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ORIGINAL RESEARCH

How Medical Students Apply Their Biomedical Science Knowledge to Patient Care in the Family Medicine Clerkship

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Abstract

Medical students enter clerkships with the requisite biomedical science knowledge to engage in supervised patient care. While poised to apply this knowledge, students face the cognitive challenge of transfer: applying knowledge learned in one context (i.e., preclinical classroom) to solve problems in a different context (i.e., patients in the clinic). To help students navigate this challenge, a structured reflection exercise was developed using Kolb's experiential learning cycle as an organizing framework. Students selected a patient encounter (concrete experience), wrote and addressed biomedical science learning objectives related to the care of the patient (reflective observation), reflected on how addressing the learning objectives influenced patient care (abstract conceptualization), and described their attending engaging in a similar process (active experimentation). A directed content analysis of students' written reflections revealed that most students wrote clinical science learning objectives in addition to biomedical science learning objectives. When viewed through the lenses of knowledge encapsulation theory and illness script theory, some students recognized knowledge encapsulation as a process beginning to occur in their own approach and their attendings' approach to clinical reasoning. Students readily applied their biomedical science knowledge to explain the pathophysiologic basis of disease (fault illness script domain) and signs and symptoms (consequence illness script domain), with fewer addressing predisposing conditions (enabling conditions illness script domain). Instances in which students observed their attending applying biomedical science knowledge were rare. Implications for using structured reflective writing as a tool to facilitate student application of their biomedical science knowledge in clerkships are discussed.

Keywords Biomedical science knowledge · Experiential learning · Structured reflection · Illness script theory · Knowledge encapsulation theory · Transfer

Introduction

Transition to clerkships is an important milestone for medical students and one of the most difficult transitions in their journey to becoming physicians. Students experience clerkships as stressful and anxiety provoking as they perceive gaps in their knowledge, navigate changing workplace social environments, and adjust to heavy workloads [1–5]. To address these challenges, the pre-clerkship curricula of most schools provide early clinical experiences, transition to clerkship courses, and transitional clerkships [2, 6–10]. Another challenge facing clerkship students is applying knowledge of the biomedical sciences learned in the pre-clerkship curriculum to care for patients. Studies show that students learn the biomedical sciences and pass exams but then struggle to apply that knowledge to solve or explain clinical problems [11]. This difficulty relates in part to the cognitive challenge of transfer, specifically transfer-out, in which knowledge acquired in one context (e.g., classroom, simulated, or virtual setting) is used to solve a new problem in another context (e.g., patient care in the clinical setting) [11]. Transfer-in, a related phenomenon, refers to the use of previously acquired knowledge (i.e., prior knowledge) to

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learn from new problems or learning situations [12]. Both forms of transfer are cognitively difficult yet vital in clinical practice.

To facilitate transfer of biomedical science knowledge to the clerkship setting, most medical schools have adopted integrated curricula, including integration across disciplines within a finite period of time (horizontal integration), integration across time (vertical integration), and a combination of horizontal and vertical integration (spiral integration) [13, 14]. A variety of teaching strategies are also used to explicitly integrate the biomedical and clinical sciences, such as problem-based learning, case-based learning, and high-fidelity mannequin and standardized patient simulations. More recently, the focus has shifted from how the biomedical and clinical sciences are sequenced and integrated in the curriculum to understanding the cognitive processes that occur in the students' minds. Studies show that even when the biomedical science content is directly followed by relevant clinical concepts, or vice versa, the temporal proximity between the two knowledge domains does not lead to integration for the learner [14, 15]. Thus, cognitive integration has gained recognition as a pedagogical strategy that purposefully links biomedical and clinical science concepts by facilitating an understanding of the causal mechanisms that produce signs and symptoms of disease [15, 16]. In contrast to the now pervasive integration of the clinical sciences into the pre-clerkship curriculum, approaches to integrate the biomedical sciences into clerkships using program-, clerkship-, and bedside-level innovations have only begun to gain traction [17–20]. Ideally, approaches to help students apply their biomedical science knowledge in the clinical environment would also provide them opportunities to develop self-directed learning skills to support lifelong learning [21].

