Enhancing Basic Sciences Teaching:

The Need for More Theory and Focus on Transfer to Clinical Reasoning

BY

JEAN-MARIE CASTILLO
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THESIS

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Defense Committee:

Yoon Soo Park, Chair and Advisor
Ilene Harris
Nicole Woods, University of Toronto

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SUMMARY

"Transfer" is the application of a previously learned concept to solve a new problem in another context. Transfer is a critical, but difficult, dimension of basic sciences education. Limited understanding of effective interventions in health professions education (HPE) can hamper teachers and researchers from enhancing transfer of learning.

This study identifies interventions designed to develop basic sciences knowledge in HPE and describes their contexts, approaches and outcomes. This study also examines evidence of interventions fostering our understanding of basic sciences education, and particularly studies documenting transfer of basic sciences knowledge to foster clinical reasoning.

An integrative literature review was conducted to identify articles related to basic sciences teaching at the "undergraduate level" in HPE, published between 1980 and 2015, including learning outcomes. Articles were selected and summarized based on their context, approaches, and outcomes. Articles reporting interventions that enhance understanding of basic sciences education were analyzed.

Out of 9,803 articles initially identified, 78 were selected for further review; ninety-eight percent (98%) focused on how to introduce the basic sciences learning concept and the remaining 2% focused on the practice of multiple clinical problems to teach the learning concept. The methods of transfer were explored in 35% of the papers. Eighty-five percent (85%) were practice-based research, 15% were use-inspired basic research (i.e., goal of improving practice and understanding of the phenomenon studied). Teaching interventions that were successful to enhance the transfer of basic sciences learning concepts to clinical reasoning developed deep conceptual structures of the learning concepts. The development of such deep conceptual structures was achieved in these studies through the presentation of causal mechanisms of clinical features or analogies, and the practice of multiple problems in multiple contexts. Factual recall memory tests did not detect differences in transfer.

Evidence is still lacking regarding transfer of basic sciences knowledge to clinical reasoning in HPE. A theoretically-grounded focus on transfer and its understanding is likely to support the development of basic sciences education.

1. INTRODUCTION

Education in the basic biomedical sciences is a major component of health professions education (HPE). Since the Flexner report, it has been argued that the importance of basic sciences education in HPE lies in its role as a foundation for clinical reasoning in future practice.[1–4] Although the value of basic sciences education in HPE has been extensively discussed, there has been limited discussion on the approaches by which basic sciences education helps students transfer basic sciences knowledge to inform their clinical reasoning.[5] There have been numerous experimental studies focused on basic sciences education in HPE. However, in HPE, we still lack an evidence-based understanding of approaches for teaching the basic sciences in order to optimize knowledge transfer to clinical reasoning.[6] In particular, there is limited evidence regarding the teaching methods used in basic sciences education, the types of outcomes assessed, and most importantly, whether basic sciences education has been successful in helping students transfer their basic sciences knowledge to clinical reasoning. Identifying educational practices that enhance the transfer of basic sciences knowledge to clinical reasoning is critical in helping educators develop conceptual frameworks and best practices for HPE basic sciences curricula and education. It is vital for the field of HPE to identify studies which provide insights regarding students' transfer of basic sciences knowledge to the activity of clinical reasoning. This will help both teachers and researchers in developing guidelines for translational research and expanding the evidence base for education approaches supporting the direct transfer of basic sciences knowledge to clinical reasoning. This study contributes to addressing this need, by conducting a review of the literature focused on basic sciences education in HPE and to systematically document evidence supporting the understanding of basic sciences education, and particularly studies documenting the transfer of basic sciences knowledge to clinical reasoning.

Since the publication of the Flexner report,[1] basic sciences teaching has become firmly established as a cornerstone in HPE curricula. The traditional "2+2" medical curriculum, comprising two years of basic sciences education followed by two years of clinical apprenticeship, was implemented widely in the United States[7] and in Canada.[8] Nevertheless, some scholars have argued that this model of education is insufficient to effectively develop future physicians.[4,9] With an ever-expanding knowledge base in basic sciences, this sequential approach to teaching basic and clinical sciences may not facilitate the importance and relevance of basic sciences knowledge likely to support clinical practice.[9,10] On the contrary, it has been argued that the "2+2" curriculum has the unintended consequence of masking the value of basic sciences, while emphasizing clinical knowledge and experience as the basis of future medical practice. In response to these limitations of the "2+2" curriculum, the construct of integration has been developed as a curricular strategy[11] to better link basic and clinical sciences education and, therefore, support the value and educational role of basic sciences knowledge. Integration can be defined as a deliberate process to connect discrete elements[12] to serve curricular goals and may be applied through interventions implemented at different levels of the curriculum.[11]

Multiple approaches aimed at integrating basic and clinical sciences have been described, but identification of optimal formats of integration still challenges the field.[13] Reports from leading educators and education agencies in the United States[14] and in Canada[15] have recently reinforced the importance of achieving better integration between basic and clinical sciences education. The Association of Faculties of Medicine of Canada (AFMC) stated that "the physician of the future requires skills that will involve further adaptations and reforms to our medical systems" and asserted that "both human and biological sciences must be learned in relevant and immediate clinical contexts throughout the MD education experience".[15] While the aspiration for a better integration of basic and clinical sciences has been identified, it remains unclear how to effectively enhance existing curricula. Each context is unique and each curriculum may need specific adjustments. Therefore, to better support educators and institutions in achieving these recommendations, it is important to understand the role of basic sciences in clinical reasoning.

