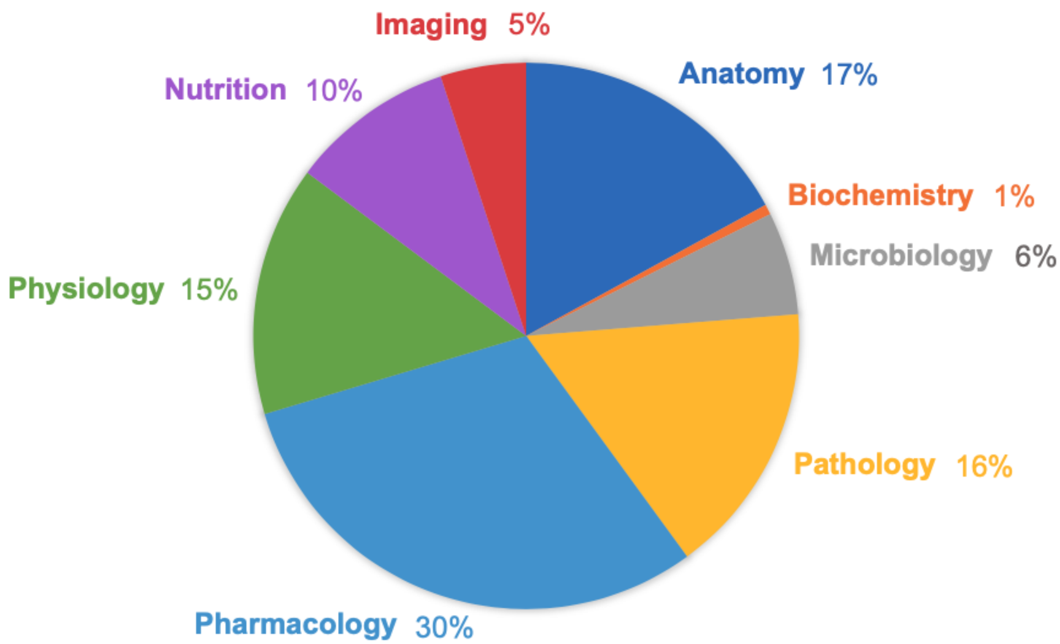


Figure 6: Overall frequency of basic sciences that medical students are expected to know prior to clerkship as identified by clerkship directors. Pharmacology was the most prevalent (30%), while biochemistry was the least prevalent (1%) basic science theme discussed.

Interview transcripts indicated that pharmacology had the highest frequency rate for four clerkship rotations: internal medicine, surgery, family medicine, and psychiatry (**Table 5**). The clerkship directors of these rotations identified classes of drugs, drug dosing, and drug interventions as fundamental pharmacological concepts that undergraduate medical students should know prior to entering clerkship year. Contrary to this, biochemistry was only deemed necessary by the OB/GYN clerkship directors, and this was in regard to hormones and hormone structure. Directors of surgery and paediatrics rotations deemed the anatomical sciences of higher importance compared to other basic sciences. Some examples of gross anatomical and embryological concepts highlighted were arterial supply, innervation, anatomical relationships, normal embryological development, and malformation. Histology and neuroanatomy were seldom mentioned by clerkship directors as these topics tend to become more of a focus in upper year electives. The data also demonstrated that pathology and physiology knowledge is expected in every rotation. The most prevalent pathologies identified by the clerkship directors were pneumonia, chronic obstructive pulmonary disease, diabetes, hypertension, and polycystic ovarian syndrome. These conditions were supported by the physiology concepts deemed necessary by clerkship directors, such as heart and lung physiology, IV fluids, ovulation, and the underlying physiology of cellular dynamics and the coagulation cascade. Furthermore, microbiology concepts of infection, abscesses, and common bacteria were deemed necessary by family medicine, internal medicine, emergency medicine, OB/GYN, surgery, and paediatrics directors. Microbiology was not identified by the psychiatry or anesthesia clerkship directors, as they indicated that they typically do not deal with microorganisms within their respective specialty.

Table 5: Average percent frequencies of basic science themes identified by UME clerkship directors as necessary for their rotation.

	% Frequency							
Basic Science Themes	**Paeds**	**OB/GYN**	**Internal Med.**	**Emerge Med.**	**Family Med**	**Psych**	**Surgery**	**Anesthesia**
ANATOMY	**30.6**	**20.3**	**10.8**	**17.4**	**11.3**	**15.4**	**28.3**	**7.5**
Gross Anatomy	0.7	10.9	2.0	9.3	0.5	2.6	9.4	3.0
Embryology	18.2	9.4	0.5	0	7.5	1.3	11.0	0
Histology	0	0	0	0	1.1	0	1.3	0
Imaging	11.7	0	8.3	8.1	2.2	3.8	5.7	4.5
Neuroanatomy	0	0	0	0	0	7.7	0	0
BIOCHEMISTRY	**0**	**4.7**	**0**	**0**	**0**	**0**	**0**	**0**
Biochemistry	0	2.4	0	0	0	0	0	0
Immunology	0	2.3	0	0	0	0	0	0
IMAGING	**0**	**7.8**	**0**	**1.2**	**6.5**	**15.4**	**8.8**	**0**
MICROBIOLOGY	**9.1**	**1.5**	**15.7**	**2.3**	**8.0**	**0**	**11.3**	**0**
NUTRITION	**18.2**	**10.2**	**4.9**	**2.3**	**21.0**	**14.1**	**3.2**	**3.0**
PATHOLOGY	**10.3**	**11.7**	**17.6**	**44.2**	**15.6**	**5.1**	**4.4**	**19.4**
Pathology	9.1	11.7	13.2	26.7	13.4	3.9	3.8	16.4
Imaging	0.6	0	4.4	17.4	2.2	1.3	0	3.0
Immunology	0.6	0	0	0	0	0	0.6	0
PHARMACOLOGY	**14.9**	**14.1**	**37.3**	**31.4**	**24.2**	**29.5**	**30.8**	**56.7**
Pharmacology	13.0	14.1	37.3	31.4	24.2	29.5	30.8	56.7
Immunology	1.9	0	0	0	0	0	0	0
PHYSIOLOGY	**16.9**	**29.7**	**13.7**	**1.2**	**13.4**	**20.5**	**8.2**	**13.4**
Physiology	3.9	16.4	2.9	1.2	2.6	6.4	8.2	13.4
Genetics	10.4	13.3	9.8	0	10.8	14.1	0	0
Immunology	2.6	0	0.9	0	0	0	0	0

Nutrition and imaging are not classified as core basic sciences, however, these topics were also discussed with clerkship directors as they are an integral part of pre-clerkship and must be integrated with the basic and clinical sciences (Windish et al. 2004; Wenrich et al. 2010). With respect to imaging, understanding the benefits and drawbacks of different imaging modalities, along with an approach to a chest x-ray, were the main concepts identified by surgery, family medicine, OB/GYN, psychiatry, and emergency medicine clerkship directors. Nutrition was deemed important for all eight required clerkship rotations and was focused around basic dietary needs of different patient populations, along with drug interactions with certain foods, vitamins, and minerals.

3.1.2 Clerkship Directors' Perceptions of Students' Basic Science Knowledge

3.1.2.1 Students' Strengths

When discussing basic science concepts that current students are proficient in prior to clerkship, directors from two rotations, internal medicine and family medicine, were able to identify perceived student strengths, which were anatomy and physiology (**Table 6**). These rotation directors indicated that students coming into their rotations "*knew their anatomy*", however, they also noted that students only needed a 'general' anatomical knowledge base, with less specifics, for these specialties. Physiology was also identified as a student strength by the internal medicine clerkship directors, as they stated that current students "*typically have a solid foundation of physiology*" upon which important clinical concepts can be built, but once again were only expected to have a general knowledge of this basic science. The clerkship directors of the remaining rotations (emergency medicine, surgery, anesthesia, OB/GYN, paediatrics, psychiatry) did not indicate any student strengths, despite being asked directly for comments on student basic science knowledge strengths.

3.1.2.2 Areas in Need of Improvement

Clerkship directors identified areas where students could improve their level of knowledge in every basic science. However, anatomy (surgery, emergency medicine, OB/GYN, anesthesia), microbiology (family medicine, internal medicine, OB/GYN, paediatrics), and pharmacology (internal medicine, emergency medicine, OB/GYN, anesthesia) were identified as the most prevalent basic sciences requiring improvement (**Table 6**). Surgery rotation directors identified arterial supply, important arterial branches, and anatomical relationships as anatomical areas requiring improvement. One example provided by surgery clerkship directors was that students should know the head of the pancreas is resected with the duodenum because of the shared blood supply between the two structures during a Whipple's procedure. The clerkship director of emergency medicine identified a lack of knowledge in musculoskeletal anatomy, specifically the hand, since many individuals present to the emergency department with hand lacerations. Anatomy of the vasculature of the pelvis and respiratory system were identified as areas requiring improvement by OB/GYN and anesthesia clerkship directors, respectively. When discussing microbiology, OB/GYN clerkship directors identified infectious diseases, wound infection, and abscesses as areas where student knowledge is currently lacking. Collectively, family medicine, internal medicine, and paediatrics rotation directors identified general microbiology and underlying microorganisms as an area needing improvement for current students. In regard to pharmacology, antibiotics and appropriate treatment of infectious diseases were identified as topics requiring improvement by both internal medicine and OB/GYN clerkship directors. The emergency medicine rotation director indicated toxicology and pharmacological resuscitation as areas where students should improve their knowledge prior to clerkship. Many students are presented with patients suffering from hypotension, hypertension, bradycardia, or tachycardia during their clerkship year, thus, the anesthesia rotation director identified that incoming student's knowledge of pharmacological treatments for these conditions could be improved.

Table 6: The most prevalent basic science topics identified by UME clerkship directors as necessary for their rotation, along with their perceptions of current student strengths and areas in need of improvement.

Basic Science	Clerkship Directors' Expectations	Clerkship Directors' Perceptions of Current Student Strengths	Clerkship Directors' Perceptions of Current Student Areas in Need of Improvement
Anatomy	Arterial supply, innervation, anatomical relationships, normal embryological development, malformation	General anatomy	Arterial supply, arterial branches, anatomical relationships, musculoskeletal anatomy of the hand, respiratory system anatomy
Biochemistry	Hormones, hormone structure	N/I	N/I
Imaging	Approach to a chest x-ray, benefits and drawbacks of different imaging modalities	N/I	N/I
Microbiology	Infection, abscesses, common bacteria	N/I	General microbiology, infectious diseases, wound infection, abscesses
Nutrition	Basic dietary needs of different populations, drug interactions with certain foods, vitamins, and minerals	N/I	N/I
Pathology	Pneumonia, chronic obstructive pulmonary disorder, diabetes, hypertension, polycystic ovarian syndrome	N/I	N/I
Pharmacology	Classes of drugs, dosing of drugs, drug interventions	N/I	Antibiotics, toxicology, pharmacological resuscitation, treatment for: infectious diseases, hypotension, hypertension, bradycardia, and tachycardia
Physiology	Heart and lung physiology, ovulation, IV fluids, underlying physiology of the coagulation cascade	General physiology	N/I

Legend: *N/I = Not Identified*

3.1.3 Students' Self-Perceptions of their Basic Science Knowledge

When surveying students at the end of their clerkship training, the majority of medical students (73%) felt that they retained relevant physiological knowledge learned during their pre-clerkship training (X_2 (1) = 18.88, $p<0.001$), which is in line with the internal medicine rotation directors' perceptions which indicated that physiology knowledge is a current student strength prior to entering their rotation (**Figure 7**). In the remaining basic science disciplines, survey data revealed that more students feel their basic science knowledge is lacking, compared to the number of students who felt that they retained their basic science knowledge from pre-clerkship. More specifically, approximately one-third of respondents felt they retained their knowledge in the topics of biochemistry (28%) (X_2 (1) = 15.74, $p<0.001$), microbiology (29%) (X_2 (1) = 15.38, $p<0.001$), pathology (33%) (X_2 (1) = 9.12, $p<0.05$), and nutrition (37%) (X_2 (1) = 5.50, $p<0.05$). Once again, these perceptions are in line with clerkship directors' perceptions of potential areas of improvement with respect to students' basic science knowledge. For the topics of anatomy, imaging, and pharmacology less than one-half of the students indicated that they felt they had retained their knowledge in these disciplines [anatomy, 45% (X_2 (1) = 0.73, $p>0.05$); imaging, 46% (X_2 (1) = 0.29, $p>0.05$); pharmacology, 47% (X_2 (1) = 0.18, $p>0.05$)]. While general anatomy was perceived to be a student strength from the internal medicine rotation directors, the remaining directors perceived more complex anatomy to be an area that needs improvement, which aligns with students' perceptions of this discipline. Interestingly, imaging was not perceived as a strength nor an area in need of improvement by clerkship directors, which is supported by 46/52% split of student perceptions (2% of students did not provide an answer). In contrast, student perceptions of pharmacology were identical to imaging which is in direct contradiction with clerkship directors' perceptions as, according to them, this discipline was the most frequent area in need of improvement.

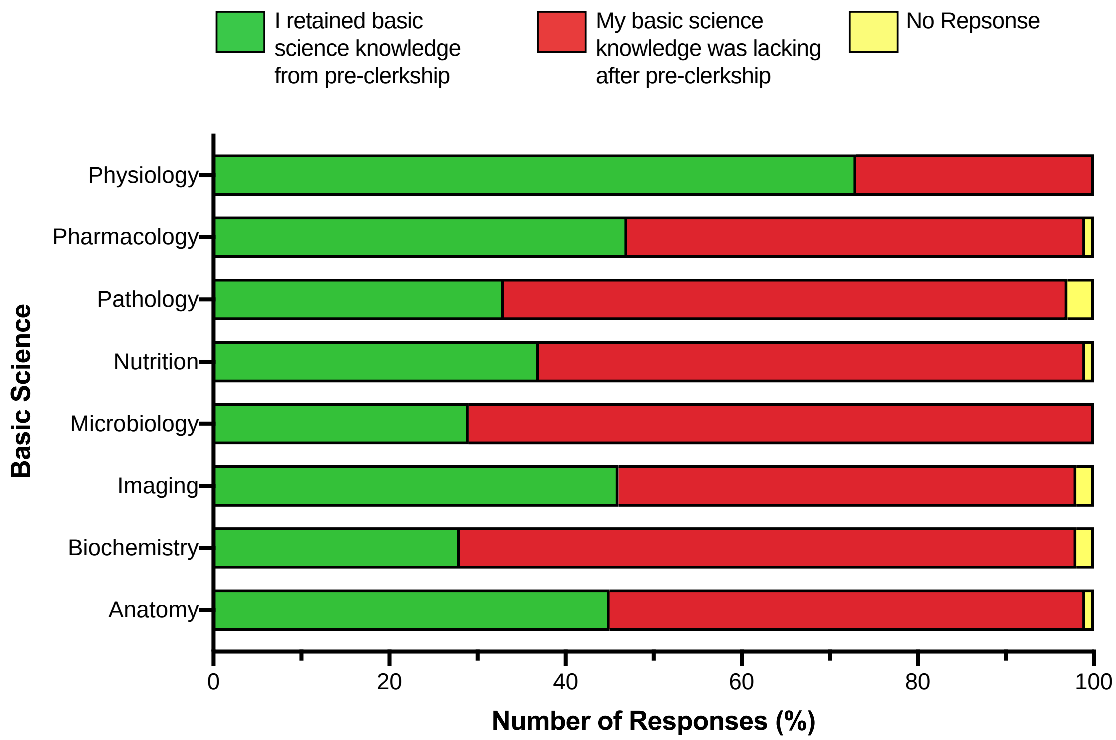


Figure 7: Students' perceptions of their pre-clerkship basic science knowledge after completing clerkship. More students felt their knowledge was lacking in each basic science, with the exception of physiology (X_2 (1) = 18.88, p<0.001), compared to the number of students who felt they retained basic science knowledge from pre-clerkship. There was a near equal split of students who felt they retained their knowledge versus students who felt they didn't retain their knowledge in the topics of anatomy (X_2 (1) = 0.73, p>0.05), imaging (X_2 (1) = 0.29, p>0.05), and pharmacology (X_2 (1) = 0.18, p>0.05). The majority of students felt their knowledge was lacking in biochemistry (X_2 (1) = 15.74, p<0.001), microbiology (X_2(1) = 15.38, p=0.001), pathology (X_2 (1) = 9.12, p<0.05), and nutrition (X_2 (1) = 5.50, p<0.05) after completing pre-clerkship.

3.2 Students' Basic Science Knowledge Retention

The concepts identified by clerkship directors were used to build a basic science assessment, comprised of clinical vignette style multiple-choice questions, for all six core clerkship rotations. During the 2017-18 academic year, Schulich's UME minimally acceptable grade was 60%, and the assessment data revealed that third-year medical students achieved an average of greater than 60% on the pre-test prior to entering each clerkship rotation (**Figure 8**). More specifically, the highest average scores were achieved in internal medicine (72%), and the lowest in surgery (63%). No significant differences (p>0.05) were identified among the rotation specific assessments.