While managing the cognitive challenges associated with knowledge transfer, students must also begin to hone their clinical reasoning skills, which are supported and guided by biomedical science knowledge [22, 23]. Knowledge encapsulation theory and illness script theory are two predominant theories for understanding how clinical reasoning evolves. Knowledge encapsulation theory posits that early in training, medical students focus on explaining the causes and consequences of disease in terms of the underlying pathophysiology. Over time and with increased clinical experience, biomedical science knowledge becomes closely linked with clinical knowledge and subsumed in the form of high-level explanatory models or diagnostic labels that "encapsulate" a larger number of lower-level concepts. Hence, this process is referred to as knowledge encapsulation [24, 25]. A second shift occurs when encapsulated knowledge is reorganized into illness scripts, which are knowledge networks stored in and retrieved from memory and used to support diagnostic reasoning [23, 26]. Illness script are precompiled knowledge structures representing clinical knowledge organized around three domains: enabling conditions (patient and contextual factors that influence the probability for disease), fault (underlying pathophysiologic causal mechanisms causing a particular condition), and consequences (signs and symptoms of the condition). With additional experience accumulated over years, expert physicians continually refine and expand their illness scripts.

To provide insight into how clerkship students begin to apply their biomedical science knowledge to care for patients, we previously designed a reflective writing exercise using Kolb's experiential learning cycle as an organizing framework [27]. This study revealed that clerkship students perceived the relevance of their biomedical science knowledge to (1) the practice of medicine (i.e., knowledge required to make a diagnosis, manage patients, tolerate ambiguity, and ensure patient safety), (2) continued learning throughout practice (i.e., lifelong learning), (3) establishing relationships with patients (i.e., to educate and empower patients and to develop patients' trust), and (4) support their emerging professional identity as a physician (i.e., develop confidence and competence and transition from layperson to physician). Although clerkship students recognize the importance of their biomedical science knowledge, whether they can be effectively guided through the process of applying it in the context of patients encountered during clerkship rotations remains underexplored. Therefore, in the present study, we modified our reflective writing exercise to help guide clerkship students through the process of applying their biomedical science knowledge. The completed exercises were analyzed and viewed through the lenses of knowledge encapsulation theory and illness script theory. Here, we provide an in-depth analysis of the students' reflective writing exercises and share insights that may be used by others to help students with the cognitive challenges of transfer, lifelong learning, knowledge encapsulation, and illness script formation.

Materials and Methods

Participants

A purposive sampling strategy was used to select study participants, which included medical students enrolled at the Western Michigan University Homer Stryker M.D. School of Medicine in the Family Medicine clerkship rotations (47 of 72 students). Students whose curriculum was reorganized in response to the COVID-19 pandemic were not included in the study.

Study Context

This study took place at the Western Michigan University Homer Stryker M.D. School of Medicine, a private not-for-profit graduate entry medical school. The curriculum and teaching methods used to deliver the curriculum have been previously described in detail [28].

Structured Reflection Exercise

Several revisions were made to the reflective writing exercise described in our previous study [27]. First, to focus the exercise entirely on the four cycles of Kolb's experiential learning theory, we eliminated the initial essay addressing "how is biomedical science knowledge relevant to clinical medicine?" Next, because students in previous cohorts preferentially chose complex patient cases for the exercise, the instructions were modified to prompt students to select their next patient encounter that was not a health maintenance or well child exam. This encouraged student application of biomedical science knowledge to all conditions or diseases typically encountered by a family medicine physician. Second, because many students failed to write demonstrable learning objectives, a table adapted from Anderson and Krathwohl's revision of Bloom's taxonomy was provided to help students write learning objectives. This list of verbs for writing learning objectives included six domains (remember, understand, apply, analyze, evaluate, and create), which range from lower order to higher order. Third, a list of biomedical science disciplines was provided to cue students to explore a variety of disciplines applicable to patient care. Finally, clearer instructions were provided to improve students' description of what they learned by addressing their learning objectives.