Research in expert problem-solving suggests that the role of biomedical knowledge in clinical reasoning is predominantly tacit.[16] Biomedical knowledge can be retrieved by the medical expert when prompted, but experts do not necessarily require conscious role in clinical reasoning, especially with familiar problems.[17] The tacit role of biomedical knowledge in clinical reasoning results from the mental representations of diseases in which biomedical knowledge is encapsulated with clinical knowledge through “diagnostic labels or high-level, simplified causal models that explain signs and symptoms”.[18] In other words, expert physicians cluster symptoms into meaningful patterns based on implicit pathophysiological knowledge and a repertoire of experience.[16] For example, if a patient presents with fever, shivers, sweating, toxic appearance, prostration and high pulse rate,[19] a novice student may independently process each feature whereas an expert will automatically cluster these features in the biomedical concept of ’sepsis’ to solve the problem (i.e., systemic response of the body to an infection).[19] The concept of ‘sepsis’ encapsulates all the features described and presents a way to explain them simultaneously, thus facilitating problem-solving.[19]

The value of basic sciences in clinical reasoning goes beyond development of static knowledge structures. Rather, basic science knowledge provides dynamic mental structures to support medical problem-solving. For this reason, the research and scholarship focused on basic sciences education must extend beyond the focus on curricular integration of basic and clinical sciences knowledge to explore how basic sciences education can be developed to support problem-solving in clinical reasoning. In other words, the value of basic sciences knowledge lies in its potential to support the application of “knowledge acquired in one context to solve a new dissimilar problem in another context", thus defining transfer of knowledge to support clinical reasoning.[6]

The problem of optimizing the transfer of basic sciences knowledge to clinical reasoning presents a complex curricular challenge to HPE.[6] Transfer of knowledge from one context to another is important, but transfer of knowledge is also difficult.[6] Successful retrieval of a previously learned concept to solve new problems depends on the problem mental representation[6], described by Feltovich et al. as a cognitive structure using knowledge and its organization as the basis.[20] In order to use a concept in clinical reasoning, the trainee must first effectively characterize the problem; and when the application of the concept to the problem is completed, the problem is essentially solved.[6] The difficulty in identifying the applicability of the concept to the problem comes from the fact that "the similarity must be identified at the level of the deep (conceptual) structure"[6] (e.g., laminar-turbulent flow in fluid dynamics can be identified in both the cardiovascular and the respiratory systems[21]). The ability to identify deep conceptual structures in clinical problems is limited in novices, because they represent problems by surface structures, whereas experts "see the problem as an underlying principle".[6] In other words, when encountering a new problem, a novice is more likely to build his mental representation of the problem based on contextual and superficial cues (i.e., what is visible). The superficial representation of the problem can be misleading as it hampers identification of the correct basic science concepts to solve the problem. Conversely, an expert will build his representation of the problem by abstracting the underlying concept that lies below the surface details, thus facilitating the correct retrieval of the appropriate basic science knowledge.[21] For example, in a physics problem, experts identified conservation of the momentum while novices focused on contextual details such as inclined plane.[22]

The development of deep (conceptual) structures that foster transfer of basic sciences knowledge to clinical reasoning should therefore be a primary goal of basic sciences education.

The literature on basic sciences education in HPE, especially those interventions that focus on transfer of basic science knowledge to clinical reasoning, might shed some much needed light on the education, teaching and learning approaches that might best support transfer of basic sciences knowledge to clinical reasoning. Thus, a synthesis of what is currently known is needed to improve our understanding of effective interventions that support teachers in encouraging transfer of basic science knowledge to clinical reasoning and to aid researchers in guiding their scholarship in basic sciences education.

In this paper, we conducted a review of the literature to identify education interventions designed to develop basic sciences knowledge in HPE and describe their contexts, approaches and outcomes. We also sought to explore the available evidence regarding the interventions fostering our understanding of basic sciences education, and particularly the studies documenting transfer of basic sciences knowledge to clinical reasoning.

2. METHODS

Evidence synthesis constitutes an important category of knowledge translation in HPE research. This study used an integrative review to gather evidence from the literature. Traditional Cochrane-like systematic reviews are designed to answer focused research questions by collecting and analyzing "all evidence that fits pre-specified eligibility criteria".[23] Moreover, systematic reviews have largely been used to document evidence on a wide range of topics,[24] but they may not be the most appropriate methods for all types of evidence synthesis.[25–27] Systematic reviews are designed to provide an answer relevant to a single, empirical, focused question, but are less appropriate if the purpose aim of the review is to provide a richer understanding of a phenomenon such as a concept/intervention. Therefore, we conducted an integrative review.

2.1 Conceptual Framework: Integrative Review

An integrative review is a synthesis methodology that summarizes previous empirical or theoretical evidence to provide a greater understanding of a specific phenomenon or healthcare problem.[28] Integrative reviews present the current evidence, support theory building, and directly apply to practice and policy.[29] Integrative reviews have the potential to comprehensively portray concepts, theories, or healthcare problems by the ability to capture the context, processes and subjective elements on the topic. [29]

2.2 Search Strategy

PubMed, EMBASE, PsycINFO, ERIC, Web of Science, EBSCOhost's Professional Development Collection, and CINAHL were used to conduct the literature search based on a comprehensive search strategy developed collaboratively with a medical informationist.

The search strategy was designed to retrieve citations from the intersection of two concept sets: 1) the basic sciences disciplines (e.g., anatomy, physiology) together with 2) HPE categories associated with medicine, dentistry, nursing, pharmacy and psychology. Filters were applied to limit citations to those articles published in English or French between 1980 and 2015.