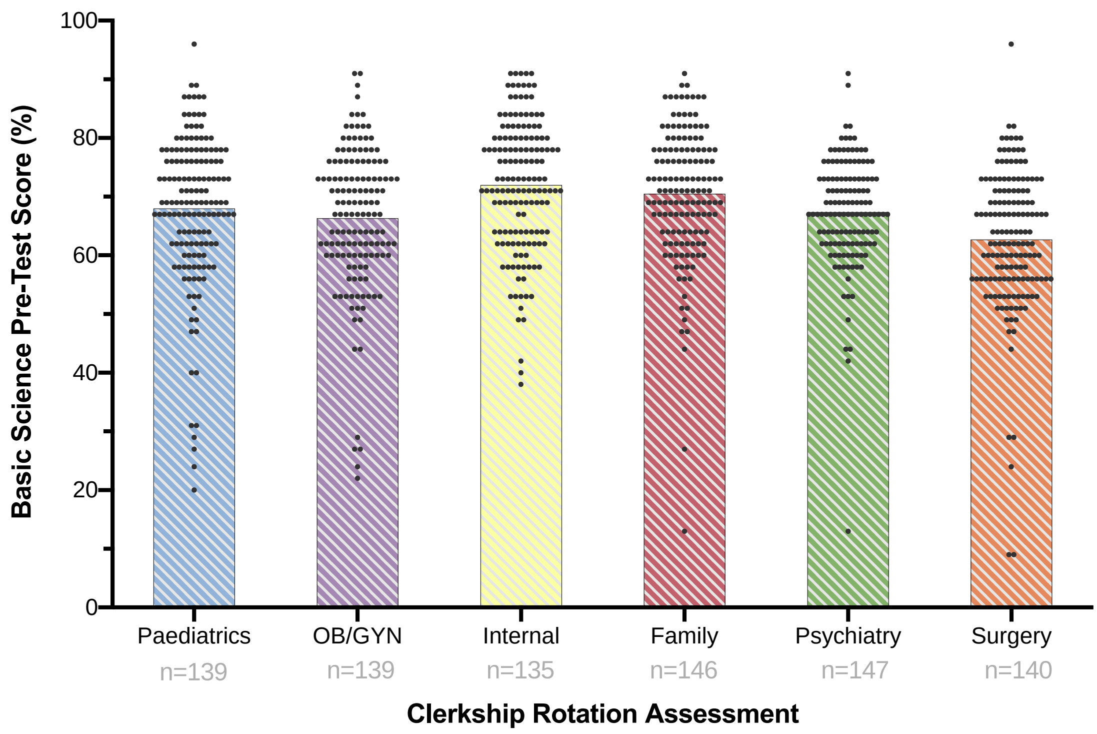
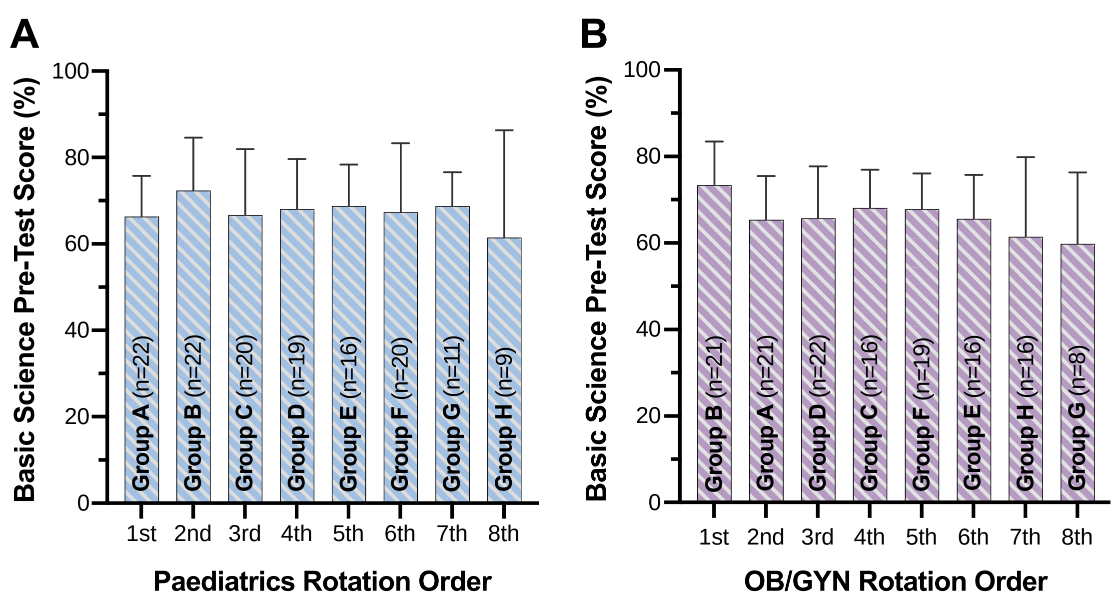


Figure 8: Third year medical students, on average, achieve >60% on each basic science pre-test assessment, indicating that they retained relevant basic science knowledge from pre-clerkship. Scatter plots demonstrate the range of individual student scores on the pre-test. No significant differences were identified among the clerkship rotation pre-test assessments (ANOVA, p>0.05). (*n=number of students who completed the assessment)*

When we interviewed clerkship directors, they indicated that they expected students in their final rotation to have a better working knowledge of the basic sciences compared to students who are entering their first rotation. However, when we examined the pre-test scores with a focus on students' rotation order, we found that there were no statistically significant differences among the eight groups (ANOVA; $p>0.05$) (**Figure 9).** For example, for students completing paediatrics as their first rotation (Group A), versus students completing paediatrics as their last rotation (Group H), there were no significant differences between the student groups (**Figure 9A**). This finding was evident for all six clerkship rotations (**Figure 9**).



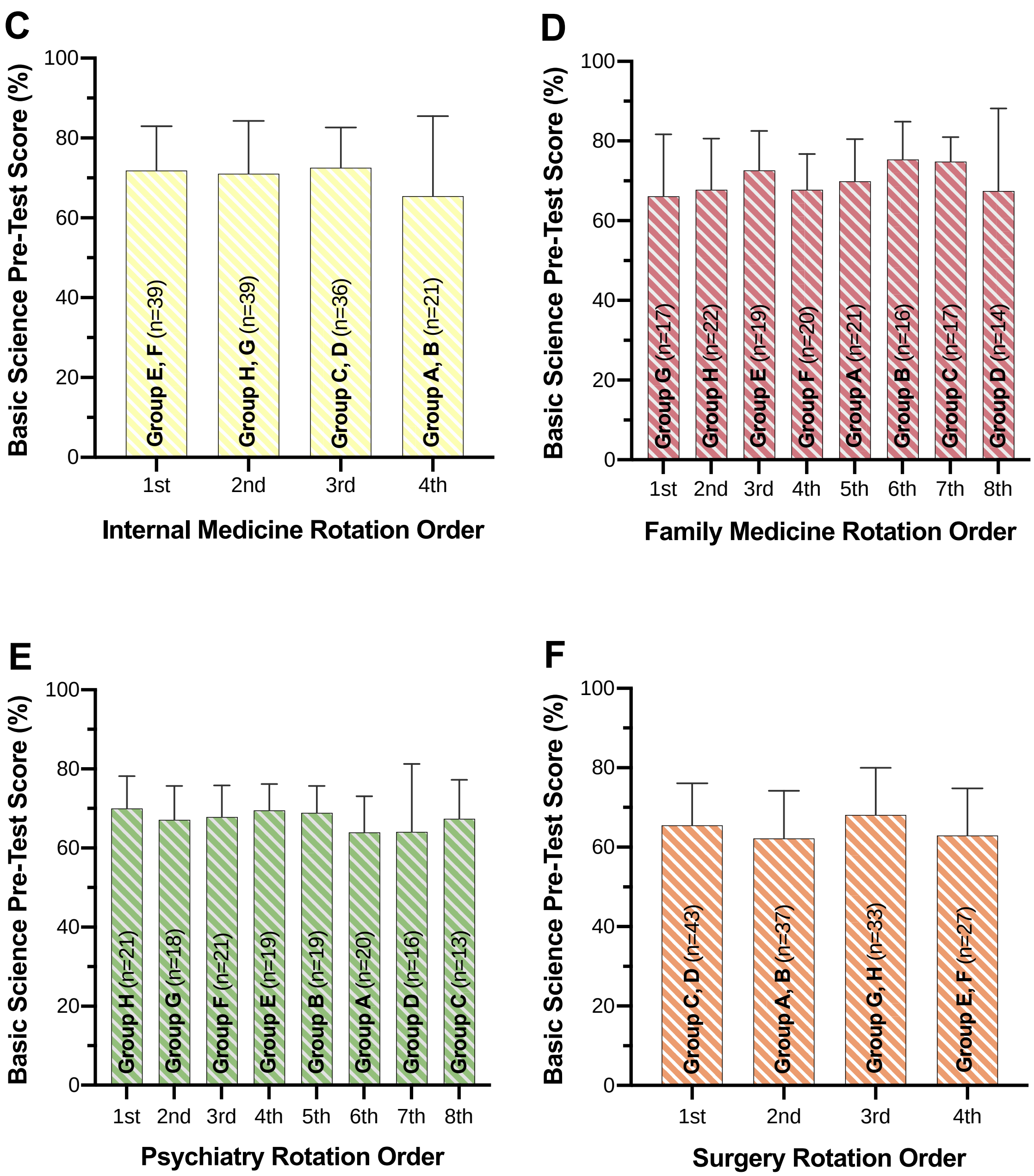


Figure 9: Medical students' basic science knowledge retention was not influenced by clerkship rotation order. Pre-test scores (± SD) plotted against students' clerkship rotation order, demonstrating no significant differences among the student groups (A-H) for each clerkship rotation (**A-F**), suggesting that students' pre-test performance was not influenced by their clerkship rotation order (ANOVA; $p>0.05$). (*n=number of students*)

Each assessment question (n=270) was categorized according to which basic science was assessed (anatomy, biochemistry, microbiology, pathology, pharmacology, physiology, nutrition, imaging), and the question scores were analyzed. Data revealed that the average score was at least 60% in each basic science discipline on the pre-test, with the highest mean scores achieved in biochemistry (85%) and the lowest mean scores achieved in anatomy (61%) (**Figure 10)**. It should be noted that only two assessment questions were mapped to the discipline of biochemistry. Regardless of the average score of each basic science discipline, data also revealed that there were some assessment questions in which, on average, students did not achieve ≥60%. There were no statistically significant differences among the average scores in the individual basic sciences disciplines (ANOVA; $p>0.05$).

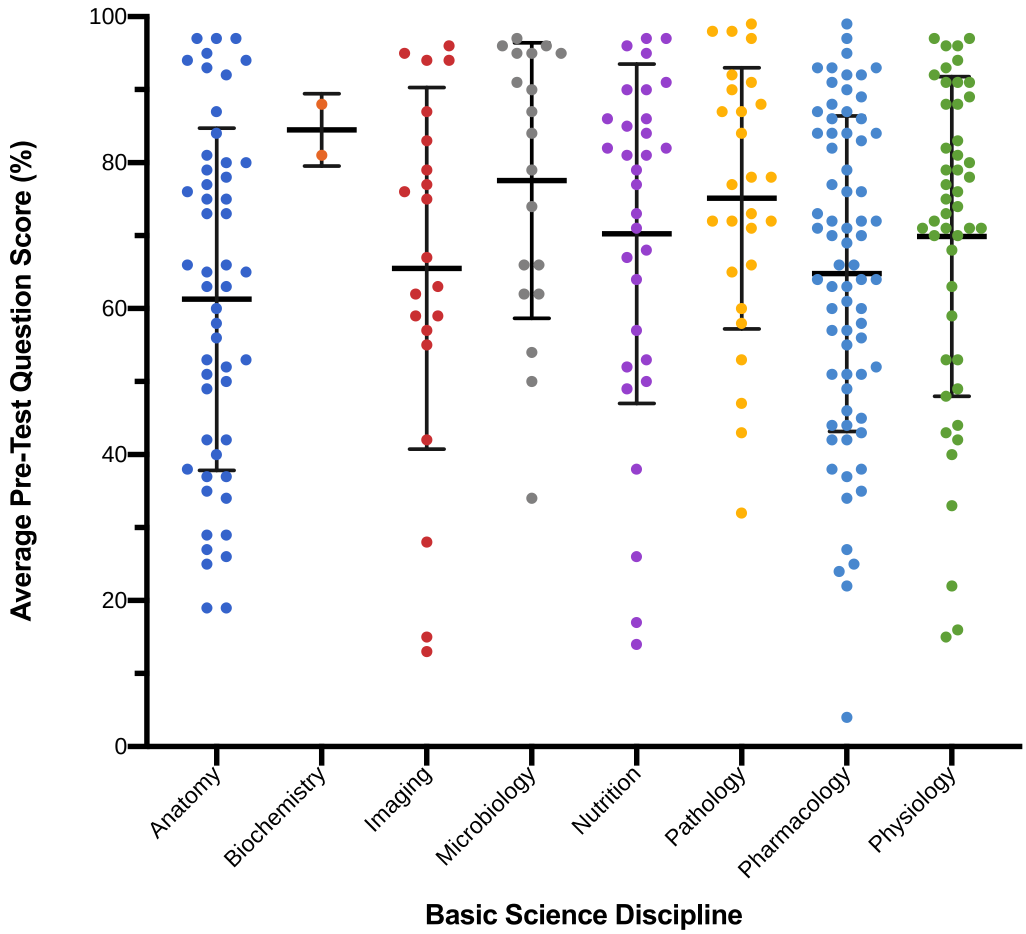


Figure 10: Medical students' basic science knowledge was not influenced by the basic science discipline being assessed. Average pre-test assessment question scores (± SD; n=270) plotted against the basic science discipline that was being assessed, revealing that students achieved, on average, >60% in each basic science discipline. No significant differences were identified in assessment question scores among the basic science disciplines (ANOVA; p>0.05).

3.3 Mapping

3.3.1 Mapping Assessed Basic Science Concepts to Curricular Content

The assessed basic science concepts were mapped to pre-clerkship curricular learning objectives, which were then linked to the pre-clerkship course(s) which covered the outlined learning objective. This revealed that clerkship directors expect students to retain knowledge from every systems-based pre-clerkship course, and therefore, each pre-clerkship term. With the high amount of variability in students' pre-test assessment scores (**Figures 8 and 10**), we wanted to determine if the pre-clerkship course(s) in which the concept was linked had any influence on students' pre-test performance. Thus, we evaluated students' average score on each assessment question (n=270) based on the course in which the concept was taught. It should be noted that if a concept was linked to more than one curricular learning objective, and consequently delivered in more than one pre-clerkship course, the assessment question is accounted for in both courses. On average, students achieved >60% on the assessed concepts within most pre-clerkship courses, with the exception of Blood (44%) and Skin (58%). Note that no statistically significant differences were found in students' scores among the pre-clerkship courses (ANOVA; p>0.05) (**Figure 11**).

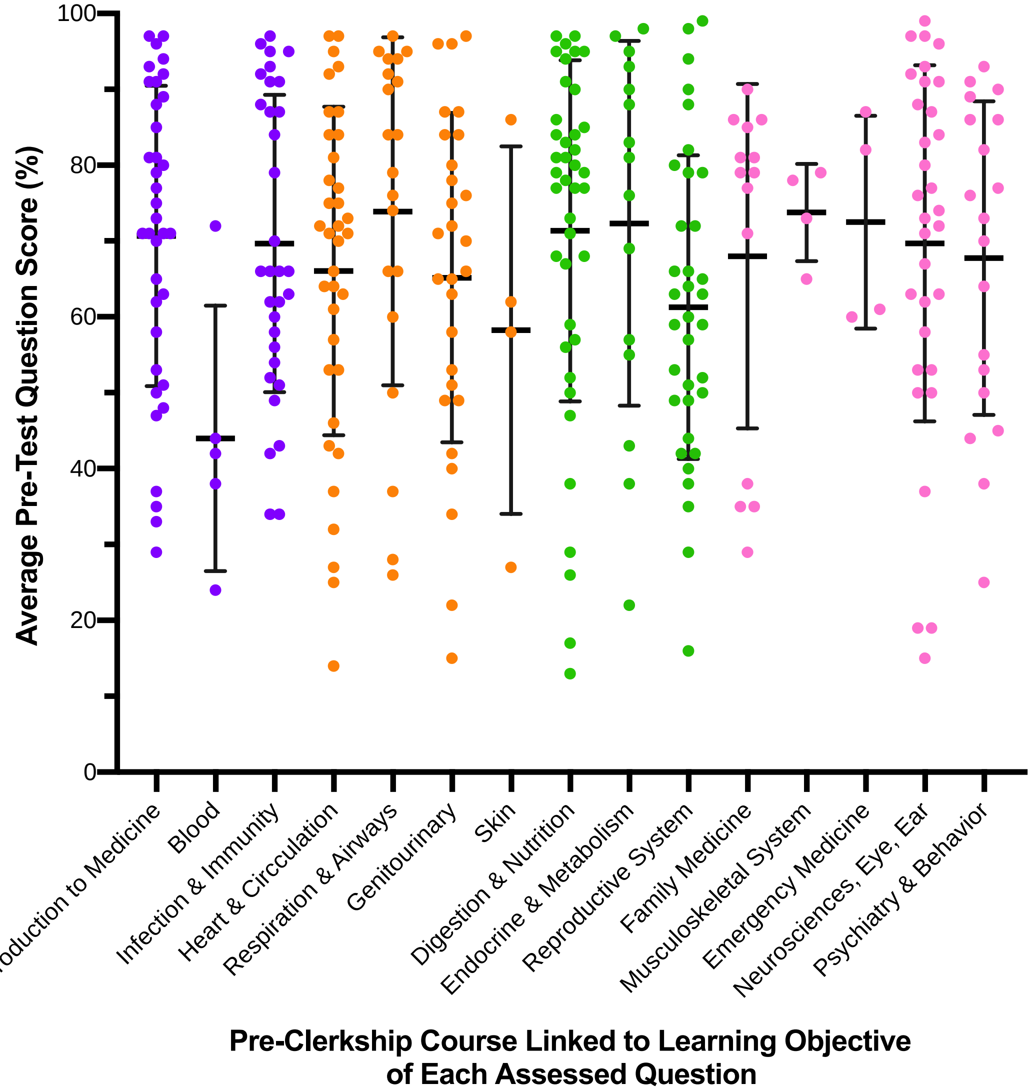


Figure 11: Medical students' basic science knowledge was not influenced by the pre-clerkship course in which the concept was delivered. Average pre-test assessment question scores (± SD; n=270) plotted against the pre-clerkship course in which the concepts were delivered, demonstrating that students achieved, on average, >60% in most pre-clerkship courses, with the exception of Blood (44%) and Skin (58%). No significant differences were identified in assessment question scores among the pre-clerkship courses (ANOVA; p>0.05).

Using the pre-test assessment data that was associated with the pre-clerkship course(s) (**Figure 11**), we can determine if the pre-clerkship term in which the assessed concepts were delivered had any influence on students' basic science knowledge retention. We expected students to have increased knowledge retention of concepts that were taught in Term 4, compared to concepts taught in Term 1. However, after mapping each assessed concept (n=270) to the pre-clerkship term in which it was delivered, analysis revealed that there were no differences in mean assessment question scores among the pre-clerkship terms (ANOVA; p>0.05) (Term 1=68.3%; Term 2=67.2%; Term 3=67.6%; Term 4=68.5%) (**Figure 12**).