With these revisions, the structured reflective writing exercise (Appendix 1) first prompted students to identify their next patient encounter and to reflect on aspects of the patient's condition requiring them to access and/or expand their biomedical science knowledge (concrete experience). They then wrote 3–5 biomedical science learning objectives related to the care of the patient, identified appropriate learning resources to acquire new knowledge, and explained the biomedical science links they discovered (reflective observation). Learning objectives were crafted using Bloom's taxonomy of verbs to make them actionable objectives to support the reflective process. Students next reflected on how engaging in this process influenced their care of the patient and how it might influence the care of other patients in the future (abstract conceptualization). In the final step of Kolb cycle, students described a situation in which their attending used a similar reflective process in patient management (active experimentation).

Completion of the exercise was required to pass the clerkship. Exercises were reviewed by the clerkship director (not a member of the study team) and informed the narrative comments provided to students by the clerkship director upon completion of the rotation.

Data Collection and Analysis

Student exercises were collected and de-identified by an administrative assistant. Two members of the research team (B. L. D. and K. A. P.-S.) who were not involved in assessing student performance in the family medicine clerkship, individually performed a directed content analysis of all of the reflective writing exercises [29]. Differences in data analysis were resolved by discussion. ATLAS.ti was used for data organization and analysis (ATLAS.ti Scientific Software Development GmbH). All members of the study team reviewed the reflective writing exercises and contributed to the final report. A description of how each section of the exercise was analyzed is provided in Table 1.

Table 1 Approach to data analysis

Exercise section and Kolb cycle	Analysis
1: concrete experience	• Reason for visit/patient concern • Relevant history and exam • Assessment/diagnosis • Management plan
2A: reflective observation	• Biomedical science learning objectives • Clinically oriented learning objectives
2B and 3: reflective observation and abstract conceptualization	• Biomedical science disciplines utilized • Clinical reasoning • Application of biomedical science knowledge to address illness script domains • Perception of biomedical science knowledge as relevant and contributory to development of medical expertise and professional identity formation • Utility of assignment
4: active experimentation	• Observation of attending applying biomedical science concepts to patient care • Observation of attending engaging in a reflective process like that described in the assignment

Philosophical and Theoretical Bases of the Study

A developmental perspective guided the development of the exercise to promote student reflection on learning and to help students reframe clerkship transition as a transformative process [1, 30]. To design the reflective writing exercise, we embraced the constructivist view that individuals construct new knowledge from experience and by reflecting on that experience. The Kolb experiential learning cycle was selected in recognition of the highly experiential form of learning that occurs in the clinical environment [31, 32]. The last prompt of the exercise was shaped by Billett's workplace learning theory to recognize the socio-cultural learning that occurs between students and clinical educators in the workplace [33].

Reflexivity

Five authors (B. L. D., K. V., K. G., K. A. P.-S., and L. G.) published a previous manuscript that informed this study [27]. Their review of the student exercises from prior classes resulted in revisions to the instructions with the goal of stimulating student reflection and eliciting responses to exercise prompts to facilitate students' application of biomedical science knowledge.

Rigor and Quality

Investigator credibility/trustworthiness was ensured by investigator triangulation by including two biomedical science faculty (B. L. D. and K. A. P.-S.), three clinical faculty (K. V., K. G., and L. G.), and a medical student (E. S.) on the research team. Involving multiple researchers in analyzing the data enabled diverse observations and different perspectives to be expressed [34]. Theory triangulation was achieved by using more than one theoretical framework in the interpretation of the data, specifically experiential learning theory, knowledge encapsulation theory, and illness script theory.

Compliance with Ethical Standards

The Western Michigan University Homer Stryker M.D. School of Medicine Institutional Review Board determined this study to be exempt under 46 CFR 46.101(b), 1.

Results

Concrete Experience and Reflective Observation

Students described a wide variety of both common (e.g., community-acquired pneumonia and sinus headache) and less common (e.g., glioblastoma multiforme and idiopathic asymptomatic anemia) presumptive or confirmed diagnoses for their patient encounters. All but one student provided thorough and rich descriptions of the presenting concern, relevant history, available exam findings, and assessment and plan. When prompted to write learning objectives that addressed foundational biomedical science knowledge underlying the patient's reason for visit/patient concern, most students (44 students, 94%) wrote between 1 and 8 biomedical science learning objectives (Table 2). Although unprompted, most students also wrote between 1 and 10 learning objectives focused on clinical aspects of