Targeted articles were peer-reviewed original articles related to the teaching of basic sciences at the "undergraduate level" in the health professions and including the assessment of at least one learning outcome.[30] Additional inclusion criteria included a comparison group, an explicit randomization of groups, and an intervention that would typically fit within the normal curriculum (i.e., excluding interventions designed to explore alternative formats such as intensive trainings or boot camps). Additional exclusion criteria comprised of correlational studies, historical control group, control group at another institution, and interventions based on assessment strategies (e.g., formative testing).

2.3 Selection and Appraisal of Documents

Following the initial database search, the titles and abstracts of retrieved article citations were screened to identify those potentially describing an intervention in basic sciences instruction and measures of educational outcomes (JMC, MDC). Then, selected articles were evaluated for eligibility and study inclusion by a pair of reviewers based on full-text readings (JMC, MDC). Inter-rater agreement was 91%; disagreements were resolved by discussion.

2.4 Data Extraction and Analysis

Pairs of trained reviewers extracted data for analyses by category (JMC, MDC, JJC, LS). Any disagreements were resolved by discussion to reach consensus.

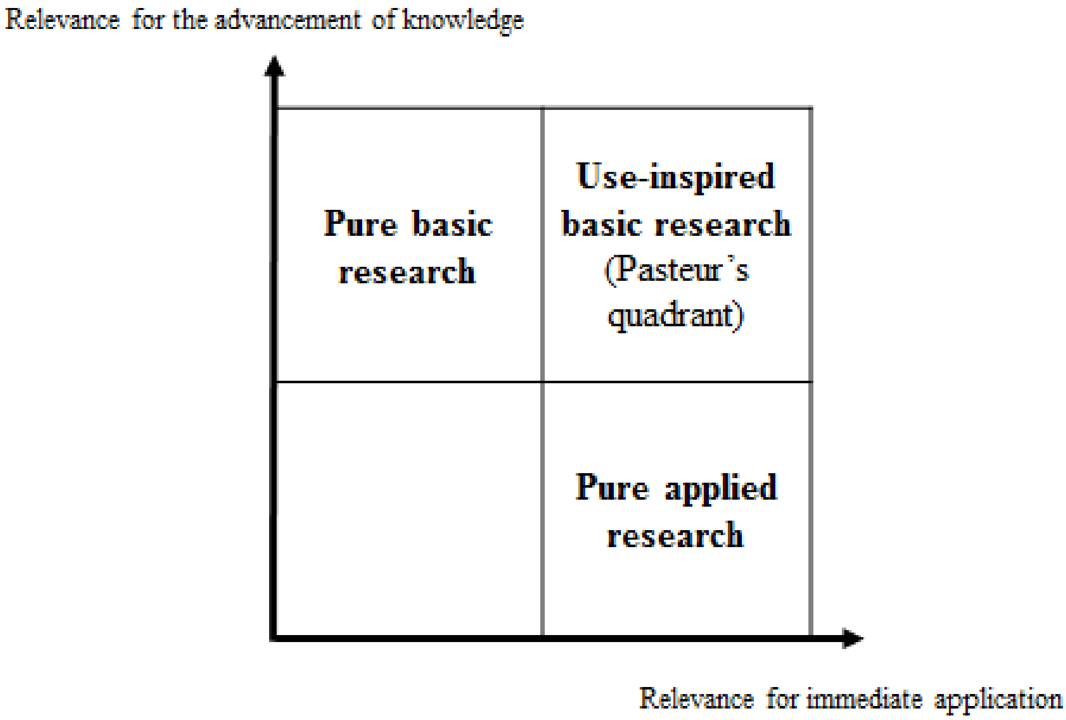
The *context of interventions* included the discipline studied (e.g., biochemistry), the profession, and the students' level in the curriculum (e.g., first year medical school).

Approaches to teach basic sciences knowledge were described according to the characteristics of the education intervention and the research method employed. Characteristics of the education intervention were further described by the way to teach the basic sciences learning concept, and the topic explored in the study (e.g., 3 dimensional teaching, problem-based learning). Instructional method used to teach the basic sciences learning concept was classified using a rubric that characterized the diverse strategic elements that support the process of learning a concept (e.g., laminar-turbulent flow in fluid dynamics).[6] These elements of learning strategy included: 1) how the concept is introduced, 2) the use of concept examples, and 3) the practice of multiple problems associated with the concept. Each element of learning strategy was further subdivided into specific strategies according to the rubric.[6] How the concept is introduced included the use of analogies, the effect of multimedia learning (including the effect of a medium, single versus multimedia, and contiguity/proximity effect), and the exploration of the relation between the problem context and the concept. The use of teaching examples was divided in single versus multiple examples; and explicit comparison and contrast of the teaching examples versus no such active process. The practice of multiple problems was subdivided in blocked (i.e., one single learning concept) versus mixed practice (i.e., multiple concepts simultaneously), and massed versus distributed practice. Finally, the *topic of the intervention* explored in each study was extracted and mapped to the study's theoretical framework or its practical aim (Table II).

The type of research method was characterized based on Stokes' model (Figure 1).[31] Stokes' model classifies research into two axes: application to practice (X-axis) and advancement of knowledge (Y-axis). The model describes four quadrants, including pure basic research (i.e., theory-based research), pure applied research (i.e., practice-based research), and use-inspired basic research (i.e., understanding and improving practice) also known as Pasteur's quadrant.

Figure 1. Stokes' model of science

Adapted from Donald E. Stokes, Pasteur's Quadrant – Basic Science and Technological Innovation, Brookings Institution Press, 1997.



Outcomes were categorized using Bloom's revised taxonomy.[32] The taxonomy includes six cognitive domain objectives: remember, understand, apply, analyze, evaluate, and create. Taking into account the lack of unique consensus definition of the concept of transfer[33], we classified outcomes as assessing transfer of knowledge to use in clinical reasoning, or not, based on the cognitive domain objectives. We decided that any outcomes in the "remember" cognitive domain was not labeled as investigating transfer, whereas any other cognitive domain objectives were labeled as potentially useful for transfer of knowledge (e.g., use of facts acquired in one context to understand or solve a new problem).