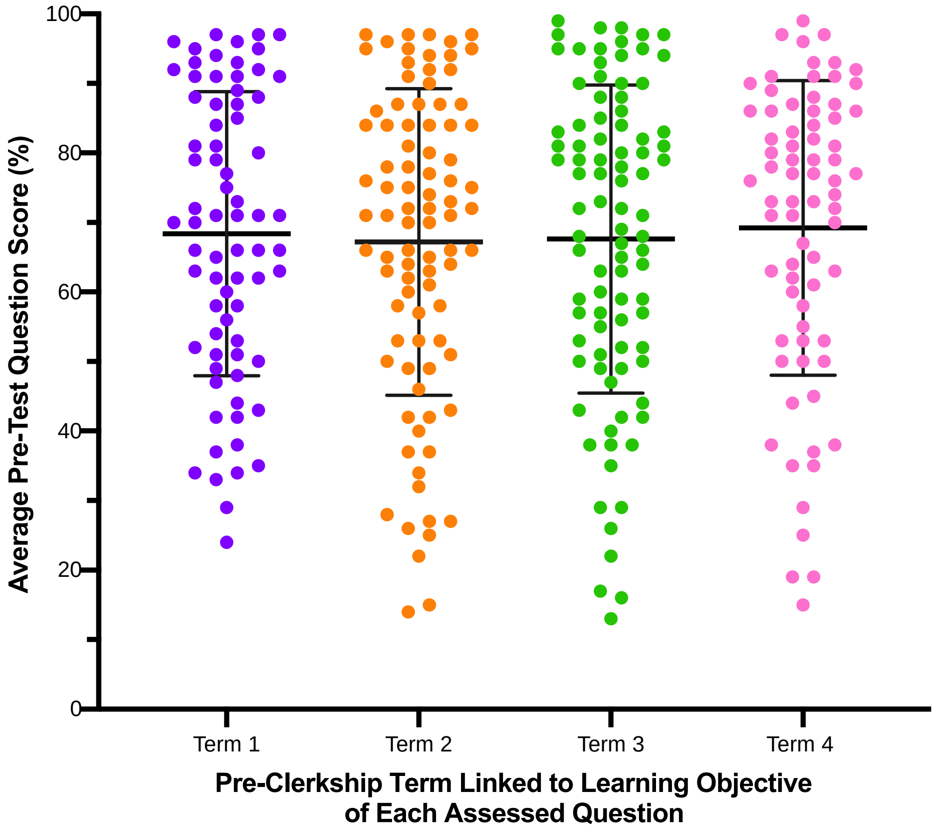
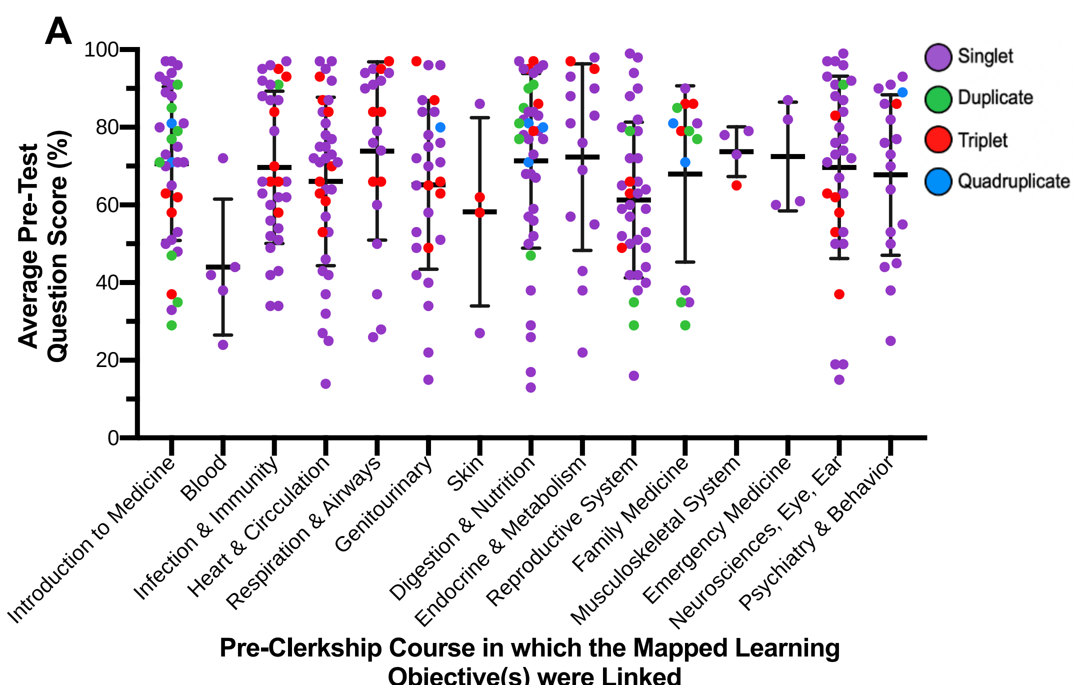


Figure 12: Medical students' basic science knowledge was not influenced by the pre-clerkship term in which the concepts were delivered. Average pre-test assessment question scores (± SD; n=270) plotted against the pre-clerkship term in which the concepts were delivered, demonstrating that students achieved, on average, >60% in each pre-clerkship term (Term 1=68.3%; Term 2=67.2%; Term 3=67.6%; Term 4=68.5%). No significant differences were identified in assessment question scores among the pre-clerkship terms (ANOVA; p>0.05).

The pre-test assessment scores were then analyzed based on the number of times they were mapped to a pre-clerkship learning objective to determine whether reinforcement had any influence on students' basic science knowledge (**Figure 13**). For example, if a concept is delivered more than one time in the curriculum, do more students retain that particular concept, and thus, improve their score? The average of each pre-test assessment question (n=270) was analyzed based on the number of pre-clerkship curricular learning objectives it was linked to indicating the degree at which the concept was reinforced throughout the curriculum. We found that the majority of concepts (n=162) were linked to one curricular learning objective, 57 assessed concepts were associated with two curricular learning objectives, 11 concepts were linked to three curricular learning objectives, and 4 concepts concept was linked to four curricular learning objectives (**Figure 13A**). Interestingly, there were 36 concepts that clerkship directors expect students to know that were not linked to any learning objective. No significant differences were identified among the average question scores regardless of the number of times a concept was linked to an objective during the pre-clerkship courses (ANOVA; $p>0.05$).



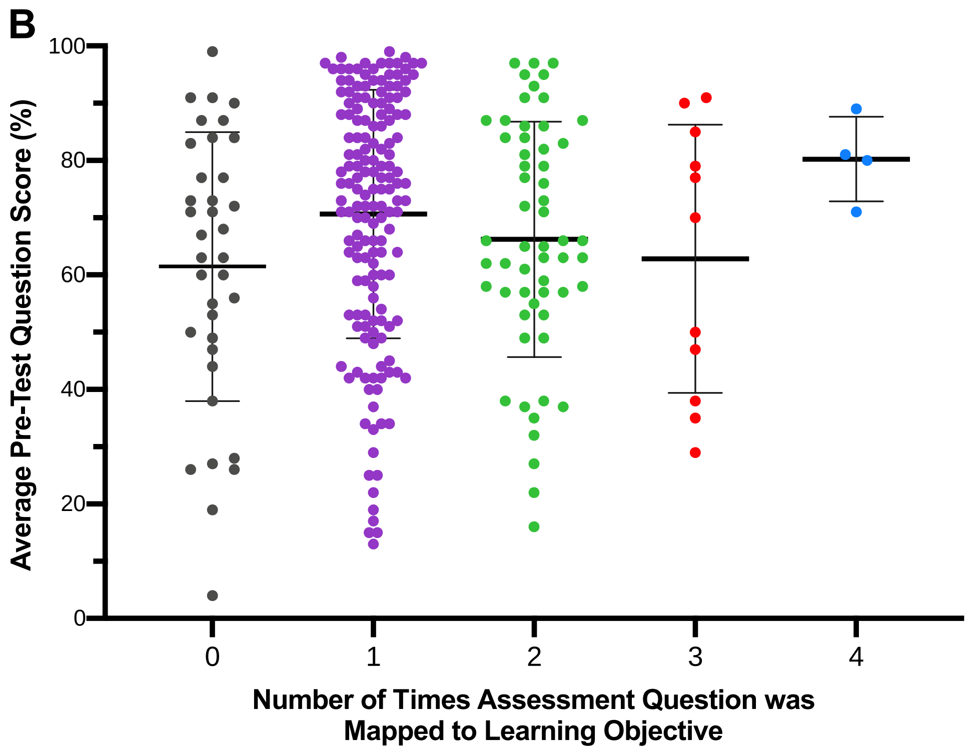


Figure 13: Average assessment question score categorized by the number of times a concept was linked to a curricular learning objective. (**A**) Average assessment question scores (± SD; n=270) plotted against the pre-clerkship course in which the concepts were delivered, demonstrating that majority of assessed concepts were linked to one learning objective throughout pre-clerkship, with some concepts linked to two, three and four learning objectives. (**B**) Average assessment question score (± SD; n=270) plotted against the number of times it was linked to a learning objective, demonstrating that students, on average, achieved >60% regardless of how many times the concept was delivered during pre-clerkship. No significant differences were identified among assessment question scores regardless of the number of times a concept was repeated during pre-clerkship (ANOVA; $p>0.05$).

The identified concepts that were mapped to curricular learning objectives were also linked to the instructional method(s) in which they were delivered, which revealed that the majority of assessed basic science concepts (68.5%) were linked to large group learning sessions (range=55.1% [surgery] – 79.4% [internal medicine]) (**Figure 14**). Sixteen percent of the mapped learning objectives are taught using small group learning methods such as laboratory sessions and small group discussions, (range=11.4% [family medicine] – 22.9% [OB/GYN]), with the remaining concepts (8.4%) delivered via independent learning modules (range=4.3% [psychiatry] – 14.5% [OB/GYN]). The remaining basic science concepts (7.1%) were not associated with a learning objective, and thus, may not be formally taught in the pre-clerkship curriculum.

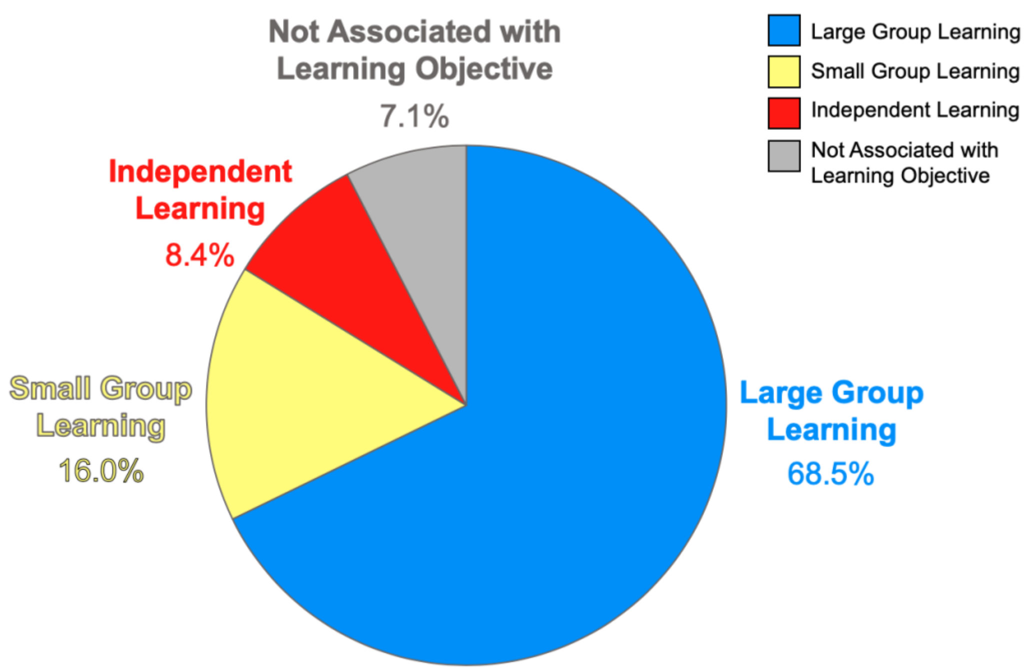


Figure 14: Instructional methods employed in the basic science pre-clerkship curriculum to deliver the assessed basic science concepts. The majority of identified concepts (68.5%) are currently taught via large group learning sessions, with small group learning (16%), and independent learning (8.4%) following. Some assessed concepts (7.1%) could not be associated with a formal curricular learning objective in the pre-clerkship curriculum.

When evaluating the average assessment question score according to how the concept was delivered: large group learning (LG), small group learning (SG), independent learning (IL), or a combination of instructional methods, we found that, on average, student scores were >60% regardless of how the concept was delivered (**Figure 15**). However, very few concepts were linked to small group learning (n=3) and independent learning (n=9), or a combination including those methods (LG+SG, n=22; LG+IL, n=15; LG+SG+IL, n=4).

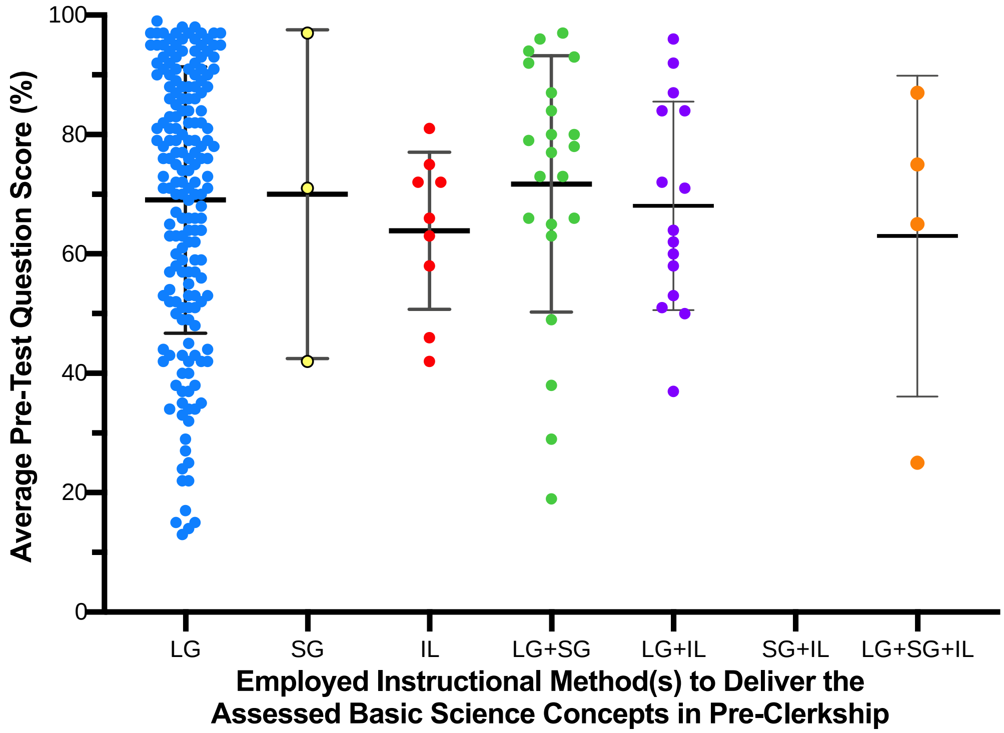


Figure 15: Medical students' basic science knowledge was not influenced by the instructional method(s) employed to deliver the basic science concepts during pre-clerkship. Average pre-test assessment question scores (± SD; n=270) plotted against the instructional method(s) used to deliver the identified basic science concept during pre-clerkship, demonstrating that students achieved, on average, >60% regardless of how the concept was delivered. No significant differences were identified in the assessment question scores among the employed instructional methods. (ANOVA; p>0.05) *Note: no concepts were linked to small group learning and independent learning combined. (Legend: LG, large group learning; SG, small group learning; IL, independent learning)*

3.3.2 Students' Perceptions of Basic Science Instruction

Students were surveyed at the end of their clerkship year to determine their perceptions of whether or not basic science concepts were covered during their pre-clerkship training (**Appendix D**). Survey results indicated that the majority of students (66%) felt that the assessed basic science concepts were taught during pre-clerkship (X_2 (1) = 4.78, $p<0.05$). Further analysis of the survey responses revealed that, overall, students felt the disciplines of imaging, pharmacology, microbiology, and nutrition were not adequately covered during pre-clerkship. It should be noted that only 27% of the class responded to this survey question.

3.4 Students' Basic Science Knowledge Reinforcement

Students' average post-test scores were significantly higher compared to their pre-test scores for all rotations ($p\leq0.05$) (**Figure 16**), indicating that they reinforced fundamental basic science knowledge during every rotation. Students achieved the highest average post-test score in the paediatrics rotations (78%), and conversely, had the lowest average post-test score in the surgery rotation (68%). The largest increase, from pre- to post-test score, occurred during the paediatrics rotation (10%), with the smallest increase taking place in internal medicine (2%).

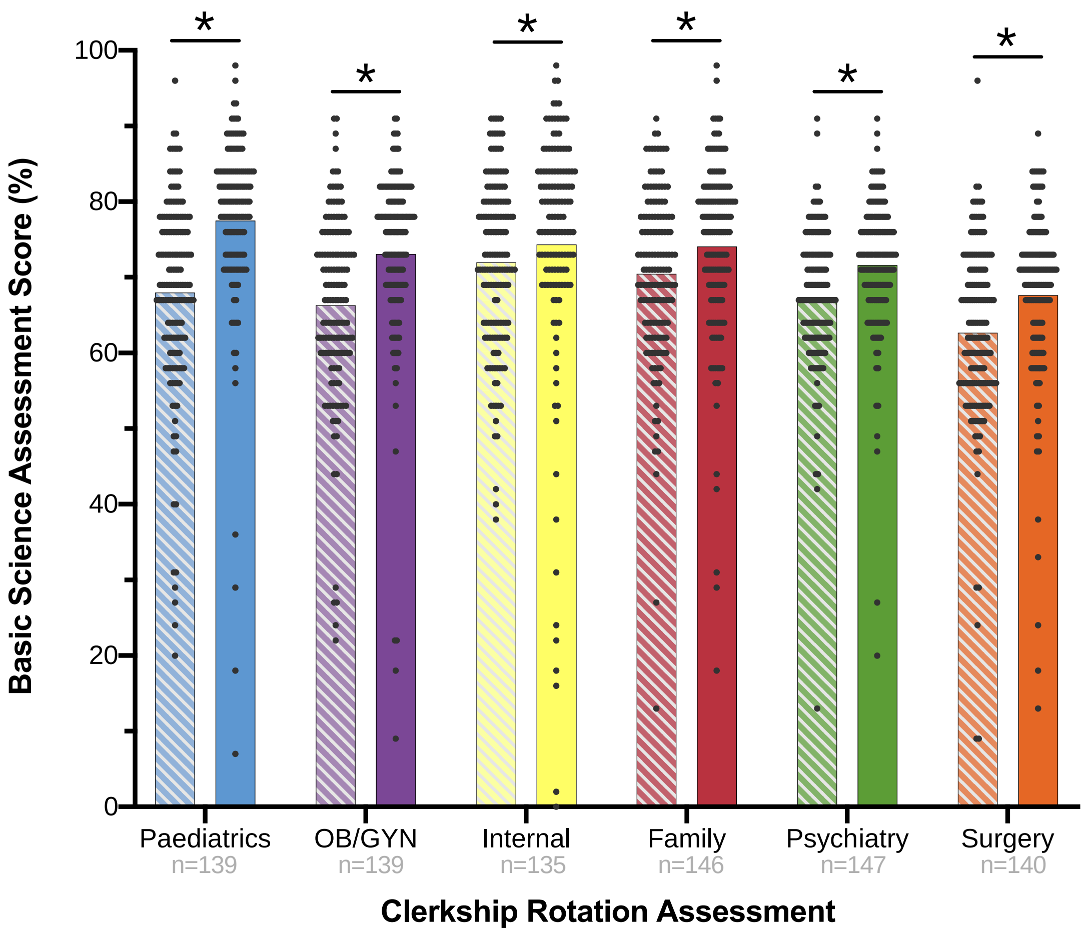
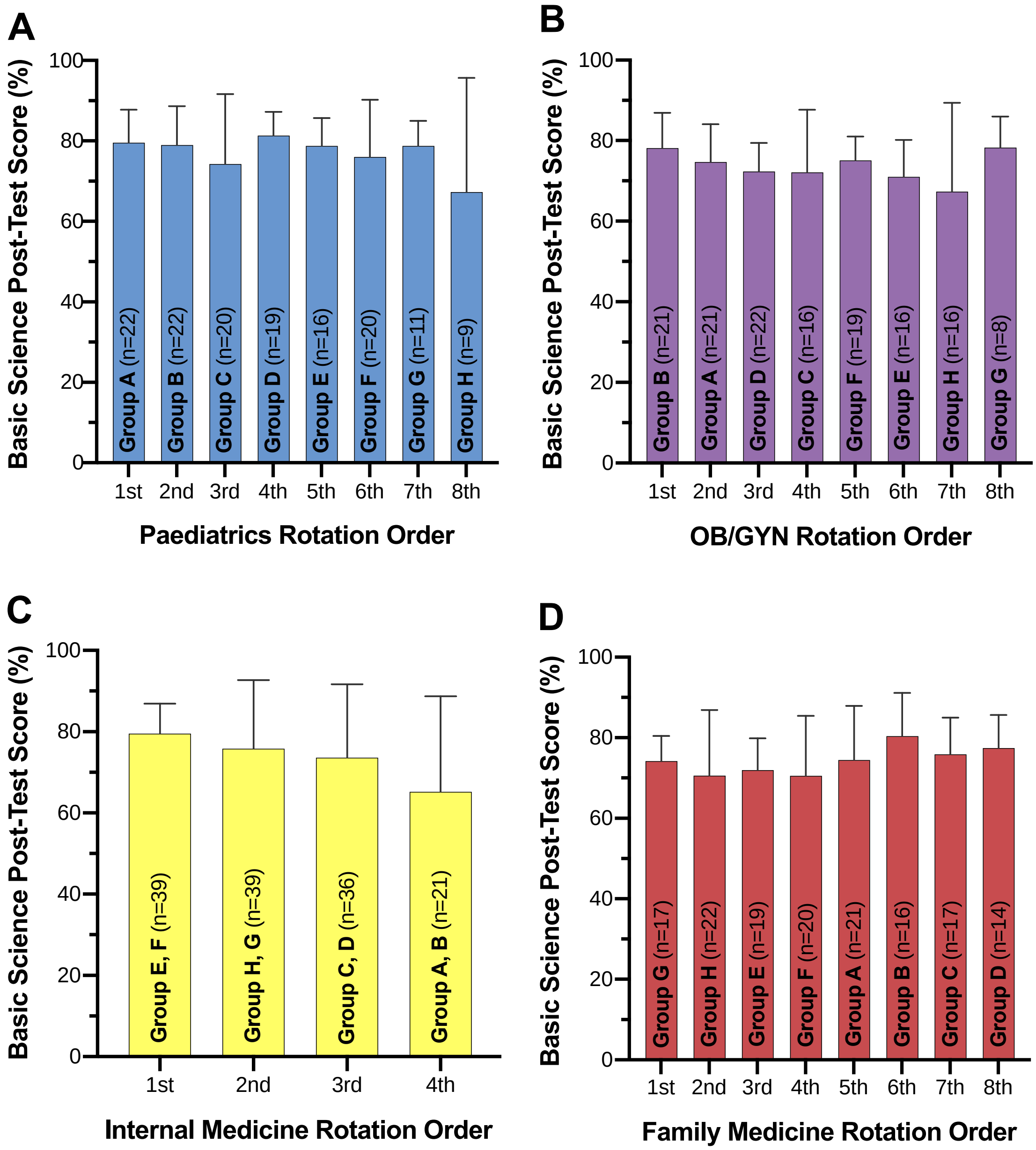