Table 2 Student-generated learning objectives

Biomedical science learning objectives	
Presumptive or confirmed diagnosis	**Learning objective (Bloom's taxonomy level)**
Herpes zoster ophthalmicus	"Explain the mechanism of the pharmacotherapy used for a patient with a Varicella-zoster virus infection." (Understand)
Right-sided pneumonia	"Distinguish the key differences between the two pneumococcal vaccines. Compare the type of vaccine they are and the MOA in the body (type of antibodies it generates)." (Analyze)
Cervical intraepithelial neoplasia grade 3	"Describe the histologic changes seen in CIN." (Understand)
Clinical learning objectives	
Presumptive or confirmed diagnosis	**Learning objective (Bloom's taxonomy level)**
Herpes zoster	"Outline the recommended vaccination schedules for varicella and shingles." (Analyze)
Bilateral Morton's neuroma secondary to type 2 diabetes	"Discuss the potential morbidity of this patient if his diabetes remained uncontrolled, including effects to his daily pain and suffering, his ability to work, and the effects on his mental health." (Understand)
Ankle sprain, grade 1 or 2, involving the anterior talofibular ligament	"Utilize the Ottawa ankle rules for evaluating ankle pain to decide whether or not to x-ray." (Apply)

care (41 students, 87%) (Table 2). By contrast, few students exclusively wrote biomedical science learning objectives (6 students, 13%) or clinical learning objectives (3 students, 6%), with the majority writing a combination of both (38 students, 81%).

Abstract Conceptualization

Half of the students "unpacked" their learning objectives, making links between biomedical science concepts and their patient's presenting concern, signs, and symptoms, and most used the exercise to revisit and build their fund of biomedical science knowledge (25 students, 53%) (Table 3). The other half did not demonstrate meeting their learning objectives and instead wrote statements reflecting weak or poor application of the biomedical sciences (22 students, 47%):

> … pseudomonas exotoxin A functions in much the same way as diphtheria toxin does… empiric coverage of enterococcus can be a little difficult. Enterococcus has developed resistance to several antibiotics recently, including vancomycin.

Table 3 Examples of students' application of biomedical science knowledge

Biomedical science discipline	Presumptive or confirmed diagnosis	Student examples
Genetics	Basal cell carcinoma	"… metastatic forms of BCC are more likely to have p53 mutations in addition to their PTCH mutations, while less invasive forms of BCC are more likely to have bcl-2 mutations. The distinguishing factor between the two is that bcl-2 mutations generally promote cell survival, while p53 mutations also promote cell proliferation, leading to growth and increased mutation."
Molecular biology	Herpes zoster	"[Antivirals] are monophosphorylated by viral thymidylate kinase, which creates a structure similar enough to a nucleoside that the host's cellular machinery recognizes the analog and subsequently phosphorylates them to become triphosphorylated nucleotide analogs. These analogs have no ribose sugar and therefore have no 3'OH group necessary for continued DNA synthesis. Once these analogs are incorporated into the host or viral genome during DNA synthesis, replication is terminated. This ultimately leads to death of the host cell and suppression of viral replication."
Neuroscience	Hypoxia secondary to chronic obstructive pulmonary disease and lung cancer	"Nicotine … stimulates nicotinic receptors in autonomic ganglia. This causes both sympathetic and parasympathetic stimulation and leads to euphoria. Withdrawal from nicotine results in dysphoria, irritability, frustration, restlessness, and anxiety."
Pathology	Alcoholic cirrhosis with recurrent ascites	"Cirrhosis is the process of progressive fibrosis of the liver. This damage results in distortion of architecture and formation of regenerative nodules. In general, cirrhosis results from chronic damage to the liver through either inflammation or cholestasis. This constant damage causes the normal hepatocytes to be replaced by fibroblasts, forming the bands of fibrosis found on histologic liver specimens. The death of hepatocytes also prompts the remodeling cycle that causes the formation of the regenerative nodules seen on histological specimens."
Pharmacology	Coagulopathy secondary to hepatocellular carcinoma	"… clopidogrel and ticagrelor … block ADP from binding the P2Y12 receptor on platelets, a key biochemical step in getting platelets to aggregate with each other … drugs such as apixaban and rivaroxaban work by inhibiting Factor X directly. Factor X is the key protein that sits at the center of the two clotting cascade pathways… Out of all the antithrombotic medications only warfarin would result in less clotting factors present in a patient's blood. The other drugs do not work at the level of hepatic protein synthesis required to block creation of the factors."