2.5 Ethics

The institutional review board of the University of Illinois at Chicago approved this study.

3. RESULTS

A total of 9,803 studies were identified (after excluding duplicate articles); 627 studies were retrieved for full text evaluation; and 78 articles were finally selected for analysis (see Figure 2 and detailed table in supplemental materials). The interventions took place predominantly in medical schools (83%), especially during the early years of the curriculum (Year 1: 55%, and Year 2: 32%), in anatomy (59%) and in physiology courses (23%) (Table I). In terms of characteristics of the education intervention, 98% of identified studies explored the influence of how the concept was introduced as a means of teaching the basic sciences learning concept, including investigation of the effect of a medium (e.g., text versus video) (51%), and the relationship between the problem context and the concept (41%). One study explored the influence of practicing with multiple problems when learning a concept[34] and none specifically explored teaching examples (Table I). *Outcomes* included in the recall category (i.e., remember) were investigated in 91% of the studies (Table I). *Transfer* was studied in 35% of the articles, and cognitive domain objectives were understanding and application (12% and 23% respectively). Practice-based research was reported in 85% of the articles and the most frequent topics explored in the interventions were three-dimensional technology (24%), computerized modules (15%), and problem-based learning (6%). Use-inspired basic research was reported in 15% of the articles and was predominantly associated with interventions focused on conceptual coherence (5%) and transfer (3%) theories. No studies were identified as pure basic research (see Tables I and II). Based on the review of these papers, the following recurring concepts and inferences were identified as enhancing the understanding of basic sciences teaching.

Figure 2. Flow chart

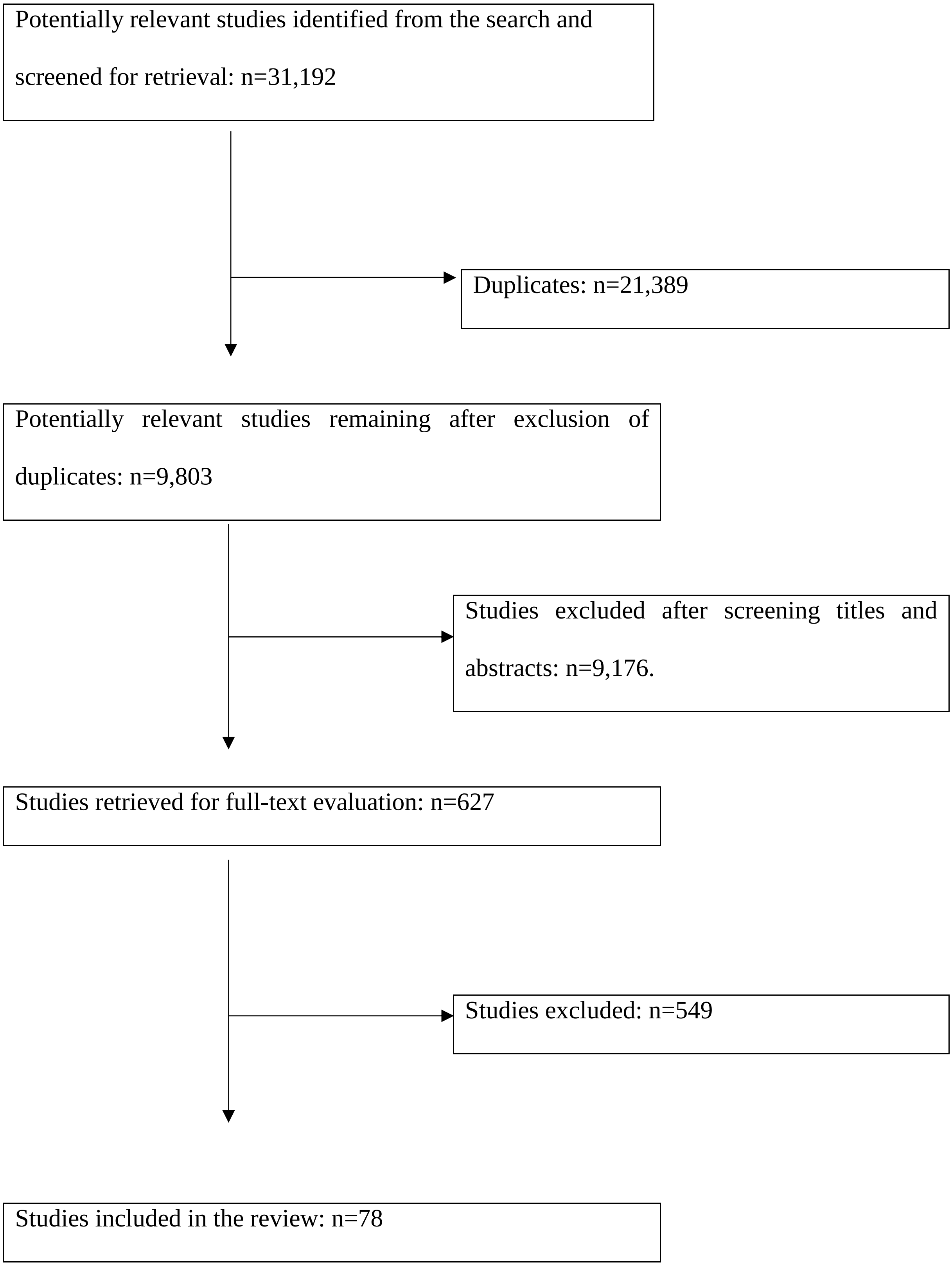


TABLE I

CONTEXT, APPROACHES AND OUTCOMES OF THE 78 ARTICLES INCLUDED IN THE REVIEW

CONTEXT

Discipline		**Year**		**Profession**	
Anatomy	59%	1	55%	Medicine	83%
Physiology	23%	2	32%	Dentistry	13%
Pharmacology	9%	3	15%	Psychiatry	5%
Biochemistry	6%	4	9%	Physical Therapy	3%
Histology/Pathology	6%	5	4%	Physician assistant	3%
Microbiology	4%	6	1%	Sciences	3%
Embryology	3%	NA	6%	Nursing	1%
Genetics	1%			Pharmacy	1%
Immunology	1%			Veterinary	1%