Figure 16: Third year medical students, on average, achieve >60% on each basic science pre-test, and their average scores significantly improve in every rotation on the post-test assessment. Third year medical students achieved, on average, >60% on the pre-test assessment in each rotation, (▧) indicating that they retained relevant basic science knowledge from pre-clerkship. On average, the post-test scores (■) were significantly higher in all six clerkship rotations indicating that students, on average, reinforced basic science knowledge during each rotation (Paired samples t-test; *p≤0.05). Scatter plots demonstrate the range of student scores on both the pre- and post-test assessment. (*n=number of students who completed the assessments*)

To determine if the clerkship groups were comparable to one another and if prior clerkship experiences reinforced students' basic science knowledge, students' post-test scores were analyzed according to clerkship rotation order. No differences were found among the clerkship groups with respect to their basic science knowledge (ANOVA; p>0.05) (**Figure 17**). This finding was evident for all six clerkship rotations.



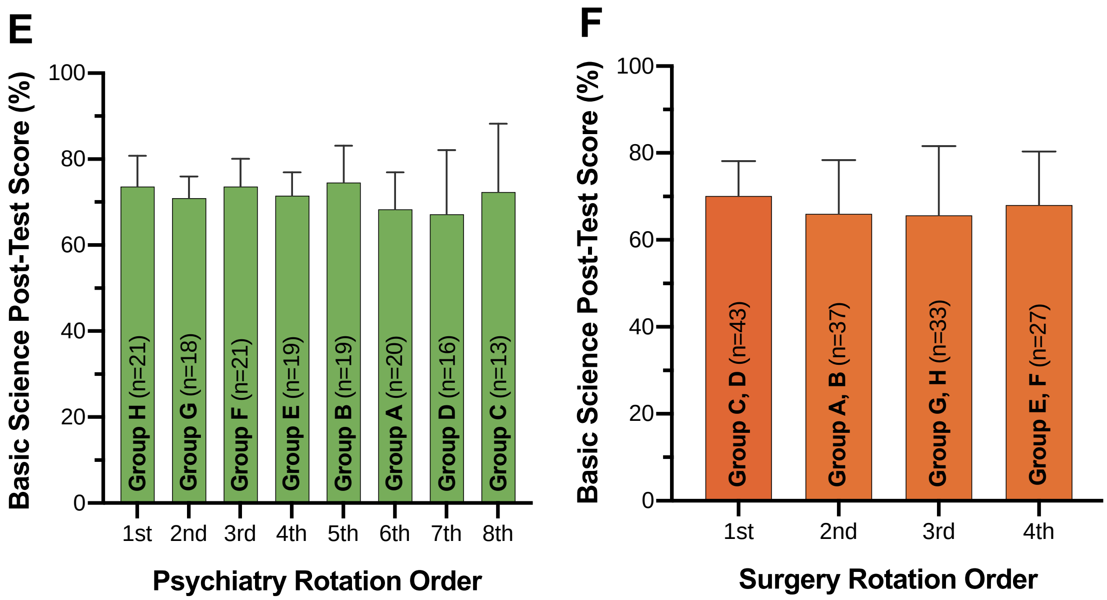
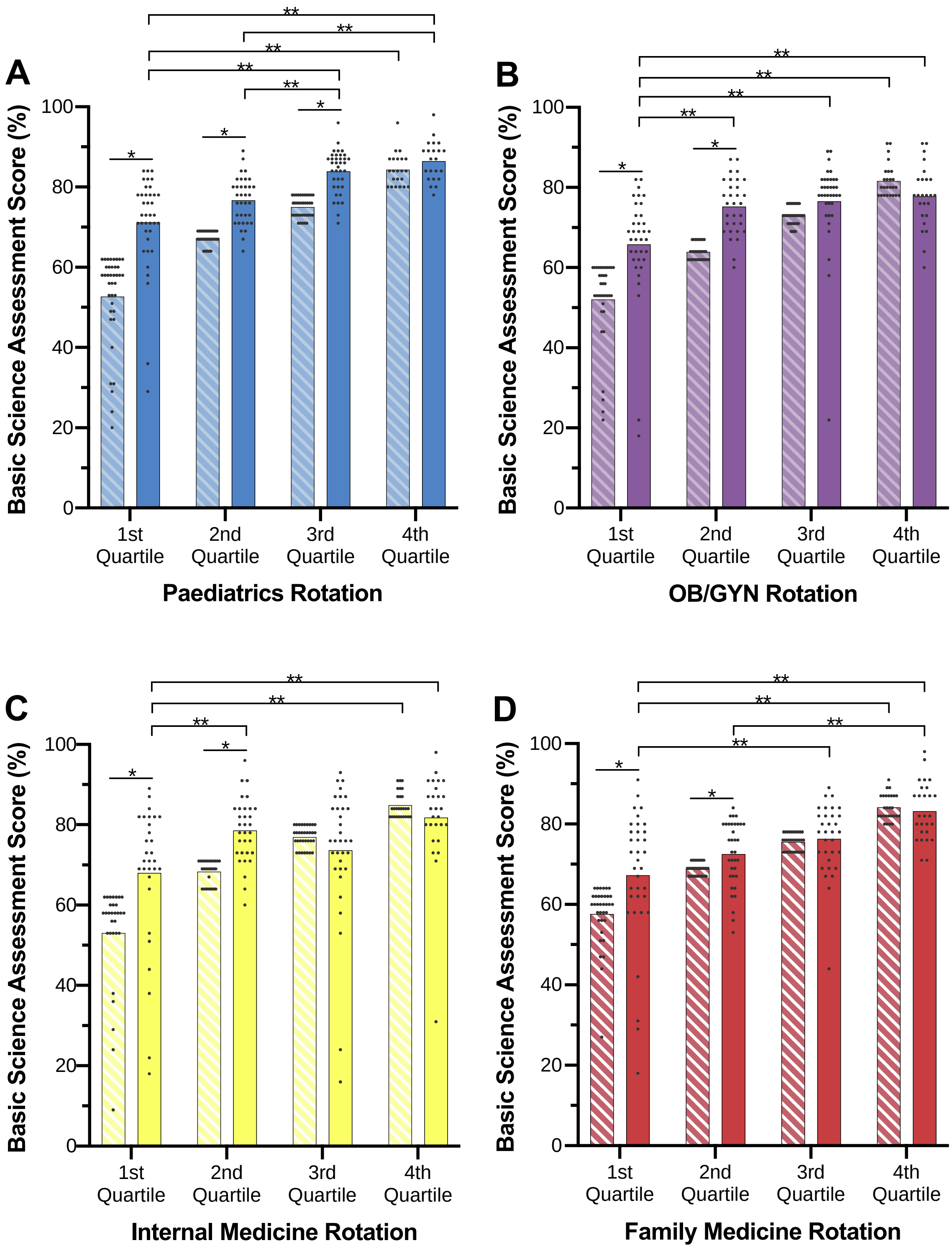


Figure 17: Medical students' basic science knowledge reinforcement, following each clerkship rotation, was not enhanced by previous clerkship experiences. Students' post-test scores (± SD) were plotted against students' clerkship rotation order. No significant differences among student groups were found (**A-F**). (ANOVA; p>0.05). (*n=number of students*)

Students' pre-test scores were divided into quartiles to determine if lower-performing (Quartile 1 & 2), higher-performing (Quartile 3 & 4), or all students were improving their basic science knowledge levels between pre-test and post-test assessments (**Figure 18**). The analysis revealed that lower-performing students' post-test scores were significantly higher ($p \leq 0.01$) compared to their pre-test scores for all clerkship rotations. Additionally, the post-test scores were also significantly higher for students whose pre-test scores were in the third quartile during the paediatrics (**Figure 18A**; $p<0.001$) and psychiatry (**Figure 18E**; $p=0.005$) rotation. For students in the fourth quartile, there were no differences between their pre- and post-test scores, except for psychiatry, where the post-test score was significantly lower than the pre-test score (**Figure 18E**; $p=0.001$).

While Quartile 1 students achieved significantly higher scores on the post-test compared to the pre-test, their post-test scores were significantly lower ($p_{bonf} \leq 0.01$) compared to students' pre-test scores in Quartile 4 in all six clerkship rotations (**Figure 18**). Additionally, Quartile 1 students' post-test scores remained significantly lower ($p_{bonf} \leq 0.05$) compared to students' post-test scores in Quartile 4, which was identifiable in five clerkship rotations, with the exception of psychiatry.


A
B
C
D
Basic Science Assessment Score (%)
100
80
60
40
20
0
*
**
1st Quartile
2nd Quartile
3rd Quartile
4th Quartile
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OB/GYN Rotation
Internal Medicine Rotation
Family Medicine Rotation

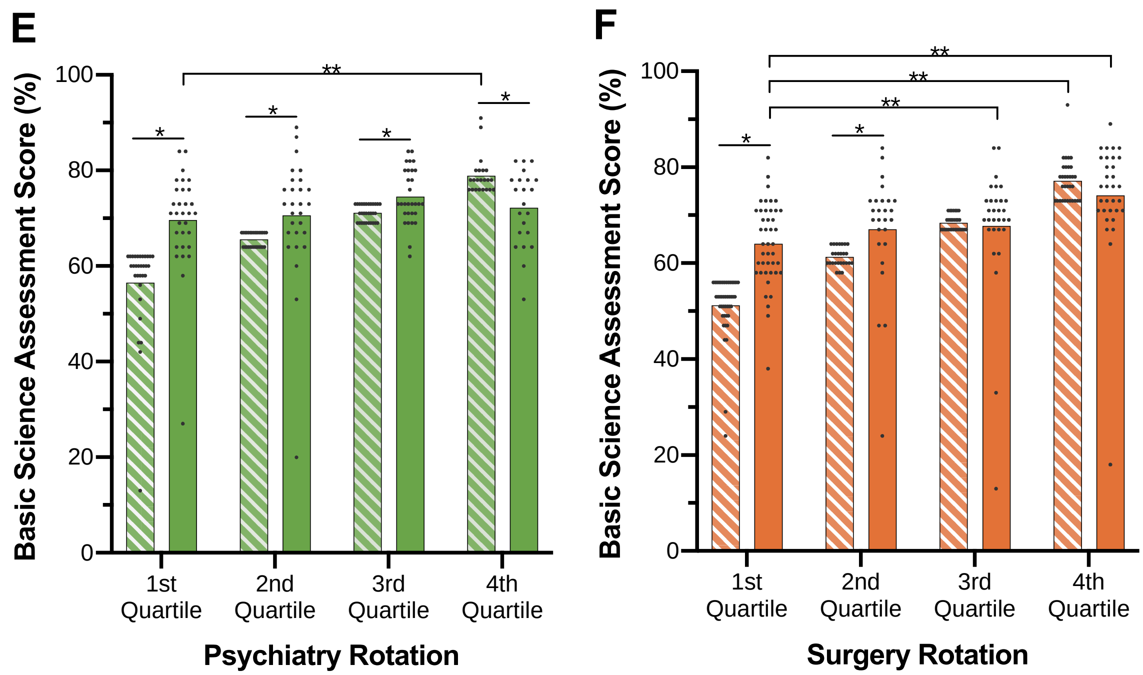

Figure 18: Lower-performing students improve their basic science knowledge during clerkship, however, they do not achieve the knowledge levels of higher-performing students. Students' pre-test scores (▧) were used to generate quartiles. Analysis revealed that lower-performing students (Quartile 1 and 2) achieved significantly higher scores on the post-test (■) assessment in all clerkship rotations (**A-F**), and Quartile 3 students achieved significantly higher scores on the post-test during paediatrics and psychiatry (t-test; $^*p \leq 0.01$). Additionally, higher-performing (upper quartiles) students' pre- and post-test scores were significantly higher compared to lower-performing (lower quartiles) students' post-test scores in five clerkship rotations, with the exception of psychiatry (ANOVA, Bonferroni Post Hoc Test; $^{**}p_{bonf} \leq 0.01$), suggesting that lower performing students do not achieve the knowledge levels of higher-performing students. *Note: each data point represents an individual students' score on the basic science assessments.*

Chapter 4

4 DISCUSSION

With basic science education being a cornerstone of UME, it is necessary for students to acquire a strong basic science foundation if they wish to achieve overall competence (Flexner 1910; Miles 2005; Woods et al. 2005; Norman 2007; Finnerty et al. 2010; McColl et al. 2012; Prober and Khan 2013). While UME programs share a common goal of graduating students who are well-equipped with the fundamental knowledge and skills that are required for clinical success, there is a large amount of variability across UME curricula with respect to learners and educators, along with the basic science knowledge that medical students are expected to be proficient in (van Zanten et al. 2008). Furthermore, with a finite amount of time in UME curricula, one may argue whether or not all trainees are learning and retaining the high-yield fundamentals prior to entering a clinical setting. Thus, with a large amount of program variation, and a lack of assurance that all graduates display competence and proficiency in the necessary fundamentals, many educators are in support of re-designing curricular components to ensure all trainees attain the knowledge that is required to manage today's health care demands (Weinberger et al. 2010; Dwyer et al. 2015). However, when approaching curriculum reform, the specific basic science concepts that students must retain from pre-clerkship, students' knowledge retention of those identified concepts, and the influence of clinical experiences on students' basic science knowledge were unknown.

This thesis has provided the first methodology for critically evaluating the efficacy of basic science education at the pre-clerkship level using an evidence-based approach. To our knowledge, no other studies have used clerkship directors' perceptions to assess whether pre-clerkship curricula are equipping students with the basic science knowledge that is necessary for their success in clerkship. Through this investigation we found that clerkship directors expect students to have some knowledge of every basic science prior to entering the clinical setting of clerkship. Further to this, clerkship directors and trainees perceive there to be more areas in need of improvement, compared to areas of strength, with respect to students' basic science knowledge levels. While the majority of basic science knowledge retention research utilizes already instated course assessments, the present study was the first of its kind to evaluate students' basic science knowledge levels according to the concepts that clerkship directors deem necessary for them to know prior to entering each clerkship rotation. We revealed that students, on average, retain necessary basic science knowledge from their pre-clerkship training. There is a plethora of literature analyzing the influence of curricular design and content delivery on students' knowledge levels. Through this investigation we revealed that where, when, how, or if the concept was delivered during pre-clerkship did not influence students' basic science knowledge, nor did clerkship group or rotation order. Additionally, there is limited research focusing on students' reinforcement of basic science knowledge during clerkship year, yet our findings indicate that students, on average, further learn, or reinforce, fundamental basic science knowledge during their clerkship training. Interestingly, the clinical experience of clerkship was found to be most beneficial for lower-performing students with respect to enhancing their basic science knowledge, which is consistent with some literature, however, they still left clerkship year with some deficits in their basic science knowledge when compared to their higher-performing peers. Through this research methodology, we created an original curriculum evaluation tool to critically analyze the efficacy of basic science education, and this tool provides the means to consistently monitor the influence of curricular revisions on the effectiveness of basic science education in pre-clerkship curricula.

4.1 Perceptions

4.1.1 Perceptions of Medical Students' Basic Science Knowledge

One way to help increase continuity in trainees' medical education, and ease the transition to their clinical training, is by fostering communication between pre-clerkship and clerkship educators to determine which basic science concepts students are expected to be proficient in prior to entering a clinical setting, and incorporating the basic science concepts that clerkship directors deem "necessary for students to know" into the pre-clerkship curriculum. Thus, we set out to determine which basic science concepts clerkship directors expect medical students to know after completing pre-clerkship. Through our interviews we found that they expect students to have some knowledge of every basic science prior to entering clerkship year, with pharmacology being the most prevalent, and biochemistry the least prevalent.

Pharmacology is a fundamental aspect of medical education (Kwan 2004; Wiernik 2015), and as such was identified by all clerkship directors as a key basic science, as students must know common drugs and classes of drugs for every specialty. Based on our interview results, it was the most prevalent basic science identified in family medicine, surgery, internal medicine, and psychiatry, as these specialties heavily rely on pharmacological interventions. In addition to identifying the importance of this discipline, four rotation directors (internal medicine, emergency medicine, OB/GYN, and anesthesia) identified pharmacology as a basic science where students could improve their knowledge level. Aligned with these perceptions are students' self-perceptions of their knowledge in this basic science, as 52% indicated that they felt their basic science knowledge was lacking in pharmacology, a finding that has also been documented in recent literature (Surmon et al. 2016). One student commented that the "*in depth details of [pharmacology] were rarely discussed*". However, medical students are not the only cohort struggling with pharmacology, as other studies indicate that junior doctors also lack confidence and proficiency in their ability to safely prescribe medications (Ross and Loke 2009; Harding et al. 2010). The field of pharmacology is consistently changing to keep up with the evolution of healthcare, and thus aspects such as dispensing and dosing are consistently evolving (Shah et al. 2016). As a result, it may be challenging for students to keep up with the dynamic field of pharmacology, which may contribute to clerkship directors' and students' perceptions of knowledge in this discipline. Furthermore, with pharmacology essentially being a hybrid of physiology and biochemistry, students must integrate their knowledge of these two basic science disciplines in order to comprehend pharmacological concepts (Rangachari 1997; Woodman et al. 2004; Aronson 2010), and this complexity of pharmacology may lead to clerkship directors and students both perceiving a lack of knowledge in this basic science discipline (Ross and Loke 2009). Interestingly, biochemistry was only deemed necessary for students to know by OB/GYN directors in regard to reproductive hormones, which on the surface suggests that most rotation directors do not consider this basic science necessary for students to know prior to entering clerkship. From the learner's perspective, only 28% of students felt as though they retained their biochemistry knowledge from pre-clerkship. As mentioned above, biochemistry underpins pharmacology (Aronson 2010), and based on the importance of pharmacology, this suggests that it is necessary for students to have some working knowledge of biochemistry for all rotations. For clerkship directors, practicing physicians, and experts in the field, this biochemical knowledge may now be second nature as they are relying on it daily when prescribing and adjusting pharmacological treatment plans (de Vries 2003; Vollebregt et al. 2006); but medical students, on the other hand, still need to develop their foundations in this discipline. Thus, with both pharmacology and biochemistry being fundamental for students to learn during pre-clerkship, the way in which they are integrated into pre-clerkship may need to be revised to highlight the clinical relevance of these two basic sciences (Dennick 1996; Woodman et al. 2004; Hadimani 2014) to promote students' proficiency in these interconnected disciplines.