Consistent with the numerous clinically oriented learning objectives, many students wrote statements focused on clinical reasoning or clinical aspects of care (31 students, 66%):

> In researching spinal pain [I] learned a number of new physical exam techniques that I was able to utilize in the exam room. These include tests for cervical radiculopathy such as the Spurling's test, where the head is flexed various directions by the examiner. Additionally, I learned the Valsalva maneuver can be utilized to look for the presence of stenosis in the spinal column due to increases in intrathoracic pressure.

Active Experimentation

When asked to comment on an instance in which they observed their attending physician applying biomedical science concepts to patient care or engaging in a similar reflective process, 18 students provided examples:

> My preceptor then delved back into the basic science to brush up on the pathology of hemangiomas, how they affect the physiology of the body including liver enzymes…

Knowledge Encapsulation Theory and Illness Script Theory

Although unprompted, 9 students recognized knowledge encapsulation as part of their development as physicians in training:

> Some of the knowledge of disease processes and treatments has become almost second nature for me as a 3rd year medical student and I would imagine even more so for an attending physician.

In addition, 8 students cited examples of knowledge encapsulation as part of their attendings' practice and thought process. Three of these students were those that also recognized knowledge encapsulation as important to their own development as physicians in training:

> … my attending doesn't necessarily have to consider the pathophysiology and basic science of disease. He has reached the point in his career where he has assigned treatments to various clinical presentations.

Few students applied biomedical science concepts to explain how predisposing conditions contributed to the patient's reason for visit/patient concern (i.e., the enabling condition illness script domain) (9 students, 19%) (Table 4). By contrast, more students applied their biomedical science knowledge to explain the pathophysiologic basis of disease (i.e., fault illness script domain) (19 students, 40%) and to explain signs and symptoms (i.e., consequences illness script domain) (18 students, 38%) (Table 4).

Expertise Development and Professional Identity Formation

To determine whether this reflective exercise prompted students to reflect on and articulate the importance of their biomedical science knowledge to the development of expertise and professional identity formation, we examined exercises

Table 4 Biomedical science knowledge applied to illness script domains

Illness script domain	Presumptive or confirmed diagnosis	Examples
Enabling condition	Pulmonary embolism versus acute exacerbation of heart failure with reduced ejection fraction	"… nephrotic syndromes decrease protein, which decreases the amount of ATIII in circulation, predisposing patients to thrombosis … there is a possibility that her history predisposed her to have another PE, resulting in dyspnea."
Fault	Acute exacerbation of chronic obstructive pulmonary disease	"Emphysema … is characterized by enlargement of the alveoli and the destruction of the alveoli's elastic recoil ability. The majority of the changes in COPD are in the airways themselves but the vasculature and parenchyma are also affected. There are an increased number of goblet cells, mucus gland hyperplasia, destruction of small airways, and alveolar wall destruction."
Consequence	Radiculopathy secondary to disc herniation	"With her history of breast cancer, it is possible that the leg pain was due to a paraneoplastic syndrome. Compression of the spinal cord due to a tumor or due to substances released by a tumor could explain some of the symptoms. Her symptoms could also be due to chemotherapy-associated peripheral neuropathy, in which case stopping the tamoxifen would help with symptoms …"

for examples of the codes identified in our previous qualitative research study [27]. All but 1 of the 10 codes, transition from layperson to physician, were identified by students' exercises (Table 5).