APPROACHES

Way to teach the basic sciences learning concept	
How to introduce the concept - Use of analogy	1%
How to introduce the concept - Multimedia: effect of the medium	51%
How to introduce the concept - Multimedia: multi versus single media	4%
How to introduce the concept - Multimedia: Contiguity effect	1%
How to introduce the concept - Relation between problem context and concept	41%
Teaching examples - Single versus multiple examples	0%
Teaching examples - Comparison and contrast versus not	0%
Problems practice - Blocked versus mixed practice	1%
Problems practice - Massed versus distributed practice	0%

Type of research involved:	
Pure basic research	0%
Pure applied research	85%
Use-inspired basic research	15%

OUTCOMES

Remember	91%
Understand	12%
Apply	23%
Analyze	0%
Evaluate	0%
Create	0%

TABLE II

FOCUS OF THE 78 ARTICLES INCLUDED IN THE REVIEW

3 Dimensional technology	24%
Computerized modules	15%
Problem-based learning	6%
Concept maps	5%
Conceptual coherence	5%
Images	5%
Integration of basic and clinical sciences	5%
Simulation	5%
Experiential learning	4%
Drawing	3%
Gaming	3%
Supervision	3%
Transfer	3%
Videos	3%
Body-painting	1%
Constructivism	1%
Cooperative learning	1%
Dissection	1%
Information delivery	1%
Inquiry-based learning	1%
Personalized instruction	1%
Preparation for future learning	1%
Self-directed learning	1%

3.1 How the Concept Is Introduced

3.1.1 Three-dimensional teaching

Several studies explored and developed our understanding of the value of three-dimensional (3D) models to teach 3D structures. It may seem intuitive that students learn 3D structures better when taught with 3D models. However, Garg et al. explored whether viewing of computers models from many different perspectives (i.e., 3D presentation) hampers the learning of spatial relationships in anatomy.[35] They demonstrated that multiple views in presentation of concepts had no overall instructional advantage over a simple presentation of key views to develop short-term knowledge of the carpal bones anatomy tested immediately after a 90-minute learning session. After control for spatial ability, Garg et al. demonstrated that the key views presentation (i.e., anterior and posterior views) showed an overall advantage over the multiple views presentation (i.e., views available by rotation at 10° intervals) to teach the concept of carpal bones anatomy. Furthermore, for students with low spatial ability, the use of multiple views presentation was detrimental to their test performances on knowledge objectives. In order to explain these results, the authors argued that the mental models built by the students when learning the carpal bones concept could only include the key views of the carpal bones anatomy. The authors suggested that when students needed a view of the carpal bones anatomy that was different from the key views, they constructed the needed view from the key views stored in their mental models of the carpal bones anatomy. In another study, Garg et al. explored the potential benefits of a multiple views presentation (i.e. views available by rotation at 10° intervals, total of 36 views) over a key views presentation (i.e., anterior and posterior) to learn the concept of carpal bones anatomy. The authors compared short-term factual recall of anatomical knowledge of the carpal bones between two groups. The first group was taught carpal bones anatomy using a multiple views presentation including the whole set of views available (i.e., 36 views with 10° interval rotations). The second group was taught the same anatomical concept using the key views (i.e., anterior and posterior) and a limited number of views located immediately around the key views (i.e., plus or minus 10° views around the key views) to detect the depth of the structures.[36] After control for spatial ability, there was no difference in the short-term factual recall of anatomical knowledge of carpal bones anatomy between groups. In the study, the authors also noted that students in the first group (i.e., access to the multiple views presentation) spent the majority of their time looking at the key views (i.e., anterior and posterior) with some small variations around these views (i.e., limited rotations around the anterior and posterior views). The authors concluded that certain key views of an object are "critically important for spatial learning" and that multiple views provided "no particular advantage over access to orientations close to the key view".[36] One limitation identified by Garg et al. regarding their study was that carpal bones anatomy "fall naturally into two planes" and may have limited the educational value of the multiple views presentation.[36] Levinson addressed this potential limitation by exploring a more complex 3D structure , the surface anatomy of the brain.[37] Levinson also expanded our understanding of teaching concepts using 3D by exploring the effects of learner control over the e-learning environment. A two-by-two factorial design was used. The first factor was the type of presentation: key views presentation or multiple views presentation. In the key views presentation groups, the brain surface anatomy was presented using four key views: superior, inferior, lateral, and anterior. In the multiple views presentation groups, the same anatomical concept was presented using multiple views including the key views and views situated every 30° around the key views. The second factor was the control over the presentation. Half of the groups had the control over the presentation of brain surface anatomy. The second half of the groups had no control over the presentation of the anatomical concept, and the time spent on each view was controlled by a computerized program. The group combining key views controlled by the program had the best factual recall anatomical knowledge test performance, whereas the group with multiple views controlled by the program had the worst performance on the factual recall anatomical knowledge test. Groups with multiple or key views controlled by the students had intermediate performances. Similarly to previous studies, students with low spatial ability had scores significantly lower when assigned to learn a concept with multiple views. While these studies enhance our understanding of teaching concepts with 3D, none of them specifically explored transfer of basic sciences knowledge to clinical reasoning and additional investigations are required to deepen our understanding of the transfer of basic sciences concepts to clinical reasoning.