In the current study, anatomy and physiology were also deemed fundamental for students to know by all rotation directors, which is still in agreement with what Flexner (1910) proposed over a century ago stating that anatomy and physiology are the pillars of a strong basic science foundation. This notion continues to be echoed by other educators who also suggest that UME curricula must ensure that medical students are receiving a robust education in these two basic sciences (Harris et al. 2004; Ghosh 2007; Drake et al. 2009; Finnerty et al. 2010). The family medicine and internal medicine clerkship directors identified 'general' anatomy as current student strength, while physiology was also deemed a student strength by the internal medicine rotation directors. In contrast, clerkship directors for the remaining rotations (paediatrics, OB/GYN, psychiatry, surgery) indicated that students' knowledge of anatomy and physiology required improvement, noting that these four rotations require students to know more complex and detailed concepts related to each basic science discipline. Aligned with the family medicine and internal medicine rotation directors' perceptions are students' self-perception revealing that 73% felt that they retained their knowledge in physiology. However, only 45% of students indicated that they retained their anatomy knowledge from pre-clerkship, which is echoed by literature revealing that students have self-reported knowledge deficiencies in this basic science discipline prior to entering clerkship (Surmon et al. 2016). While there are multiple factors that could influence students' knowledge retention of these two basic science disciplines (Costa et al. 2007; Wai et al. 2010), anecdotally, many medical students have completed a previous degree in the discipline of physiology or have taken physiology courses to fulfil other degree requirements. Additionally, the majority of students have completed the Medical College Admission Test (MCAT), which encompasses physiological sciences questions (Callahan et al. 2010). Therefore, exposure at the bachelor's degree level may be providing students with a 'general' foundation in physiology when entering pre-clerkship. Furthermore, with anatomy and physiology being complementary basic sciences, structure and function are often taught in tandem with one another at the UME level, and this integration during pre-clerkship may symbiotically promote knowledge retention of each subjects' general concepts (Norman 2007). However, even when anatomy and physiology are taught simultaneously with one another, our findings indicate that students are not proficient in the anatomy and physiology concepts clerkship directors expect students to know when entering the remaining rotations (paediatrics, OB/GYN, psychiatry, and surgery). This may suggest that the UME is not covering the amount of detail that is necessary for students to know when entering paediatrics, OB/GYN, psychiatry, or surgery, which could be due to curricular time constraints. Alternatively, the remaining clerkship directors' (paediatrics, OB/GYN, psychiatry, surgery) expectations could have been very specific to their specialty as both anatomy and physiology are necessary for understanding many clinical approaches in these four rotations. Present-day UME curricula are designed to ensure that graduates have a general understanding of all basic science disciplines (Leinster 2014) upon which they can build their knowledge and skills in their post-graduate specialty of choice, and thus, limit the amount of time focused on specialty-specific concepts.

Overall, our data revealed that students' educational experiences prior to entering clerkship are providing them with the general anatomical and physiological knowledge necessary for success during family medicine and internal medicine rotations. However, the majority of students' feel as though their knowledge of the anatomical sciences could be improved, which could be a true representation of their knowledge levels or may suggest some misalignment between what clerkship directors expect students to know and what is actually taught in the curriculum. Regardless, based on the necessity of a strong foundation in these two basic science disciplines for the successful practice of medicine (Flexner 1910), we must ensure that students are learning and retaining the necessary concepts that are fundamental for every clerkship rotation. As demonstrated thus far, there is some discrepancy with respect to stakeholders' (clerkship directors and pre-clerkship students) perceptions of students' basic science knowledge in the disciplines of anatomy and physiology. Moving forward, it would be beneficial to determine whether or not clerkship directors and students' expectations of these two basic sciences are realistic for the pre-clerkship level. Therefore, by implementing the curriculum evaluation model described in this thesis at other academic institutions, we can examine clerkship directors' and preceptors' perceptions of basic science education at a national level, thereby highlighting any potential inconsistencies and ultimately fostering improvements in the basic sciences across UME curricula.

Pathology was deemed necessary by all rotation directors, which aligns with literature indicating that it is a vital component in the study of medicine (Mattick et al. 2004; Maley et al. 2008; Wood et al. 2010). Clerkship directors did not identify pathology as a student strength nor an area requiring improvement, which may suggest that they perceive students to have a sufficient level of pathology knowledge when entering each clerkship rotation. However, contrary to this, only 33% of students felt that they retained important pathology concepts from their pre-clerkship training. With many present-day UME programs integrating the clinical and basic sciences into pre-clerkship curricula, the underlying pathologies and clinical conditions are often taught in conjunction with the 'normal' structure and function. However, the discrepancy between clerkship directors' and students' perceptions of pathology knowledge may highlight a potential disconnect in trainee's education at the UME level, and suggest that there should be further integration of fundamental pathology concepts throughout pre-clerkship. This symbiotic integration of normal and pathological structure and function may foster students' knowledge retention of fundamental pathology concepts.

Microbiology was deemed necessary for students to know in five of the six core clerkship rotations, with the exception of psychiatry. Knowledge in this discipline is essential for navigating the increasing prevalence of infections that occur in a clinical setting (Melber et al. 2016), and it is suggested that microbiology knowledge provides the basis for understanding topics of infection control and prevention (Rediske 2016). Microbiology was further identified as an area where students could improve by family medicine, internal medicine, OB/GYN, and paediatrics clerkship directors. In support of these perceptions, the majority of students (71%) also felt that their microbiology knowledge was lacking after completing pre-clerkship with student comments indicating that they [the students] are "*uncomfortable with this topic*" and "*believe that microbiology teaching can be improved during pre-clerkship*". The literature indicates that there is limited time dedicated to the study of microbiology in UME (Mann and Wood 2006), which was evident in Schulich's traditional curriculum as the majority of microbiological concepts were delivered during the Infection & Immunity course during the first term of study (**Section 1.4; Table 1**), and furthermore, lacked reinforcement throughout the remainder of pre-clerkship. The limited curricular time dedicated to teaching the complexities of this basic science discipline, in conjunction with a siloed course centered approach, may lead to a lack of microbiology knowledge in current students (Mann and Wood 2006; Sancho et al. 2006; Bauler et al. 2016; Melber et al. 2016), and consequently translate to decreased diagnostic accuracy of infections (Chamberlain et al. 2012). With the study of microbiology being essential in UME (Melber et al. 2016), the results of our study and supporting literature suggest that the integration of microbiology content into the curriculum should be revised, and perhaps the clinical relevance of microbiology should be woven throughout pre-clerkship in conjunction with other relevant basic science disciplines to ensure that all trainees are confident in treating and managing the infections that are on the rise in a clinical setting (Ramos et al. 2017).

Nutrition was deemed fundamental for students to know for each rotation, as it can play an integral role in disease prevention and treatment (Adams et al 2010a; Devries et al. 2014). Based on the fact that knowledge in this discipline and nutritional guidance can drastically influence the course or outcome of a patients' disease (Adams et al. 2010b), following the interviews with the clerkship directors, it was clear that they also support that students should receive a comprehensive education in nutrition across all specialties and body systems. Despite the importance of knowledge in the nutritional sciences, all clerkship directors perceived students as being uncomfortable with the discipline and 62%

of students felt they did not retain their nutrition knowledge from pre-clerkship. Further to this, a student commented that "*classes did not go into depth with respect to nutrition"* during pre-clerkship. The literature indicates that nutrition education is inadequate in many UME curricula (Adams et al. 2010a; Gramlich et al. 2010), and as a result, many practicing physicians are not confident in providing nutritional counselling to patients once they enter a clinical setting (Adams et al. 2010b; Mogre et al. 2018). Since nutrition can positively influence the course and outcome of diseases throughout all body systems, we need to ensure that all trainees are proficient in this discipline (Adams et al. 2010b). In the traditional UME curriculum at Schulich, the nutritional sciences were primarily taught in the second-year course, Digestion & Nutrition. Thus, moving forward, by weaving the nutritional sciences throughout all systems-based courses during pre-clerkship, we can help foster trainees' confidence in providing basic nutritional counselling for all of their patients (Ball et al. 2014; Mogre et al. 2018).

Imaging was deemed essential by the clerkship directors of surgery, family medicine, OB/GYN, and psychiatry. While students are not required to understand the intricacies and complexities of all imaging modalities prior to clerkship, clerkship directors noted that it is essential that they know general x-ray practices, along with general benefits and drawbacks of various imaging modalities. Just like pathology, imaging was not deemed a strength nor an area in need of improvement by clerkship directors. Students' self-perceptions of their knowledge in this discipline were similar as 46% felt they retained knowledge and 52% felt their imaging knowledge was lacking (2% did not provide an answer). The use of all imaging techniques in a clinical setting is on the rise due to improved technology and an increased demand from today's patient population, and when used appropriately, imaging can lead to earlier diagnoses for certain clinical conditions (Smith-Bindman 2008; Hricak et al. 2011). However, errors in diagnosis, or misdiagnosis, can result in serious or fatal medical mistakes (Weingart et al. 2000; Wright and Reeves 2017). Therefore, it is imperative that pre-clerkship trainees are learning and retaining the necessary fundamentals of medical imaging modalities, such as identifying the imaging modality of best fit for a patient or approaching a chest x-ray, so that they can further learn how imaging can be effectively utilized as a supplemental tool in each clerkship rotation.

4.1.2 Curriculum Evaluation: Through the Lens of Clerkship Directors' Perceptions

When the basic science concepts that were deemed necessary for students to know by clerkship directors were mapped to curricular learning objectives, we were able to determine where and when the concepts were delivered during the pre-clerkship curriculum. The process revealed that the identified concepts were linked to every systems-based pre-clerkship course (**Section 3.3; Figure 11**). This finding suggests that clerkship directors expect students to attain knowledge from each pre-clerkship course, prior to entering the clinical setting of clerkship. Thus, with every pre-clerkship course being relevant to students' basic science education, high-yield concepts should continue to be delivered in each course to ensure that students are learning and retaining the necessary fundamentals and are prepared for entering the clinical setting of clerkship in their third year of training.

Out of the 270 assessment questions that were included in this study, we found that the majority of concepts assessed were only linked to one learning objective in the pre-clerkship curriculum (n=162) (**Section 3.3; Figure 13**). This is in line with other UME curricula as there is little opportunity for repetition due to the high volume of material and limited amount of curricular time devoted to basic science education (Friedlander et al. 2011). There were some concepts that were linked to more than one objective (two, n=57; three, n=11; four, n=4) indicating some repetition exists within the pre-clerkship curriculum. Revisiting previously presented material has been criticized by students in programs such as social work who indicated that content repetition is not beneficial to their learning and overall outcomes (Dalton 2004). Contrary to this, content repetition has been shown to be favored by medical students (Muller et al. 2008), and with many

UME curricula placing a greater emphasis on content integration, repetition of concepts is on the rise (Barrow et al. 2010). Interestingly, there were 36 concepts (12.6%) that were deemed necessary by the clerkship directors that were not associated with a formal pre-clerkship learning objective. This finding may indicate that these unlinked basic science concepts are not delivered during pre-clerkship. However, the majority of students (66%) who responded to the survey at the end of clerkship felt that the assessed basic science concepts were delivered during pre-clerkship, which may indicate that these basic science concepts are in fact taught, but the content may not be formalized as a curriculum learning objective. Therefore, the alignment of the stated curricular learning objectives versus what was actually delivered during pre-clerkship could influence whether or not the objective was mapped. These unlinked learning objectives highlight a potential disconnect between pre-clerkship and clerkship educators with respect to the concepts they deem necessary for students to be proficient in prior to clerkship, which provides the impetus for UME educators and curriculum committees to evaluate curriculum learning objectives to ensure that they are aligned with what is being taught or revised to include what should be taught during pre-clerkship. If a collaborative relationship between pre-clerkship and clerkship educators can be established, we can hopefully foster synchrony between the basic science concepts that clerkship directors expect students to be proficient in and the pre-clerkship concepts being delivered.

When linking the identified basic science concepts to how the concepts were delivered, our data revealed a high volume of large group learning sessions employed in the basic science pre-clerkship curriculum, relative to small group learning and independent learning modules (**Section 3.3; Figure 14**). Large group learning, such as didactic lectures, has long been the gold standard for delivering basic science content to students in not only medical education, but many other undergraduate and professional programs (Singh and Kharb 2013; Freeman et al. 2014). The prevalence of large group learning is seen across many UME curricula where this method takes precedence as the primary instructional method during pre-clerkship (Drake 1998; Freeman et al. 2014), and the findings from our study support this longstanding trend. We also found that there were some concepts that were delivered using a combination of instructional methods, such as large group + small group learning, large group + independent learning, often referred to as blended learning, or a combination of all three methods (large group + small group + independent learning). This finding is consistent with other higher education programs where combination instructional methods, specifically blended learning, are employed to deliver relevant content to students (López-Pérez et al. 2011). Overall, the employed instructional methods at Schulich UME are consistent with the design of other curricula, but with small group learning and independent learning on the rise in medical education, Schulich UME will be following suit and employing more of these learning sessions as they transition towards their new curriculum. Moving forward, using the curricular evaluation tool we developed for this study, we can elucidate how future curricular revisions may impact stakeholders' perceptions of the effectiveness of basic science education.

4.1.3 Summary of Perceptions

Overall, clerkship directors' expected students to have some working knowledge of every basic science discipline prior to entering the clinical setting of clerkship. Furthermore, clerkship directors identified more areas in need of improvement, compared to strengths, with respect to students' basic science knowledge. While educational experiences prior to or during pre-clerkship are providing students with a strong foundation in anatomy and physiology for internal medicine and family medicine rotations, clerkship directors feel students' knowledge could be improved in these two basic science disciplines prior to entering the other rotations (paediatrics, OB/GYN, psychiatry, surgery). Trainees' perceptions were aligned with clerkship directors' perceptions of students' physiology knowledge as the majority of students indicated that they were comfortable with their knowledge retention of only physiology concepts pre-clerkship. Additionally, clerkship directors perceived students' knowledge to be lacking in the remaining basic science disciplines, which is supported by the literature showing that clinical directors feel as though students are lacking basic science knowledge after completing pre-clerkship (D'Eon 2006; Spencer et al. 2008; Nouns et al. 2012; Weggemans et al. 2017), and perceive students to be ill-prepared for clinical practice (Windish et al. 2004). To further echo clerkship directors' perceptions, the majority of students also self-reported that they feel their knowledge was lacking in the remaining basic science disciplines (anatomy, biochemistry, imaging, microbiology, nutrition, pathology, pharmacology) after completing pre-clerkship. It is important for curriculum developers to be aware of these potential shortcomings in basic science knowledge as they may persist as students progress into their post-graduate medical training (Tokuda et al. 2010; Chen et al. 2015), which can unfortunately translate to a lack of overall competence.

The perceptions identified in this study are likely multifactorial, but why are negative perceptions outweighing strengths with respect to students' basic science knowledge? Some studies have reported that negative interactions tend to have a stronger impact on individuals' perceptions, compared to positive interactions (Ito et al. 1998), which could explain why clerkship directors' perceptions of areas in need of improvement outweighed areas of strength. Alternatively, even though the goal of UME is to graduate students who have a general knowledge of all relevant disciplines, perhaps clerkship directors' expectations were too specific to their specialty, which would influence our perception data. Due to curricular limitations, such as time constraints, clerkship directors must understand that it is infeasible to cover the details required for each specialty during pre-clerkship. Perhaps pre-clerkship curricula should be incorporating more clinically-relevant basic science concepts to help ensure students are equipped with the relevant knowledge that is necessary for success in every clerkship rotation.

When analyzing the design of the UME curriculum, our findings revealed that the majority of identified basic science concepts mapped to at least one curriculum learning objective within each pre-clerkship systems-based course, suggesting that all pre-clerkship courses are relevant for delivering the fundamental basic science concepts that clerkship directors deem necessary for students to know. Further to this, we found that UME employed a high volume of large group learning sessions to deliver these basic science concepts. Interestingly, there were some basic science concepts that were identified by clerkship directors that were not formally associated with a learning objective. This finding may highlight a disconnect between which basic science concepts pre-clerkship educators are teaching and which concepts clerkship educators expect students to be proficient in. Therefore, by increasing communication between pre-clerkship and clerkship educators, we can hopefully create more transparency with respect to basic science education, and firmly establish which concepts should be a fundamental component of pre-clerkship curricula. Bridging this gap and creating a continuum throughout medical education (Teunissen and Westerman 2011) will enable students to better integrate their knowledge, enhance their transitions to subsequent stages of medical training, and ultimately foster their overall competence as a future physician (Aschenbrener et al. 2015), thereby promoting more positive perceptions among medical educators and students.

Throughout **Section 4.1** of this thesis, we revealed that UME clerkship directors expect students to have some working knowledge of every basic science discipline prior to entering their clerkship training. Further to this, we elucidated that both clerkship directors and trainees perceive there to be more areas where students could enhance their basic science knowledge, compared to areas of strength. These results may suggest a disconnect between which concepts clerkship directors expect students to be knowledgeable in and which basic science concepts are actually delivered during pre-clerkship. Therefore, by increasing transparency across the stages of medical training, and firmly establishing which concepts students should be proficient in prior to entering clerkship, we can effectively integrate the identified concepts throughout pre-clerkship to ensure that all students are learning the necessary fundamentals prior to transitioning to clerkship.