Student Perceptions of the Exercise

Although students were not asked to comment on the practicality of the exercise, many mentioned that they found it useful (31 students, 66%):

> This allowed for an exercise that is not typically done in medical school, or likely even residency which is answering the question of 'why' rather than 'what'… Answering the 'why' is crucial in furthering our understanding of medical management principles…

Three students, however, commented that the exercise was not useful and/or practical. In addition, 9 students articulated insights or discoveries they made while completing the exercise:

Table 5 Application of biomedical science knowledge to support the practice of medicine, lifelong learning, building relationships with patients, and developing a perception of self as a physician in training

Theme	Code	Example
Knowledge to practice medicine	Diagnosis	"It's important to be able to identify these organisms and one of the primary ways of doing so is recognizing them on a sputum sample. This also includes knowing the best way to diagnose organisms that may not be seen on atypical sputum stain or culture, including *M. pneumoniae* and *Legionella*. These organisms are intracellular-dwellers, so unique methods are needed to diagnose them."
	Patient management	"… understanding the course of illness of viral vs bacterial infections, firstly, helped narrow down what type of infection the patient [had]. This is important because it greatly influences what the diagnostic and treatment protocol are – yes or no chest X-ray; yes or no rapid strep test; supportive treatment vs antibiotics."
	Tolerance of ambiguity	"Other professions may be taught to recognize patterns and follow algorithms, but there are so many cases that don't fit those protocols. … Each time you reflect on a case, you gain insight into why certain practices are the way they are, and also develop a sense of what to do when problems don't fit a certain mold."
	Patient safety	"Tylenol was prescribed in this patient because NSAIDs are harder on the kidneys and diabetics often have kidney disease. I will review metabolism/excretion pathways of various drugs to prevent giving them to patients with impaired metabolic/excretory systems for those drugs."
Lifelong learning	Continue learning throughout practice	"This has also allowed me to reflect on the need for physicians to be self-directed learners while in practice. …. It is important to reflect on one's areas of knowledge deficit, develop learning objectives or questions that need to be addressed, and efficiently research those topics. I will try to use this strategy in the future when I am researching a new topic. This will only become more important with the fast pace data driven era of medicine that we live in."
Physician–patient relationship	Educate patients	"If patient's taking Coumadin have INRs that are sub-therapeutic, I can discuss dietary factors that may be influencing the effectiveness of Coumadin given the relationship to vitamin K."
	Empower patients	"The ability to explain why someone is experiencing a symptom in a clear and understandable way enhances the bond between a patient and physician. Understanding the basic science principles provides the tools to have these discussions with patients and engage them in their treatment plan."
	Develop patient trust	"Without confidence, you will be less likely to garner trust with the patient, which can result in the patient withholding key pieces of the clinical picture from you, or even cause the patient to lose trust in healthcare and fail to seek medical care during future illnesses or times of crisis."
Learner perception of self	Develop confidence and competence as a physician	"Overall, my care of this patient [with essential hypertension] was not changed dramatically by my better understanding of his underlying condition, but I felt more confident in providing care for him…"

> … building an understanding of the basic science allows you to not just regurgitate lists of possible problems and possible solutions, but instead break down what is happening at a chemical, molecular, physiologic, or anatomic level in your patient. It broadens your ability to not just solve old problems that are already known, but to know how to solve new problems that have not yet been encountered.

Discussion

The structured reflective writing exercise described in this study provided students an opportunity to apply Kolb's experiential learning model to a patient encounter. Students wrote rich descriptions of these encounters with details of past medical histories, presenting concerns, findings on physical exams, differential diagnoses, and assessment and treatment plans, which was unsurprising given the students' focus on diagnosis and treatment during clerkships. Although students were asked to use their next patient encounter for the exercise, many students selected patients with conditions or diseases uncommon to those typically encountered in family medicine. This suggests that students perceived complex cases, but not common ones, as requiring application of biomedical science knowledge even though routine cases (e.g., acute otitis media, arthritis, dermatitis) offer ample opportunities to apply biomedical science concepts. This finding is supported by another study, which found that internal medicine teams on teaching rounds primarily discussed biomedical science content when the patient was complex [35]. Interestingly, although the exercise clearly asked students to write and address biomedical science learning objectives, most students also wrote and addressed clinical science learning objectives, perhaps reflecting the perceived expectation to "think like a clinician" in clerkships. Providing students with a worked example that includes biomedical science learning objectives and explicit links to patient encounters may be required to fully engage students in thinking about and applying their biomedical science knowledge.