3.1.2 Presentation of causal mechanisms of clinical features

Among studies of interventions fostering transfer of basic science knowledge to clinical reasoning (i.e., use inspired basic research), a robust body of evidence supported the conceptual coherence theory.[38] The conceptual coherence theory posits that learning about the underlying causal mechanisms provides students with a coherent mental representation of the clinical features of problems, thus enhancing long-term memory and transfer by making sense of the features of each diagnostic category.[38] Woods et al. explored the role of basic sciences knowledge, specifically the knowledge of causal mechanisms (e.g., what underlying pathophysiological process leads to the clinical feature) in novice diagnosticians.[39] The authors demonstrated that students who learned the underlying causal mechanism for each feature of endocrine disorders had similar immediate diagnostic accuracy to students who were taught only about the clinical features without any causal explanations. After a one-week delay, students in the causal learning condition improved their diagnostic accuracy scores and outperformed the other group.

Baghdady et al. demonstrated that dental students taught about basic sciences with causal mechanisms outperformed students taught with features lists or structured algorithms on an oral radiology initial diagnostic test.[40] The drop in the diagnostic performance was less in the group taught with causal mechanisms after a one week delay. In another study, a significant effect of learning conditions was found in favor of the causal mechanisms group when compared with a segregated features group (i.e., basic sciences explanations first followed by clinical features) on both immediate and delayed diagnostic accuracy testing.[41] Kulasegaram et al. compared four learning conditions for similar neurology and rheumatology disorders. The integrated causal mechanisms group received the clinical features of the diseases, and each feature was immediately explained with the underlying pathophysiological mechanism. A second group received all basic sciences mechanisms followed by all clinical features for each disease. A third group received all clinical features followed by all basic sciences mechanisms for each disease. Finally, a fourth group received only lists of clinical features corresponding to the diseases.[42] No differences between groups were found in their diagnostic performance immediately; but after a one-week delay, diagnostic accuracy was greater for the integrated causal mechanisms group.

Some points in the articles are critical to further our understanding of the transfer of basic sciences concepts to clinical reasoning. The effect on diagnostic accuracy of the integration of causal mechanisms with clinical features was identified only after a delay in assessment. Also, the differences in transfer of basic science knowledge to yield diagnostic accuracy was not captured in memory test performance. In these studies,[39–42] no group effect was observed in performance on memory or recall-type tests on immediate or delayed testing. If authors had focused solely on factual recall, no difference would have been captured in the transfer of basic sciences knowledge to clinical reasoning.

Mylopoulos et al. further documented the value of learning basic sciences causal mechanisms by exploring their impact on learning new related content (preparation for future learning).[43] Students had to learn four broad categories of neurological disorders and were divided in two groups: learning clinical features for each category, or learning clinical features plus the causal mechanisms. Subsequently, students had to learn four specific examples based exclusively on the clinical signs and symptoms. Diagnostic accuracy was similar for the two groups after the initial phase of training (categories), but students in the causal group scored higher in the diagnostic test after the learning phase of the specific diseases. Learning basic sciences causal mechanisms supported “preparation for future learning” and thereby the application of diagnostic reasoning to “novel related content”.[43] Again, there were no difference in groups with the two different learning conditions in factual recall memory test performances.

3.1.3 Cognitive meshing

Prakash explored the influence of explicitly probing learners’ prior knowledge and subsequently delivering related content through a series of logical questions to help students construct their knowledge (“constructivist lectures”).[44] When compared with students participating in “typical lectures”, students in the “constructivist lectures” group outperformed their counterparts on immediate testing of factual recall. No differences in performance of the two groups were found on testing four months later. While the study had potential limitations (e.g., increased teaching time in the “constructivist lectures”), it is interesting to note that, similarly to the studies described previously[39–43], the explicit linkage between logical questions to help students construct their knowledge may represent a promising approach to teach basic sciences concepts. Nonetheless, approaches to maintain the effect of explicit linkage between basic sciences facts over time is unclear. Similarly, the results do not allow for inferences regarding a potential gain due to the explicit linkage of basic sciences facts to the transfer of basic sciences learning to clinical reasoning.

3.1.4 Use of analogies

Analogies may be used to support understanding of the structure of abstract concepts that lie below surface details of clinical disease presentations.[21] Kulasegaram et al. investigated the effect of using analogies and context familiarity for transfer of learning physiological concepts to clinical reasoning.[21] The control group read standard explanations while the intervention group read an additional analogy. At immediate testing of the explanation of clinical presentations, the analogy group performed significantly better in explaining the clinical reasoning related to the cases compared to the control group. When testing one week later, the analogy group still performed better than the control group, although the differences were not statistically significant. The differences between analogy and control groups at immediate testing were statistically significant for “far transfer” cases (i.e., novel organ system) but not for “near transfer” cases (i.e., similar organ system).

3.1.5 Sequence between theory and problem

Boreham et al. explored the effect of the sequence of instruction on pre-clinical students' cognitive preferences and recall in the context of a problem-based method of teaching.[45] Within a biochemistry course, the authors tested two potential sequences to introduce a concept: theory followed by clinical application, or clinical application followed by theory. The results demonstrated the contrast between students’ preferences and effective recall. Students who started with the clinical application of the concept had a greater preference for being taught specific facts of basic sciences knowledge, but displayed significantly lower scores on theoretical knowledge recall tests when compared to the group that started with the theory followed by clinical applications. The sequencing between clinical application and theory may be an important point to consider when the focus is learning outcomes and not students’ preferences. Further investigations are be needed to explore whether differences occur in relation to sequence of learning theory and clinical applications in terms of transfer of basic sciences knowledge to clinical reasoning.