4.2 Students' Basic Science Knowledge Retention: Pre-Test Analysis

4.2.1 Knowledge Retention According to Clerkship Rotation

With knowledge retention being multifactorial, there is a large amount of variation in the literature with respect to students' basic science knowledge retention levels (Swanson et al. 1996; D'Eon 2006; Weggemans et al. 2017; Schneid et al. 2018). Further to this, no study has examined students' knowledge retention of basic science concepts based on clerkship directors' expectations. In the present study, this was addressed and, on average, students achieved a score greater than 60% on the assessments prior to entering each clerkship rotation (paediatrics: 68% (±12%), (range: 20-96%); OB/GYN: 67% (±12%), (range: 22-91%); internal medicine: 72% (±12%), (range: 38-91%); family medicine: 70% (±11%), (range: 13-91%); psychiatry: 67% (±9%), (range: 13-91%); surgery: 63% (±12%), (range: 9-96%); **Section 3.2**, **Figure 8**). This indicates that students do, on average, retain relevant basic science knowledge from their pre-clerkship training prior to entering their clinical years, which is supported by other research demonstrating medical students maintain an average knowledge retention level of 60-69% in the basic sciences (Swanson et al. 1996; D'Eon 2006). However, as demonstrated in **Figure 8**, there are students in every rotation whose scores fall below 60% on the pre-test. This trend has been documented in the literature which reveals that students' basic science knowledge retention levels can drop below 60% within one year of initially learning the material (D'Eon 2006; Custers 2010; Weggemans et al. 2017). Even though average retention levels appear to be standard across student cohorts and curricula, the required level of basic science knowledge retention for a medical student entering a clinical setting remains unknown for all UME stakeholders.

4.2.2 Knowledge Retention is Not Influenced by Clerkship Rotation Order

As mentioned during our interviews, clerkship directors indicated that they expect more basic science knowledge from students who are in their final rotation of clerkship versus students just entering clerkship (**Section 3.2**). This trend has been identified in the literature indicating that students tend to perform better on assessments at the end of clerkship, compared to their performance at the beginning of their clinical training (Cho et al. 1998). With this knowledge, we expected that students would be more prepared in their final rotations due to the reinforcement of fundamental basic science concepts during their clinical training and, therefore, achieve higher pre-test scores as they progressed through clerkship. Through our analysis we found that rotation order had no effect on students' pre-test performance (**Section 3.2; Figure 9**), which suggests that, regardless of students being engaged in clinical learning during clerkship, their clinical experiences in previous clerkship rotations had no influence on their basic science knowledge retention. Even though students didn't achieve higher scores as they progressed through clerkship, perhaps the clinical learning aided with the maintenance of their basic science knowledge as the year progressed, which would be reflected in the relatively consistent pre-test scores. To our knowledge, there is no literature focusing on the effect of clerkship rotation order on students' basic science knowledge levels. Interestingly though, when analyzing the clinical sciences, other research has shown that students who complete their surgery, psychiatry, pediatrics, or OB/GYN rotations towards the end of clerkship year tend to perform better on rotation specific assessments (Baciewicz et al. 1990; Hampton et al. 1996; Cho et al. 1998; Manley and Heiss 2006). However, contrary to this, Park et al. (2005) highlighted that the timing of students' psychiatry rotation had no effect on student performance with respect to their psychiatry rotation exam and clinical skills assessment scores. The present study focused strictly on the basic science concepts that clerkship directors expect students to know coming into clerkship; thus, overall, these findings and some supporting literature may suggest that rotation specific learning provides learners with the opportunity to hone their clinical science knowledge more than their basic science knowledge, simply due to the fact that the focus of clerkship is primarily clinical.

4.2.3 Knowledge Retention is Not Influenced by Basic Science Discipline

Some research demonstrates that students' basic science knowledge retention can vary across the basic science disciplines (Swanson et al. 1996; D'Eon 2006), thus, we set out to determine if students' pre-test scores were influenced by the basic sciences disciplines. When we analyzed the average of each assessment question (n=270) according to the basic science subject that was being assessed, we found that, on average, students achieved >60% in each basic science discipline (anatomy, biochemistry, imaging, microbiology, nutrition, pathology, pharmacology, physiology) (**Section 3.2; Figure 10**). In agreement with our findings, other studies have found that, when testing students' knowledge after 12-21 months of initially learning the material, students, on average, did achieve a passing grade in the disciplines of anatomy (Blunt and Blizard 1975), physiology (Weitman 1964), and pharmacology (Rodriguez et al. 2002). Additionally, our findings revealed that while the average scores did vary across the disciplines, with the highest and lowest average scores achieved in biochemistry (85%) and anatomy (61%) respectively, there were no significant differences among the basic science disciplines. As mentioned above, most students are exposed to the biological sciences, such as physiology and biochemistry, to fulfil previous degree requirements or to write the MCAT prior to entering UME, which may be fostering their success in these disciplines. However, it should be noted that there were only two assessed concepts associated with biochemistry, and thus, these concepts may be identified as high yield and may not be representative of general biochemistry knowledge retention. Overall, the results from this study, which are contrary to D'Eon's (2006) findings, indicate that students' basic science knowledge retention is not discipline specific.

4.2.4 Relationship Between the Pre-Clerkship Curriculum and Students' Basic Science Knowledge Retention

Many studies demonstrate that students' basic science knowledge retention can range from 47.5%-94.0% (Blunt and Blizard 1975; Kennedy et al. 1981; Swanson 1996; Rodriguez et al 2002; Herzig et al. 2003; D'Eon 2006), however, to our knowledge, there are no studies analyzing whether pre-clerkship courses have any influence on students' basic science knowledge retention. In the present study, the assessed basic science concepts were mapped to the pre-clerkship course(s) in which the concepts were delivered, which revealed that, on average, students achieve >60% on concepts associated with most pre-clerkship courses (**Section 3.3; Figure 11**). However, there were two pre-clerkship courses, Blood and Skin, where students, on average, did not meet the minimal level of competency scoring 44% and 58%, respectively. It should be noted that students' performance is represented by only five concepts associated with the Blood course and four assessed concepts associated with the Skin course. Furthermore, both of these pre-clerkship courses fall within the first year of study in the UME curriculum. Therefore, lower retention rates could be due to the early presentation of this content during the first year of pre-clerkship, confounded by the fact that this content is not reinforced throughout pre-clerkship training.

Although there is no evidence specific to the influence of pre-clerkship courses on students' basic science knowledge levels, inadequate levels of basic science knowledge have been documented in the literature as research indicates that medical students' basic science knowledge can drop to a failing retention rate after about one year of initially learning the material (Weggemans et al. 2017; Schneid et al. 2018), and student's knowledge retention can be impacted by the duration of time that the material is unused (Custers 2010). Thus, we predicted that students would achieve higher scores on concepts that were taught at the end of the pre-clerkship versus concepts taught at the very beginning of their medical school career. However, we found that students achieved comparable grades on each assessment question (n=270) across each pre-clerkship term

(**Section 3.3; Figure 12**), just as they did across the pre-clerkship courses. Could this finding suggest that students aim for the minimum level of competency during their training? Even though Schulich UME has a passing grade of 60% during pre-clerkship, at its core, it is essentially a pass/fail system as students progress through their training as long as they achieve the minimum level of competency (60%). Research has shown that with a pass/fail grading system in higher education programs, students tend to aim at the minimum, as opposed to striving for a level of mastery (Wittich 1972). As a result, a pass/fail grading system in professional education programs can actually result in lower assessment scores, compared to traditional grading systems using letter grades (Roberts and Dorstyn 2017), which may also explain the students who are falling below the minimum level of competency (<60%) on the basic science assessments. Thus, regardless of the length of time that surpasses after the material is initially presented, students, on average, maintain relatively consistent grades in the basic sciences across all four pre-clerkship terms.

In the literature, there are conflicting views about the efficacy of content repetition on students' knowledge levels (Dalton et al. 2004; Muller et al. 2008), and the effect of revisiting curricular content on student outcomes remains inconclusive at the pre-clerkship level. In this study we found that, on average, students achieved comparable grades of >60% regardless of how many times a concept was linked to a formal learning objective within the pre-clerkship curriculum (**Section 3.3: Figure 13**). This suggests that content repetition did not greatly impact students' basic science knowledge retention, which is in line with a study demonstrating that multiple views of recorded lectures did not improve students' exam performance in an undergraduate histology course (Barbeau 2012). It is possible that the concepts that were linked to more than one learning objective could be more complex basic science concepts, thus, while there were no identified differences among students' scores according to the number of times a concept was delivered, revisiting the complex content could, in part, help prevent knowledge deficits in those complex concepts (D'Eon 2006). Despite content repetition not having an impact on students' basic science knowledge, the most interesting finding of this analysis is that even when the concepts were not associated with a formal learning objective, students still achieved an average grade of >60 percent (**Figure 13B**). Other research has found that students use their basic science knowledge to construct a mental representation of a clinical condition or disease (Woods et al. 2005; McColl et al. 2012; Nouns et al. 2012; Cutrer et al. 2018), therefore, our students may be using their existing basic science knowledge to comprehend the concepts that were not linked to a learning objective, and ultimately reach a conclusion. Alternatively, students may understand these unlinked basic science concepts, as they may in fact be delivered during pre-clerkship, but the current learning objectives may fail to capture the concepts. Overall, these findings suggest that content repetition did not impact student's basic science knowledge.

In the present study we found that students achieved an average of >60% regardless of which instructional method, or combination of methods, were used to deliver the assessed basic science concepts (**Section 3.3; Figure 15**). Similar findings have been documented in the literature which demonstrates that there are no differences between student performance scores when learning via large or small group learning sessions during OB/GYN, trauma, and orthopaedics training (Bulstrode et al. 2003; Fischer et al. 2004). However, some contradictory evidence indicates that medical students display improved performance when learning via small group rather than large group instruction (Costa et al. 2007; Thomas and Bowen 2011), and similar results were found when assessing independent learning modules when students were learning about electrocardiography (Fasce and Ibanez 1994). Interestingly, the medical education studies which demonstrate a positive impact of small group learning and independent learning on students' knowledge levels are primarily focused on the clinical sciences and clinical learning (Fasce and Ibanez 1994; Costa et al. 2007; Thomas and Bowen 2011), as opposed to basic science pre-clerkship education, which suggests that the effectiveness of instructional method(s) may be dependent on the stage of medical training in which they are delivered. As demonstrated throughout the literature, the most effective instructional methods for delivering basic science content in pre-clerkship curricula remain inconclusive, which is in line with the findings of this study. Further to this, due to the small number of concepts delivered via small group, independent learning modules, or a combination of instructional methods within this study, it is not possible to determine which instructional method in this study is most effective for delivering the basic sciences. With the goal of increasing student engagement and ultimately enhancing the effectiveness of learning (Freeman et al. 2014; Stuart and Triola 2015; McCoy et al. 2018), many institutions are currently revising their instructional methods and integrating more small group learning methods and independent learning modules (Spencer and Jordan 1999; Haidet et al. 2002; Searle et al. 2003; Koles et al. 2005; Roehl et al, 2013; Samarakoon et al. 2013; Freeman et al, 2014; Emke et al. 2016; Levine et al. 2016). Therefore, such implementation will provide further opportunities to examine the efficacy of these instructional methods, and combined instructional methods, on student engagement, students' basic science knowledge acquisition and retention, and overall student outcomes during their pre-clerkship training.

4.2.5 Summary of Students' Basic Science Knowledge Retention

Third-year medical students, on average, achieved a grade >60% on the pre-test assessments, which is consistent with other literature, suggesting that they retain relevant basic science knowledge from their pre-clerkship training. Further to this, neither clerkship rotation order nor the basic science discipline being assessed impacted students' basic science knowledge retention levels. This indicates that, due to the clinical nature of clerkship, students' do not hone their basic science knowledge during each rotation, and their basic science knowledge retention is not dependent on the basic science discipline being assessed. We further determined that the pre-clerkship course and pre-clerkship term in which the basic science concept was delivered did not influence students' basic science knowledge levels. Therefore, students' grades on the concepts deemed necessary by clerkship directors remain consistent throughout pre-clerkship, regardless of the length of time that passes after the material is initially presented. Furthermore, neither the number of times a concept was repeated, nor the instructional method employed to deliver the concept impacted students' basic science knowledge. Thus, overall our data suggests that regardless of where, when, how, or even if, the concept was delivered during pre-clerkship, UME students achieve, on average, a passing grade on the basic science concepts deemed necessary by the clerkship directors. However, despite the average pre-test scores scoring >60%, the data presented throughout **Section 4.2** also indicates that there are still some concepts where the average grade of the students is below the minimal level of competency (60%). One potential solution to help increase students' basic science knowledge retention could be to implement more well-defined milestones into the basic science pre-clerkship curricula (Chen et al. 2015). By implementing clear, fixed outcomes all students can work towards achieving the same educational goals and increase their self-accountability as they do so (Simpson et al. 2002; Harris et al. 2010; O'Brien and Irby 2013; Sonnadara et al. 2014). With this curricular framework, educators and curricula committees can ensure that all students are achieving a level of competency in the basic science concepts that are expected of them prior to transitioning to their clerkship training.

4.3 Students' Basic Science Knowledge Reinforcement: Post-Test Analysis

4.3.1 Knowledge Reinforcement During Each Clerkship Rotation

While the pre-test data analysis provided insights into students' basic science knowledge retention, the post-test scores allowed us to determine if students further learned fundamental basic science concepts during clerkship, suggesting that clinical experiences may help reinforce their basic science knowledge. Students' post-test scores were, on average, significantly higher compared to their pre-test scores in each clerkship rotation (**Section 3.4; Figure 16**). This finding suggests that students continue to learn and/or reinforce fundamental basic science concepts during each rotation. More specifically, the largest increase in post-test scores was noted for students completing the paediatrics rotation (10%). Interestingly, the clerkship directors of the paediatrics rotation indicated that there was a higher volume of out-of-clinic learning sessions compared to the other clerkship rotations. These learning sessions may have provided students with significant knowledge reinforcement of the basic science concepts, leading to enhanced performance on the post-test scores. There is very little research focusing on students' reinforcement of their basic science knowledge as most of the medical education literature pertaining to clerkship year is focused on the process of learning, experiential learning, and competency acquisition (Rosenbaum and Axelson 2013; Steven et al. 2014; Han et al. 2015). However, there is some evidence in the literature indicating that the integration of the basic and clinical sciences can enhance students' understanding of clinically relevant content and help foster their knowledge retention (Dahle et al. 2002). Similarly, our data suggests that clinical learning may have a similar effect on students' basic science knowledge levels. Thus, when out-of-clinic learning sessions are simultaneously paired up with relevant clinical learning, students may be able to better integrate their basic and clinical science knowledge, which ultimately makes their learning more relevant and can better prepare them for medical practice (Wilkinson et al. 2002; Dahle et al. 2002; Finnerty et al. 2010; Brauer and Ferguson 2015).

4.3.2 Knowledge Reinforcement is Not Influenced by Clerkship Rotation Order

Consistent with the trend we saw for the pre-test, the order of clerkship rotations did not influence students' post-test scores as there were no differences among the student groups (**Section 3.4; Figure 17**). Similar results have been found pertaining to the clinical sciences during clerkship, as Myhre et al. (2014) demonstrated that two groups of third-year medical students were comparable to one another with respect to their clinical science knowledge. Thus, our findings suggest that rotation order had no effect on students' basic science knowledge reinforcement.

4.3.3 Lower-Performing Students Reinforce Their Basic Science Knowledge More Than Their Higher-Performing Peers

While students' average post-test scores significantly increased during each clerkship rotation, our data showed that lower performing students (Quartile 1 and 2) demonstrated a significant improvement on their post-test, compared to their pre-test, in all six clerkship rotations (**Section 3.4; Figure 18**). This trend has been identified at the UME level in the literature. For example, Koles et al. (2005) determined that when second-year undergraduate medical students are learning pathology with a clinical focus via team-based learning and case-based learning, the lowest-performing students demonstrated the greatest improvement on their end-of-course pathology assessment. Similar results have been found in a clinical setting which indicates that undergraduate medical students who are completing their surgery clerkship rotation and are ranked in the lowest quartile on their entry exams for surgery demonstrated the greatest improvement on their final surgical examination in that same specialty, both of which consisted of multiple-choice questions and a clinical assessment (Healy et al. 2005). Taken together, these results may suggest that the clinical experience that trainees are immersed within during clerkship may enable lower-performing students to further learn, or reinforce, fundamental basic science concepts that are pertinent to that particular rotation.

Quartile 3 students also showed improvement in their post-test scores in two rotations: paediatrics and psychiatry (**Section 3.4; Figure 18A and 18E**). Just as we saw for Quartile 1 and 2, these students may also be benefitting from the clinical experience of clerkship. Alternatively, since we don't see any improvement with the remaining higher-performing quartiles, these findings, in conjunction with Quartile 1 and 2 students, could be representative of a ceiling effect which suggests that higher-performing students received their highest grade, relative to their peers, on their first examination (Albanese 2000). This phenomenon has been identified in a gross anatomy course for medical students (Lufler et al. 2012), and in other educational contexts, such as, foreign language (Rifkin 2005) and statistics (Keeley et al. 2008) courses. Therefore, perhaps the higher-performing students in this study, with the exception of Quartile 3 students in paediatrics and psychiatry, achieved their highest possible score on the pre-test, and thus, there is limited room for improvement on the subsequent post-test assessments (Albanese 2000; Lycke et al. 2009).

Interestingly, for Quartile 4 students in psychiatry, their post-test scores were significantly lower compared to their pre-test (Δ -7%, p=0.001). While these findings were an unexpected result of this study, we don't have concrete data to understand this result, nor the relationship of this finding with students' psychiatry clerkship performance.

4.3.4 Lower-Performing Students' Post-Test Knowledge Does Not Meet the Level of Higher-Performing Students' Pre- nor Post-Test Knowledge

Although students in Quartile 1 did demonstrate a significant improvement on the post-test, their average post-test scores did not rise to the level of the average pre-test assessment scores of Quartile 4 students in all six rotations (**Section 3.4; Figure 18**). This finding suggests that while the clinical experience that students are exposed to during clerkship does benefit their learning in the basic sciences, the clinical experience alone does not help lower-performing students catch up to the students coming into clerkship with the higher levels of basic science knowledge.

Other studies have indicated that prior academic performance is the best predictor of success on future assessments. For example, second year medical students' pre-test scores were found to predict their post-test performance on diagnostic classification during a microscopic pathology course (Helle et al. 2010). Further to this, when analyzing the impact of face-to-face and online instruction on student performance, incoming grades were shown to be a significant predictor, for overall course performance in both an undergraduate microscopic anatomy and a systemic human anatomy course (Barbeau et al. 2013; Attardi and Rogers 2015). Thus, in the present study we found that lower-performing students' pre-test scores were a predictor for their basic science knowledge levels at the end of each clerkship rotation, and furthermore, the clinical experience of clerkship did not make up for their initial deficit in basic science knowledge relative to their higher-performing peers. Interestingly, there is evidence to suggest that earlier exposure to the clinical sciences can have a positive impact on students' overall learning (Dyrbye et al. 2007; Tayade et al. 2014; Rawekar et al. 2016). Therefore, with enhanced integration between the basic and clinical sciences throughout pre-clerkship, and introducing clinical experiences earlier in pre-clerkship, we may be able to enhance students' knowledge acquisition and retention of the fundamental basic sciences, particularly for lower-performing students, thereby ensuring that all students are proficient in the necessary basic science fundamentals after completing their pre-clerkship training to improve their transition to clerkship (Dahle et al. 2002; Finnerty et al. 2010; Wijnen-Meijer et al. 2010; Brauer and Ferguson 2015; Hopkins et al. 2015; Rajan et al. 2016; Ryan et al. 2020).