When asked to describe how addressing their biomedical science learning objectives impacted patient care, many students missed the opportunity to unpack their learning. As mentioned above, this may reflect their perceived expectations of performance in the clinical environment. We encouraged students to use their attendings as a resource to understand the step-by-step reasoning used to develop a management plan. This was designed to address a criticism of the Kolb cycle as focused on individual learning and to recognize that knowledge is socially constructed [33]. Nonetheless, few students observed or commented on their attending engaging in a similar process of reflecting on and applying biomedical science concepts. This may be explained by the process of knowledge encapsulation and use of illness scripts by attendings, who are advanced learners. Because the internal dialogs and thought processes of the attendings were unavailable to students, most were unable to identify examples of their attendings using biomedical science knowledge. Verbalizing and sharing these processes with students would likely facilitate student learning and help to bridge the gap between the pre-clerkship and clerkship curriculum. This may require facilitating attending physicians' recognition of knowledge encapsulation and use of illness scripts.

When exercises were viewed through the lenses of knowledge encapsulation and illness script theory, we observed that some students recognized that knowledge encapsulation occurs over time and with increasing exposure to patients, and a few students recognized it as part of their attendings' approach to patient care. Perhaps unsurprisingly, students primarily applied their biomedical science knowledge to address the fault illness script domain, consistent with the tendency of novice learners to explain causal mechanisms in terms of biomedical science concepts [23]. Students also used their biomedical science knowledge to explain signs and symptoms associated with the fault, with fewer students utilizing biomedical science knowledge to explain enabling conditions, which is a process more prevalent in expert physicians [23].

The findings of this study validated those from our previous study in which students perceived their biomedical science knowledge as necessary for the practice of medicine, required for lifelong learning, and essential to developing physician–patient relationships [27]. Students also recognize their biomedical science as integral to developing confidence and competence as a physician, but they did not acknowledge its role in the transition from layperson to physician. Whether the ways in which biomedical science knowledge contributes to professional identity formation is not fully visible to students at this point in their training or the modifications that were made to the exercise rendered this connection less accessible remain to be examined.

In general, the structured reflection exercise was simple to implement and was completed by three graduating classes at our institution, suggesting sustainability and transferability. Students in the preceding two classes completed the exercise as part of either their pediatric or family medicine clerkship, suggesting generalizability to other clerkship disciplines. An orientation to the exercise and training may be needed to help attendings articulate their thought processes when working with students. In addition, providing first- and second-year students with examples of student reflections may serve as a near-peer learning opportunity to ease the transition to clerkships. Providing students with feedback on the exercises may expand their understanding of how the biomedical sciences are clinically relevant. Finally, enabling students to involve their attendings in the entirety of the exercise would strengthen social interactions between students and attendings as the students would see experts in the field actively using biomedical science knowledge.

Study Strengths and Limitations

The structured reflective writing exercise had no significant impact on student grades or ranking, and students completed the exercise on their own. These factors likely provided a safe space for authentic reflection. A limitation of the study was that it was conducted at a single institution. In addition, the students took their first medial licensing examination (US Medical Licensing Examination Step 1), which is predominantly focused on application of the biomedical sciences to the practice of medicine, mid-way through clerkships. Therefore, their responses to the exercise prompts may have reflected a timing effect as they were engaged in studying for this examination.

Conclusions

We describe a structured reflective writing exercise developed to facilitate the application and integration of biomedical science knowledge to patient care. Providing opportunities for students to create relationships between the biomedical and clinical sciences is important. When left to chance, a "transmission" model of knowledge from senior team members (residents or attending physicians) to junior team members (medical students) with only brief discussions, a sentence or two, rather than a learner-centered model may be adopted [35]. Using Kolb's experiential learning theory, students discovered important biomedical science links to their patients' clinical conditions and demonstrated varying degrees of appreciating the processes of knowledge encapsulation and illness script formation, consistent with their early stage of clinical training. Continuing to evolve our understanding of how and when clerkship students apply their biomedical science knowledge to patient care has important implications for creating strategies, tools, and curricula that promote the application of biomedical science knowledge to support clinical reasoning and decision-making.

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Data Availability Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Ethics Approval The Western Michigan University Homer Stryker M.D. School of Medicine Institutional Review Board has confirmed that no ethical approval is required.

Conflict of Interest The authors declare no competing interests.

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