3.2 Problems Practice

3.2.1 Influence of multiple contexts

Kulasegaram et al. explored the effect of context variation on transfer of basic science knowledge to clinical reasoning in multiple problems of practice. The effect of single and multiple practice contexts were compared for both blocked and mixed practice (i.e., respectively a single or multiple concepts together).[34] Students were asked to classify and explain near and far transfer cases (i.e., respectively familiar and unfamiliar contexts). Practice with a single context showed lower far transfer scores than near transfer compared to multiple contexts which had similar far and near transfer scores. Practicing with multiple contexts significantly improved far transfer regardless of mixed or blocked practice. Using only one practice context during practice significantly lowers performance even in mixed practice. Scores on knowledge testing did not differ in relation to practice mode or context, and did not correlate with performance with near or far transfer cases.

4 DISCUSSION

The purpose of this literature review was to examine interventions designed to develop basic sciences knowledge in HPE and, subsequently, to explore the evidence that support the understanding of basic sciences education and, in particular, transfer of basic sciences knowledge to clinical reasoning.

Our results demonstrated the limited attention to transfer to clinical reasoning as a learning outcome of basic sciences education in HPE (35%). This study is the first to effectively show the lack of focus on transfer to clinical reasoning. Several hypotheses may explain these findings. First, transfer can be a psychological concept that may be poorly investigated by prior studies. While these studies might agree that basic sciences knowledge is important for future clinical practice, the understanding that the matter should be transfer might be less explicit. The limited identification of transfer as a critical dimension of basic sciences education might subsequently result in the lack of focus on transfer to clinical reasoning in teaching and assessment strategies. Second, the lack of attention paid to transfer may also result from the potentially numerous objectives associated with basic sciences education. Basic sciences education has value to improve clinical reasoning and practice. Basic sciences education also has value to develop scientific reasoning and research abilities. These different perspectives in regard to basic sciences education might shift the needs, expectations and therefore outcomes. Third, in order to teach and assess the transfer of basic sciences knowledge to clinical reasoning, educators must know what is relevant for practice. Yet, not every basic sciences educator has clinical experience. Relevant knowledge requires time and expertise to be identified. Moreover, the relevance of a basic sciences learning concept might evolve with students' advancement in the curriculum. The identification of relevant concepts presupposes temporal and human resources. If these resources are missing, basic sciences learning concepts cannot be taught and assessed in light of their transfer to clinical reasoning. Lastly, the emphasis on integration of basic and clinical sciences in the literature might have shifted our attention away from the critical dimension of transfer to clinical reasoning. A large body of literature about basic sciences education focused on integration of basic and clinical sciences, and especially description of such interventions, to the cost of the evaluation of these interventions in terms of learning outcomes.[13] Integration of basic and clinical sciences represents a curricular strategy not a goal in itself.[11] The creation of dynamic mental structures to support transfer of basic sciences knowledge to clinical reasoning defines the purpose of basic sciences education. If the difference between the strategy and the educational outcome does not stand clearly in educators minds then the focus on transfer might suffer.

Moving practices forward requires a multi-faceted approach. First, faculty development is paramount to improve the knowledge and the understanding of the concept of transfer. The distinction between available curricular strategies, and teaching goals and learning outcomes should also be a part of the training. These faculty development activities should aim to serve first basic sciences teachers who are the cornerstone of undergraduate HPE curricula. The role of basic sciences teachers is critical to the success of interventions aimed at enhancing the transfer of basic sciences knowledge to clinical practice.[14,15] The need to pay more attention to the individuals and their development is a shared idea within the field of HPE.[46,47] Yet, it would be misleading to believe that only basic sciences teachers would benefit from these activities. Clinical sciences educators also need to better understand their practices and especially the predominantly tacit role of basic sciences in clinical reasoning.[16] A better understanding of transfer would also help clinical teachers to rely more explicitly on basic sciences knowledge to bridge basic sciences and clinical concepts and, therefore, foster the development of students' dynamic mental structures supportive of transfer. Worse, the belief that basic and clinical sciences educators do not have common needs would further emphasize the dichotomy between these groups of educators while they need to work synergistically. A close collaboration between basic and clinical sciences teachers is foundational to understand meaningful practical basic sciences knowledge, and relevant dimensions of clinical reasoning to investigate transfer. A fruitful collaboration should involve the identification and agreement upon the purpose, content and assessment of basic sciences teaching, beyond knowledge and assessment of factual recall. The second major facet to improve practices regarding transfer is institutional support. Directly consequential to the need for an improved collaboration between basic and clinical sciences educators, institutions should create temporal and human resources to foster this collaboration. Institutions also have a role to support and reward committed educators that will effectively engage in virtuous practices. These are not new ideas in the field. The development of incentives and promotions for basic sciences educators who engage in integration of basic and clinical sciences has already been voiced.[47] Yet, how to implement such ideas, supporting effective transfer of basic sciences to clinical reasoning, remains to be developed. Finally, institutions should engage in a reflective process to clarify the expectations associated with basic sciences education. Educators need to be supported in their educational endeavors with a clear identification of the goals and objectives associated with basic sciences education. The role of basic sciences education should be made explicit, especially beyond the transfer of basic sciences knowledge to clinical reasoning. The development of scientific reasoning, or of research skills, as a learning goal should be made explicit. The space for these specific trainings should also be detailed, within the core curriculum or within electives allowing a depth of content for example.