4.3.5 Summary of Knowledge Reinforcement

Overall, when evaluating students' basic science knowledge levels, we found that students reinforced fundamental basic science concepts during each clerkship rotation, suggesting that the clinical experience of clerkship is providing the opportunity for further learning and reinforcement of fundamental basic science concepts. Further to this, lower-performing students demonstrated a significant improvement on the post-test assessment, suggesting that the clinical experience of clerkship is an effective learning aid for reinforcing students' basic science knowledge, specifically for lower-performing students. While lower-performing students demonstrated the greatest post-test improvement, they did not achieve the level of basic science knowledge of their higher-performing peers. These findings may suggest that earlier exposure to clinical experiences may help foster students' basic science knowledge acquisition and retention, thereby ensuring optimum preparation for all students prior to clerkship, with respect to their basic science knowledge. This is supported by literature demonstrating that earlier exposure to the clinical sciences can positively influence students' overall learning (Tayade et al. 2014; Rawekar et al. 2016; Ryan et al. 2020). Therefore, by integrating clinical experiences earlier in pre-clerkship, and extending basic science education into the upper years of UME, we can improve the integration of basic and clinical sciences throughout UME curricula, and hopefully enhance all students' preparedness for their transition to the subsequent stages of medical training (Blue et al. 2000; Wijnen-Meijer et al. 2010; O'Brien and Irby 2013; Wijnen-Meijer et al. 2013).

4.4 Limitations

The results presented here are from a single academic year at one Canadian institution, therefore perceptions from clerkship directors may vary, not only between clerkship directors, but across North American UME curricula. Further to this, the interviews were guided by the use of questionnaires which provided consistency and helped guide the discussion in a sequential manner, but the structured format of the interviews may have limited the conversation, and as a result, key discussion points may have been missed. Additionally, negative interactions tend to have a stronger influence on individuals' perceptions, compared to positive interactions (Ito et al. 1998), which could have negatively biased the data when discussing students' basic science knowledge strengths and weaknesses, from both clerkship director and student perspectives. For example, clerkship directors mentioned in the interviews that they are not surprised when a clerk knows something while on rotation, but what does catch them off guard is when a clerk is lacking fundamental knowledge.

When mapping the identified basic science concepts to curricular learning objectives, some concepts were not linked to a learning objective, yet these concepts could have been covered during pre-clerkship training without a formal learning objective. This potential limitation would influence the other metrics that the learning objectives were linked to, such as pre-clerkship course and employed instructional method, all of which could influence the study outcomes.

With respect to the basic science assessments, a re-test bias could have positively influenced students' post-test scores as students may have had some recollection of the pre-test questions that they previously completed. Alternatively, students' intrinsic motivation, or lack of, could have positively or negatively impacted their assessment score(s).

Chapter 5

5 OVERALL SUMMARY

5.1 General Conclusions

The overarching goal of this research was to develop an evidence-based curriculum feedback loop to critically evaluate the basic science pre-clerkship curriculum at Schulich UME (**Figure 1**). This was completed by determining clerkship directors' perceptions of concepts they deem necessary for students to know, and evaluating students' basic science knowledge levels in conjunction with curricular content. We determined that clerkship directors expect students to have some knowledge of every basic science prior to entering clerkship, and both clerkship directors and students perceive there to be more areas where students could improve their basic science knowledge level, compared to areas of strength, as they are transitioning into clerkship. This finding may reveal a disconnect between which basic science concepts are delivered during pre-clerkship and in which concepts clerkship directors expect students to be knowledgeable. Therefore, by increasing transparency across the stages of medical training, and firmly establishing which concepts students should be proficient in prior to entering clerkship, we can effectively integrate the necessary concepts throughout pre-clerkship to ensure that all students are proficient in the necessary fundamentals prior to entering their clinical training.

The results from the present study also indicated that students maintain, on average, at least 60% of their basic science knowledge from their pre-clerkship training. However, regardless of students' average scores, our data also highlighted that there are some basic science concepts where the average grade of the students is below the minimal level of competency (60%). Based on the literature, one recommendation for helping to increase students' basic science knowledge levels is by incorporating more well-defined and fixed assessment outcomes throughout pre-clerkship. Under this curricular framework, all students can work towards achieving the same educational goals, and thus, educators can ensure that all trainees are attaining the minimum level of proficiency in the basic science concepts that are necessary for students to successfully transition to their next stage of training.

Further to this, post-test data revealed that students, on average, further learned or reinforced fundamental concepts during the clinical experience of clerkship. Most notably, even though lower-performing students demonstrated the greatest improvement on the post-test, they still displayed deficits in their basic science knowledge at the end of each rotation, when compared to their higher-performing peers. These results suggest that earlier exposure to clinical learning during UME may promote students' learning of the basic sciences, specifically lower-performing students. Thus, by integrating clinical experiences throughout pre-clerkship we can enhance the integration of the basic and clinical sciences, thereby promoting the optimal preparation in the necessary basic science fundamentals prior to clerkship.

The collected data, in conjunction with other metrics, are being used by pre-clerkship educators to help inform the design and the delivery of basic science content in Schulich's reformed curriculum. The curriculum evaluation tool developed through this research project provides a means to consistently evaluate the basic science pre-clerkship curriculum through the various lenses of clerkship directors' and students' perceptions, curricular content, and students' knowledge levels. Additionally, the tool will allow for continuous monitoring of the impact of curricular revisions on the effectiveness of basic science education at the UME level. Overall, this research methodology can be used as a template by other faculty and educators for evaluating which basic science content should be included in other pre-clerkship curricula, with goals of creating dialogue across institutions, and ultimately, fostering consistency among basic science education in UME curricula with the result that graduating students are proficient in the fundamental basic sciences that are necessary to treat and manage today's patient population.

5.2 Future Directions

The results collected from this research are informative, add to the wealth of medical education literature and provide the impetus to further explore the potential influences on medical students' basic science knowledge. While we revealed that clerkship directors expect medical students to have some knowledge of every basic science prior to entering clerkship, future studies should explore the expectations of medical students' basic science knowledge at a national level. Further to this, we found that clerkship directors' perceptions of areas in need of improvement outweighed areas of strength, with respect to students' basic science knowledge. This finding provides the basis to explore how educators and curricular designers should classify an 'adequate' level of basic science knowledge. Lastly, how do we promote consistency among basic science educators across Canada? Although this study only represents one institutions' voice, knowing that trainees rotate through institutions across Canada for clerkship and residency, this discussion should be initiated at the national level to ensure that the expectations of students, and the basic science concepts taught at the UME level, are standardized, and we can help foster continuity in trainees' education.

In addition, we revealed that students, on average, retain their basic science knowledge from pre-clerkship, and further reinforce their knowledge through clerkship. These results provide the basis to further investigate the impact of basic science knowledge on students' success in clerkship and UME, and the influence of curricular design on students' basic science knowledge levels. Furthermore, our data revealed that the clinical learning during clerkship was particularly beneficial for lower-performing students. Therefore, future research should explore the effect of increased vertical integration between the basic and clinical sciences, and ultimately earlier clinical experiences in pre-clerkship, on students' basic science knowledge levels, to help ensure all students are competent and well-equipped with the necessary knowledge prior to entering a clinical setting.

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Appendices

Appendix A: Research Ethics Board approval.

Western Research

Research Ethics

December 23, 2016

Charys M. Martin, Ph.D.
Assistant Professor

Dear Dr. Martin,

Re: A Model for Evidence Based Integration of the Basic Sciences into a Competency Based Undergraduate Medical Education Curriculum

The HSREB Chair has reviewed the above-referenced project and it does not require approval of a Research Ethics Board. In accordance with the Tri-Council Policy Statement 2: Ethical Conduct of Research Involving Humans, Article 2.5. "Quality assurance and quality improvement studies, program evaluation activities, and performance reviews, or testing within normal educational requirements when used exclusively for assessment, management or improvement purposes, do not constitute research for the purposes of this Policy, and do not fall within the scope of REB review".

In my opinion, the above-referenced research project falls within that description.

I wish you the best of luck with your work.

Most sincerely,

Nicole Kaniki
Ethics Officer, Office of Research Ethics

Western University, Research, Support Services Bldg., Rm. 5150
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Appendix B: List of interview questions that were used during the guided interviews with clerkship directors.

Clerkship Director Interview Questionnaire

1. How is your clerkship rotation set-up (routine, hours, student ratio)?
2. What basic science knowledge or skills are students expected to know coming into this clerkship rotation?
    a. Specifically, what basic science concepts are they expected to know coming into this clerkship rotation?
    b. What (if any) specific genetic conditions are students expected to know prior to the rotation?
        i. Pertaining to these conditions, how much are the students expected to know (actual affected genes, sequencing, diagnose, etc.)?
    c. What (if any) specific developmental conditions (fetal/embryonic) are students expected to have the fundamental knowledge of, in terms of identifying and explaining the anatomical basis, prior to entering the rotation?
        i. Pertaining to these conditions, how much are the students expected to know (actual affected genes, or gross anatomical developmental issues only etc.)?
    d. What (if any) knowledge of classes of drugs and specific drugs do you expect them to know?
        i. Do they need to know basic science pathway behind important drugs, or is this taught through clerkship?
        ii. Do they need to know the metabolism/dosing curve of each of these drugs or is this taught through clerkship?
        iii. What (if any) important drug interactions/contraindications do they need to know?
        iv. What (if any) adverse reactions are they expected to know?
        v. What (if any) specific pathogens they are expected to know?
    e. With respect to imaging, what (if any) modalities to you expect your clerks to have exposure to and be able to interpret normal structures on during the rotation?
        i. With respect to imaging, are there any conditions you expect clerks to be able to identify?
    f. What (if any) specific clinical conditions (related to your field) should be an integral part of the pre-clerkship training?
    g. What (if any) nutritional concepts should students know during this clerkship rotation?
        i. Are the clerks expected to do any nutritional counselling with patients?
3. What are the students expected to know after completing this clerkship rotation?
    a. Are there any basic science concepts that should be further developed throughout the clerkship rotation?
    b. Are there any basic science concepts that should be taught concurrently with this clerkship rotation?
    c. What basic science concept(s) and skills do students find most challenging during this clerkship rotation?
    d. What basic science concept(s) and skills are students proficient in during this clerkship rotation?
4. As a clerkship director, do you feel that your clerks are too knowledgeable in any area?
5. As a clerkship director, what (if any) deficits, in terms of basic sciences, do you feel that clerks currently have when entering clerkship?
6. In closing when redesigning the basic science pre-clerkship curriculum, is there anything else you would like us to note or keep in mind?

Surgery Specific:

- What incisions/sutures should students be aware of and to what level?

Appendix C: Consent form for conducting interviews with the clerkship directors.

Schulich
MEDICINE & DENTISTRY

Individual Consent Form for Clerkship Director Interview

I, ______________________________, hereby grant Madeleine Norris and Dr. Charys Martin (Department of Anatomy and Cell Biology, Schulich School of Medicine and Dentistry, Western University) permission to freely use and reproduce the information collected through notes and audio recordings in which I appear. I fully understand that the interviews and conversations will become property of Madeleine Norris and Dr. Charys Martin, and may be used without any further consultation with me.

I confirm that the content of this consent form has been explained to me, and that I have read and fully understand the meaning of this form prior to signing it.

______________________________ **Name**	______________________________ **Date**
______________________________ **Signature**	______________________________ **Witness Signature**

Appendix D: Survey questions used to assess students' perceptions of their basic science after completing the pre-clerkship curriculum.

Survey: *Student perceptions of basic science assessments*

1. Were the basic science assessments helpful to know what the clerkship directors expected from you in terms of basic science knowledge?
   a. Yes
   b. No

2. In which rotation(s) were the basic science assessments most helpful? (*Choose all that apply*)
   a. Paediatrics
   b. OB/GYN
   c. Surgery
   d. Family Medicine
   e. Internal Medicine
   f. Psychiatry

3. What was the most helpful to you throughout clerkship? (*Choose all that apply*)
   a. Pre-test assessment
   b. Pre-test feedback
   c. Post-test assessment
   d. Post-test feedback

4. Do you feel concepts covered on the basic science assessments were taught during your pre-clerkship training?
   a. Yes
   b. No

5. Which basic sciences do you feel you learned best during pre-clerkship? (*Choose all that apply*)
   a. Anatomy (gross, embryology, neuroanatomy, histology)
   b. Biochemistry
   c. Imaging
   d. Microbiology
   e. Nutrition
   f. Pathology
   g. Pharmacology
   h. Physiology

6. Which basic sciences do you feel you could've learned better during pre-clerkship? (*Choose all that apply*)
   a. Anatomy (gross, embryology, neuroanatomy, histology)
   b. Biochemistry
   c. Imaging
   d. Microbiology
   e. Nutrition
   f. Pathology
   g. Pharmacology
   h. Physiology

7. Do you have any additional comments or feedback with respect to the basic science assessments or pre-clerkship curriculum?

Appendix E: Example of basic science assessment for the Paediatrics clerkship rotation.

PAEDIATRICS BASIC SCIENCE ASSESSMENT

A 10-year-old-female is brought to your clinic by her father. Her father is concerned as she has had bouts of chest tightness, wheezing, and trouble breathing over the past few weeks, soon after purchasing a pet cat. Upon physical exam, nothing remarkable is found.

1. You prescribe salbutamol to use as needed. What expected side effect from this drug would you discuss with the daughter and the father?
    a. Drowsiness
    b. Lethargy
    c. Miosis
    d. Tachycardia
    e. Hypotension

A male infant is brought to you for a newborn checkup shortly after birth. Upon physical examination, you note a small head circumference, a flat nasal bridge, upward slanting eyes and hypotonia. Further discussion with the parents reveals that they chose not to participate in prenatal screening.

2. Which of the following chromosomal abnormalities has led to this condition?
    a. 47, XXY
    b. Monosomy 22
    c. Monosomy X
    d. Trisomy 18
    e. Trisomy 21

3. Upon further physical examination an undescended testicle is noticed. Which of the following developmental anomalies has led to this condition?
    a. Elongated gubernaculum
    b. Failure of the glans to canalize
    c. Failure of the paramesonephric ducts degenerate
    d. Patent processus vaginalis

You are performing a checkup on a recently delivered female baby. You notice lymphedema around the hands and feet as well as excess folds of skin at the neck. Other physical exam results are unremarkable.

4. Which of the following best describe this genetic abnormality?
    a. 11q deletion
    b. 22q13 deletion
    c. 47, XXY
    d. Monosomy X
    e. Trisomy 18

5. Which of the following complications will that patient NOT likely display?
    a. Infertility
    b. Intellectual disability
    c. Delayed or absent puberty
    d. Short stature

You are listening to the heart on a female infant, and make note of a wide and fixed splitting of S2 and a systolic ejection murmur best heard at the left upper sternal border. Aside from this the rest of the physical exam appears unremarkable.

6. Which of the following developmental anomalies could be the underlying cause of the infant's condition?
    a. Coarctation of the aorta
    b. Enlarged foramen ovale
    c. Overriding aorta
    d. Pulmonary stenosis
    e. Transposition of the great vessels

7. Which of the following long-term consequences could result if the atrial septal defect was left untreated?
    a. **Right ventricle dilation**
    b. Pulmonary hypotension
    c. Decreased right atrium pressure
    d. Ventricular fibrillation

8. You end the appointment by educating the parent on normal heart development. What causes the foramen ovale to close after birth?
    a. Decrease in prostaglandins
    b. **Increase in left atrial pressure**
    c. Increase in myocyte size
    d. Increase in pulmonary resistance
    e. Stronger contraction of the heart muscles

A 5-year-old-male is brought to your clinic by his mother. Upon entering the room, you immediately notice honey-coloured crusts around the child's mouth. His mother thinks he has picked it up from day care and would like something prescribed to get rid of it as soon as possible. Physical exam reveals numerous crusts affecting the lips and nose.

9. Which of the following organisms is the most likely to be causing the infection?
    a. Candida
    b. Enterococcus
    c. H. influenza
    d. Herpes simplex
    e. **S. aureus**

10. You decide to treat empirically with oral therapy. Which antibiotics do you prescribe?
    a. Azithromycin
    b. **Cephalexin**
    c. Gentamicin
    d. Moxifloxacin
    e. Vancomycin

Upon screening a newborn male infant, you notice unilateral scrotal swelling on the right side as the infant is crying. You are also unable to palpate the upper border of mass. After the baby stops crying the scrotal swelling decreases. Aside from this finding, the rest of the physical exam is normal. A congenital inguinal hernia is suspected.

11. Which of the following developmental anomalies is indicated in this condition?
    a. Elongated Gubernaculum
    b. Enlarged Labioscrotal swelling
    c. Imperforate Urogenital sinus
    d. **Patent Processus vaginalis**
    e. Patent Tunica albuginea

A 7-year-old-female is brought to your clinic by her parents with edema of the face and limbs. Upon physical examination ascites is also present. Urine dipstick testing reveals high levels of protein and no hematuria. Nephrotic syndrome is made as a diagnosis.

12. Which of the following describes why the patient presents with edema?
    a. Heart failure causing fluid retention
    b. Increased lymph fluid
    c. Increased sodium retention
    d. Increased water retention
    e. **Lack of oncotic pressure due to loss of protein**

13. If steroid resistant, an ACEI might be prescribed to help reduce the amount of protein lost in the urine. How does an ACEI accomplish this?
    a. Afferent arteriole constriction
    b. Afferent arteriole dilation
    c. Efferent arteriole constriction
    d. Efferent arteriole dilation

A 1-year-old-male is brought to the emergency department with a fever and watery diarrhea. Questioning the parents reveals the diarrhea started a few days after the onset of the fever and has not contained any blood. Physical examination reveals severe dehydration and a rapid pulse.

14. Your first goal is to address the patient's severe dehydration. Which of the following do you order?
    a. 5% dextrose in water
    b. 5% albumin
    c. 0.9% saline
    d. 0.45% saline
    e. 3.0% saline

15. After addressing the dehydration, you order D5W/0.9% saline as maintenance fluid. How would 400mL of D5W and 600mL 0.9% saline distribute?
    a. 267mL in ICF and 733mL in ECF
    b. 333mL in ICF and 667mL in ECF
    c. 667mL in ICF and 333mL in ECF
    d. 733mL in ICF and 267mL in ECF

16. Gastroenteritis can be due to viral, bacterial or even parasitic causes. If stool culture revealed the presence of Gram-negative, motile, non-sorbitol fermenting rods which bacteria would you be most concerned about?
    a. C. difficile
    b. EHEC
    c. Enterococcus
    d. Listeria

17. Vaccines are available to prevent rotavirus gastroenteritis. Which precautions, if any, should be observed following vaccination while the infant is in hospital?
    a. Airborne
    b. Contact
    c. Droplet
    d. No precautions are necessary

A 3-year-old-female presents to you in the emergency room with a fever, nausea, and complaining of a headache. Upon physical examination, you note the child has photophobia and that the child has trouble moving their head side to side. Questioning of the parents reveal they have not been compliant with the prescribed vaccine schedule.

18. Meningitis is suspected and IV empiric antibiotics are started immediately. Which antibiotics should be used?
    a. Ceftriaxone and vancomycin
    b. Ciprofloxacin and tetracycline
    c. Gentamicin and amoxicillin
    d. Meropenem and gentamicin
    e. Penicillin and moxifloxacin

19. Ceftriaxone and vancomycin are prescribed. Which of the following best describes ceftriaxone's mechanism of action?
    - **a. Disrupts peptidoglycan cross-linking**
    - b. Inhibits DNA gyrase and topoisomerase
    - c. Inhibits folate synthesis
    - d. Inhibits protein synthesis
    - e. Inhibits RNA synthesis

20. CSF spinal fluid is drawn and sent for bacteria cultures in the interim with encapsulated Gram-negative diplococcus being reported. Which of the following are you most worried about?
    - **a.** E. coli
    - b. H. influenzae
    - c. L. monocytogene
    - **d. N. meningitis**
    - **e.** S. pneumoniae

A parent of an 8-month-old male infant comes into your practice to discuss feeding issues with her child. She worries that he is not breast feeding enough and would like your advice on the issue.

21. You being the appointment by discussing appropriate supplementation while breastfeeding. What supplemental vitamin is recommended for infants breastfeeding?
    - a. Vitamin A
    - b. Vitamin B12
    - c. Vitamin C
    - **d. Vitamin D**
    - e. Vitamin E

22. You continue the appointment by take a nutritional history from the parent. You discover that the parents have been giving their child 4 8-ounce bottles of cow's milk a day. This child is more at risk for:
    - **a.** Folate deficiency
    - **b. Iron deficient anemia**
    - **c.** Vitamin A deficiency
    - **d.** Vitamin K deficiency

An infant presents to your clinic with constipation and progressive weakness. Her parents report introducing solid foods and purees at 6 months of age.

23. Which of the following is the most concerning food that could explain the child's symptoms?
    - **a. Honey**
    - b. Strawberries
    - c. Whole-grain toast
    - d. Cheddar cheese

A mother presents with her 8-month-old infant who continues to be exclusively breastfed.

24. What nutrient deficiency is she most at risk for?
    - **a. Iron**
    - b. Vitamin B12
    - c. Vitamin B6
    - d. Vitamin E

You are counselling at mother of a 4-month-old infant who is currently being breastfed. While discussing child and maternal health, she mentions that she is a strict vegan and is currently only takes iron supplements.

25. Which nutritional deficiency are you concerned about for the child?
    a. Vitamin A
    b. **Vitamin B12**
    c. Vitamin B6
    d. Vitamin E

A mother brings her 13-month-old daughter in for her 1-year well baby visit. You notice that the young toddler is snacking on goldfish crackers and has juice in her bottle. You begin to discuss adequate nutrition with the mother and start with giving advice on fat requirements.

26. Which of the following foods would you recommend as a good source of fat for a child of this age?
    a. A.
    b. B.
    c. C.
    d. D.

You are performing a well-baby check-up on an infant who is 5 days old. The parents previously refused post-natal treatment shortly after the baby's birth. The parents are concerned as they have noticed bleeding from the nose and mouth as well as in the infant's stool.

27. Which nutritional deficiency is the child likely suffering from?
    a. Iron
    b. Vitamin B6
    c. Vitamin D
    d. Vitamin K
    e. Zinc

You are counselling the family of an 18-month-old infant on an appropriate diet for their child.

28. Which of the following is inappropriate to feed a child of this age?
    a. Iron-fortified cereals
    b. Full-fat yoghurt
    c. Thinly spread peanut butter
    d. Poultry
    e. Pumpkin seeds

A 12-month-old-male infant presents to your clinic for a regularly scheduled checkup. The parents are worried that he is developing at a slower rate than other children.

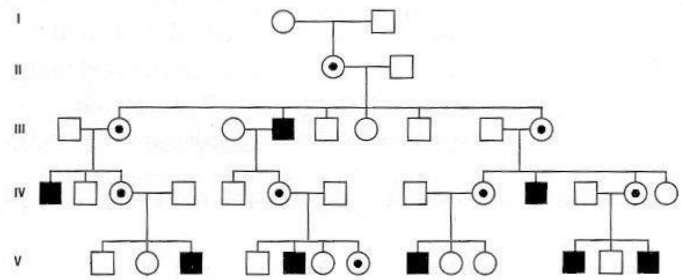
29. To begin the assessment, you observe the child's gross motor skills. Which of the following gross motor development skills is NOT expected of a 12-month-old infant?
    a. Head control in sitting position
    b. Rolling over
    c. Sitting independently
    d. Beginning to Walk independently
    e. Picking up objects without falling

30. The parents are concerned that the child is not responding to his name. At which age should a child respond to their name?
    a. 6 months
    b. 10 months
    c. 12 months
    d. 16 months
    e. 18 months

31. You see the child for a follow up appointment at 15 months and are pleased that his development is back on track. Which of the following indicates advanced functioning for a 15-month-old?
    a. Walking independently
    b. Able to place blocks in and out of a bucket
    c. Spontaneous scribbling
    d. Ability to use single words
    e. Ability to roll a ball back and forth

You are creating a pedigree for a family with a suspected genetic bleeding disorder.

32. Based on the pedigree, what is the pattern of inheritance?



    a. Autosomal recessive
    b. Autosomal dominant
    c. X-Linked recessive
    d. X-linked dominant

33. The bleeding disorder is confirmed to be hemophilia A, an X-linked recessive disorder. A female, confirmed to be recessive for the gene, asks what her chance is of conceiving a child that will be a hemophiliac. You respond to her by stating that her risk is:
    a. 0%
    b. 25%
    c. 50%
    d. 100%

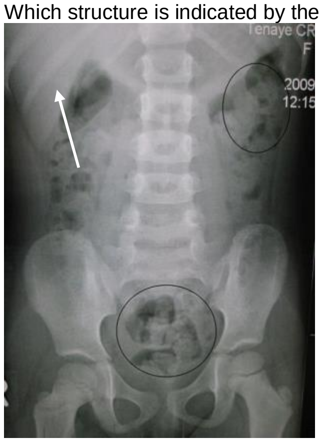
You are reviewing an abdomen x-ray of a child with constipation.

34. Which structure is indicated by the white arrow?

    a. Iliacus
    b. Levator Ani

c. Obturator Internus
d. Psoas Major
e. Quadratus Lumborum

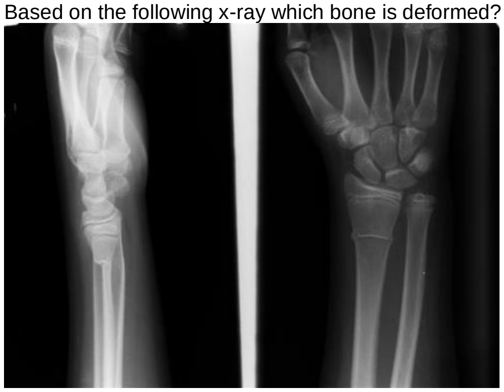
35. Which structure is indicated by the white arrow?



a. Liver
b. Pancreas
c. Spleen
d. Stomach

You are tasked with seeing a child who has tripped while running in the back yard.

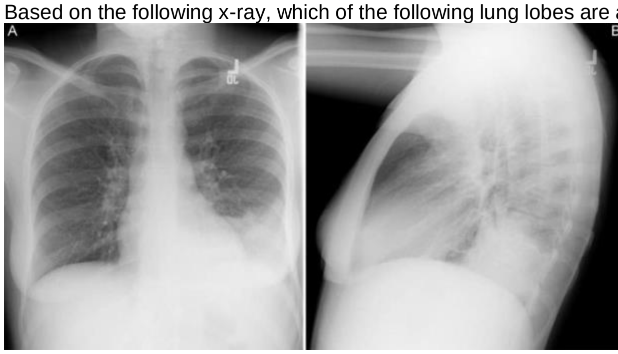
36. Based on the following x-ray which bone is deformed?



a. Capitate
b. Humerus
c. Radius
d. Scaphoid
e. Ulna

You are reviewing a film from a child diagnosed with pneumonia.

37. Based on the following x-ray, which of the following lung lobes are affected?

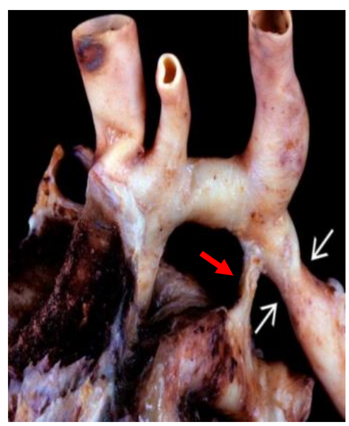


   - **a. Left lower lobe**
   - b. Left upper lobe
   - c. Right lower lobe
   - d. Right middle lobe
   - e. Right upper lobe

38. S.pneumoniae is suspected and antibiotics are prescribed. Which of the following antibiotics do you prescribe as a first line treatment?
   - **a. Amoxicillin**
   - b. Ceftriaxone
   - c. Gentamicin
   - d. Levofloxacin
   - e. Metronidazole

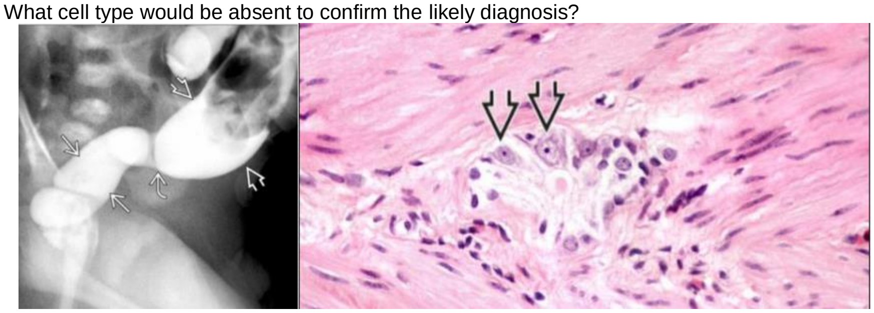
A 4-day-old infant presents to hospital with poor feeding and their clinical condition quickly deteriorates. The infant was born at full term with no complications and the mother was well during the pregnancy. Imaging of the baby showed a severe coarctation of the aorta (shown below, coarctation indicated by white arrows).

39. What normal fetal structure indicated by the red arrow can allow the shunting of blood around the coarctation?
   - a. Allantois
   - **b. Ductus arteriosus**
   - c. Ligamentum arteriosum
   - d. Ligamentum venosum
   - e. Vitelline duct



A mother brings her 4-day-old infant with trisomy 21 to the pediatric emergency department for severe vomiting. She also notes that the infant has had very few, if any, stools since being born. A Lateral radiograph after water-soluble contrast enema administration shows a small, narrow rectum with a funnel-shaped transition zone into a mildly dilated sigmoid colon. A suction rectal biopsy is arranged to confirm the diagnosis.

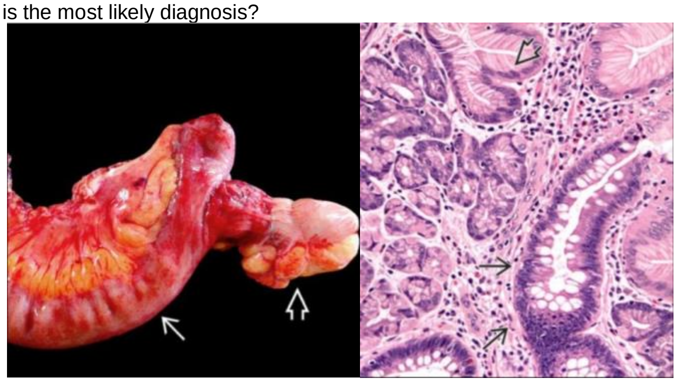
40. What cell type would be absent to confirm the likely diagnosis?



a. Enterocytes
b. Ganglion cells
c. Interstitial cells of Cajal
d. Myocytes
e. Nerves

A mother brings her 2-year-old son to the pediatric emergency department for abdominal pain. On further questioning the mother also indicates that her son has been experiencing intermittent blood in his stools. On exam, there was concern for appendicitis so her son was brought to the operating room for an appendectomy. At the time of the operation the appendix was normal; however, the structure indicated with the open arrow was noted arising from anti-mesenteric surface of the ileum. This segment of small bowel was resected by the surgeon and sent to pathology.

41. Examination of the sections from this area showed a mixture of gastric and intestinal mucosa shown below. What is the most likely diagnosis?



a. Ectopic appendix
b. **Meckel's diverticulum**
c. Mixed gastric intestinal polyp
d. Segment of intussusception
e. Small bowel adenocarcinoma

A 29-year-old pregnant woman, with an unremarkable past obstetrical history, has a fetal ultrasound performed at 13 weeks (shown). A follow-up blood test detects increased maternal alpha-fetoprotein levels.

42. Based on these findings, which of the following is the most likely cause of the developmental defect?

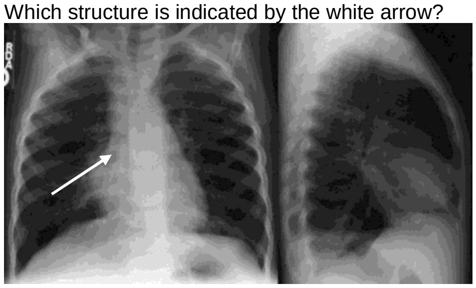
   a. Abnormal closure of the body wall causing a defect lateral to the umbilical cord
   b. Failure of neural crests to migrate into the intestines
   c. Failure of the intestines to return to the abdomen from the umbilical cord
   d. Failure of the vitelline duct to degenerate
   e. Increased intra-abdominal pressure causing the intestines to herniate

A 6-month-old infant presents to your clinic with a seal-like barking cough and stridor. Physical examination reveals a fever and tachypnea. The parents are anxious and would like you to prescribe something for their child.

43. Which of the following is the likely etiology of this infant's disease:
   a. H. influenzae
   b. M. pneumoniae
   c. Parainfluenza virus
   d. Respiratory syncytial virus
   e. S. pneumoniae

You are reviewing the film of a 15-month old with pulmonary infiltrates.

44. Which structure is indicated by the white arrow?



   a. Right atrium
   b. Right ventricle
   c. Left atrium
   d. Left ventricle

You could just say you're seeing a new-born with severe combined immunodeficiency and are educating the parent's about the infant's condition.

45. Which of the following best describes why a child with severe combined immunodeficiency may not start getting infections until around 6 months of age?
   a. Bone marrow production is focused on producing myeloid cells than lymphocytes
   b. Maternal antibodies provide a protective effect against infections
   c. Rapid turn over of B cells impedes the formation of an immune response
   d. The thymus has not fully matured in these infants

Appendix F: Example of pre-test assessment generalized feedback (Paediatrics) that was distributed to students after they completed the pre-test assessment to help guide their learning during the rotation.

#	Feedback
1	Pharmacology – side effects
2	Genetic conditions – mutations
3	Anatomy – GU development
4	Genetic conditions – patient presentation
5	Genetic conditions – complications
6	Anatomy – cardiac development
7	Pathology – heart
8	Anatomy – cardiac development
9	Physiology – immunology and vaccinations
10	Microbiology – infections
11	Pharmacology – infections
12	Anatomy – GU development
13	Pathology – nephrotic syndrome
14	Pharmacology – mechanism of action
15	Physiology – IV fluids
16	Physiology – IV fluids
17	Microbiology – GI infections
18	Pharmacology – immunology
19	Pharmacology – antibiotics
20	Pharmacology – mechanism of action
21	Microbiology – meningitis
22	Nutrition for infants
23	Nutrition – deficiencies
24	Nutrition – infant
25	Nutrition – deficiencies
26	Nutrition – deficiencies
27	Nutrition – deficiencies
28	Nutrition – deficiencies
29	Nutrition – infants
30	Anatomy – developmental milestones
31	Anatomy – developmental milestones
32	Anatomy – developmental milestones
33	Genetics – patterns of inheritance
34	Genetics – patterns of inheritance
35	Anatomy – approach to imaging, abdomen
36	Anatomy – approach to imaging, abdomen
37	Anatomy – approach to imaging, MSK
38	Anatomy – approach to imaging, CXR
39	Pharmacology – infections
40	Anatomy – heart development
41	Pathology – GI
42	Pathology – GI
43	Anatomy – GI development
44	Microbiology – infections
45	Anatomy – approach to imaging, CXR

Appendix G: Example of individualized post-test assessment feedback (Paediatrics) that was distributed to students after they completed the post-test assessment to provide them with formative feedback on the concepts deemed necessary by clerkship directors.

	STEM 1	STEM 2	STEM 3	STEM 4	STEM 5	STEM 6
Clinical Case	**Asthma**	**Down Syndrome**	**Turner Syndrome**	**ASD**	**Impetigo**	**Congenital Inguinal Hernia**
Question Topic	Pharmacology	Genetics	Genetics	Developemt	Microbiology	Development
		Development	Genetics	Pathology	Pharmacology	
				Development		
Total Questions	**1**	**2**	**2**	**3**	**2**	**1**
Pre-test Score						
Post-test Score						
Pre-test Mean Score						
Post-test Mean Score						

Curriculum Vitae

Name: Madeleine E. Norris

Post-secondary Education and Degrees:

University of Waterloo
Waterloo, Ontario, Canada
2009-2013 BSc. Kinesiology, Minor in Human Nutrition

The University of Western Ontario
London, Ontario, Canada
2014-2016 MSc. Clinical Anatomy

The University of Western Ontario
London, Ontario, Canada
2016-2020 Ph.D. Candidate

Honours and Awards:

Western Graduate Research Scholarship
2015-2020

Student-Postdoctoral Education Research Poster Presentation Award – 2nd place
American Association for Anatomy Annual Meeting
2019

American Association for Anatomy Travel Scholarship
2016-2019

Education Research Scholarship
American Association for Anatomy
2018-2019

Graduate Student/Post-Doc Poster Presentation Award
American Association for Anatomy Regional Meeting
2018

Francis Chan Humanitarian Award
Department of Anatomy and Cell Biology
2018

Student-Postdoctoral Education Research Poster Award – Finalist,
American Association for Anatomy Annual Meeting
2018

Ontario Graduate Scholarship
Province of Ontario Graduate Scholarship
2017-2018

Graduate Student Teaching Award,
Western University Society of Graduate Students
2017

Graduate Student Poster Presentation Award – 2nd Place
American Association for Anatomy Annual Meeting
2016

Related Work Experience

Instructor – Mammalian Histology
The University of Western Ontario
2016-2020

Head Teaching Assistant – Mammalian Histology
The University of Western Ontario
2016-2020

Teaching Assistant – Gross Anatomy, Histology
The University of Western Ontario
2014-2020

Teaching Assistant – Gross Anatomy, Neuroanatomy
University of Waterloo
2012-2013

Publications:

Norris ME, Cachia M, Johnson MI, Martin CM, Rogers KA. 2020. Are Clerks Proficient in the Basic Sciences? Assessment of Third-Year Medical Students' Basic Science Knowledge Prior to and at the Completion of Core Clerkship Rotations. Medical Science Educator. (*Submitted*)

Norris ME, Cachia M, Johnson MI, Rogers KA, Martin CM. 2020. Expectations and Perceptions of Students' Basic Science Knowledge: Through the Lens of Clerkship Directors. Medical Science Educator, 1-11. doi:10.1007/s40670-019-00913-z

Norris ME, Corbo G, Banga K, Johnson M, Sandig M, Smallman T, Getgood A, Burkhart T. 2018. The biomechanical & morphological characteristics of the ligamentum mucosum and its potential role in anterior knee pain. The Knee. 25(6):1134-1141. doi:10.1016/j.knee.2018.08.017

Corbo G, **Norris ME**, Getgood A, Burkhart T. 2017. The infra-meniscal fibers of the anterolateral ligament are stronger and stiffer than the supra-meniscal fibers despite similar histological characteristics. Knee Surgery, Sports Traumatology, Arthroscopy. 25(4):1078-1085. doi:10.1007/s00167-017-4424-y