We called for more attention to transfer of basic sciences knowledge to clinical reasoning. Yet, most learning outcomes were limited to factual recall and not transfer. This deliberate choice was made despite the observation that performances on factual recall memory tests did not appear to be correlated with transfer tests. The search strategy was not constructed to judge the optimal articulation between factual recall memory tests and transfer tests. It would seem premature to state that factual recall memory tests should be abandoned. Furthermore, a more recent study compared a group provided with integrated basic and clinical sciences to a group provided only with clinical features.[48] Performances on diagnostic accuracy tests were significantly higher in the integrated group both at immediate testing and after one week. Memory tests scores were also greater in the integrated group but only at immediate testing. These results call for caution about the use of recall outcomes. Similarly, how factual recall memory tests may subsequently trigger further learning processes supportive of the development of transfer of basic sciences knowledge to clinical reasoning remains to be elucidated. At this point, assessment of factual knowledge should not be prohibited but rather envisioned as an element of a more comprehensive approach including assessment of transfer to clinical reasoning. Optimized approaches need further scholarship to be adequately determined.

Our results demonstrated that most articles reported practice-based research focusing on how to improve practice (85%), but did not address development of conceptual frameworks for effective education for helping students transfer basic sciences knowledge to clinical reasoning. Among studies fostering our understanding about transfer (i.e., use inspired basic research), a small number of controlled experiments demonstrated that integration in education of basic sciences causal mechanisms with clinical features fostered diagnostic reasoning and preparation for future learning.[39–43] Also, instruction using concept analogies[21], and the practice with multiple problems in multiple contexts[34] demonstrated increased scores on far transfer (i.e., transfer of basic science knowledge to new clinical problems). The high prevalence of practice-based research was an important finding to illuminate researchers' future directions of scholarship. The prominence of practice-based research appeared as a limiting factor to a greater understanding of the transfer of basic sciences knowledge to clinical reasoning in the field of HPE. The focus on practical context-bound research that lacked theoretical grounding limited the development of knowledge based on preexisting knowledge. The lack of theory is recognized as a limiting factor to the development of a collective understanding of educational interventions implemented in the field of HPE.[49,50] Theories help researchers "understand what makes a particular intervention effective or ineffective"[26] and the materials' characteristics that support learning.[26,51] The lack of identification of such elements hampers the understanding of what elements should be replicated across settings and interventions. Theoretical grounding will help focus on clarification rather than effectiveness studies asking "why and how it did work?" rather than "did it work?".[52] Theories are complementary to practical needs and will serve both practice and scholarly knowledge building (i.e., use inspired basic research[31]). Lastly, theories represent an opportunity to explore more comprehensively a problem. In the present study, the vast majority of interventions explored the influence of how a basic sciences learning concept is introduced on learning outcomes (98%). This observation was closely related to opportunities generated by evolving technologies despite a general limited understanding of the phenomenon underpinning interventions and their potential benefits. Conversely, ways to introduce the basic sciences learning concept such as the use of teaching examples or the practice of multiple problems that are traditionally widespread in HPE curricula benefited from a limited attention. A more theoretically-grounded approach to the study of basic sciences education would open potentially promising alternatives to support basic sciences education in general, and transfer in particular.[6]

There are some limitations to this study. We focused our search of the literature on carefully controlled, randomized designs. This selection of literature could be narrow in scope, but was appropriate to describe the current state of the literature in terms of contexts, approaches, and outcomes among these studies; and to study the interventions that fostered our understanding of basic sciences education, particularly studies documenting education methods to help students transfer basic science knowledge to clinical reasoning. There are advantages to limit our study to such experimental studies to foster the understanding of basic sciences education. Nonetheless, some points benefited from limited attention in the selected studies such as long-term learning and interventions implemented in a traditional classroom setting by contrast to a controlled experimental setting; further evidence is needed to be able to generalize the nature of inferences observed in the selected studies to long term learning and to the classroom setting.[51] Similarly, the focus on experimental studies prevented us to access other types or research methodologies, and especially qualitative studies, traditionally used to gain deeper understanding of phenomena. Future studies would benefit from a focused qualitative literature review within the same study contexts. The focus on undergraduate HPE trainees may limit the generalizability of findings; additional evidence is required for post-graduate and continuing medical education. The present work did not explore either the potential for alternative venues to teach basic sciences concepts. Especially, it would be particularly interesting to deepen our understanding about basic sciences education displayed in a practically oriented clinical context. Finally, our definition of basic sciences, especially basic biomedical sciences, deeply influenced our search strategy and, therefore, our findings. The inclusion of social sciences or human sciences in the definition of basic sciences disciplines might have impacted the nature of the findings.

Effectively teaching basic sciences concepts requires that transfer of basic sciences knowledge to clinical reasoning is recognized as a major educational goal of HPE curricula. Transfer can be a challenging process to measure that deserves a greater attention to be explained, clarified, and promoted. Fostering basic sciences knowledge transfer to clinical reasoning requires a thoughtful theoretically-grounded scholarship to durably contribute to the field of HPE. Theoretical-grounding is critical to comprehensively study transfer and to understand causal elements that are essential to deeply impact future practices in basic sciences education.

APPENDIX

DETAILED TABLE INCLUDING THE CONTEXT, APPROACHES AND OUTCOMES OF THE 78 ARTICLES INCLUDED IN THE REVIEW

ARTICLE		CONTEXT			APPROACHES			OUTCOMES
Fist Author	**Year**	**Discipline**	**Year**	**Clinical profession**	**Way to teach the basic sciences learning concept**	**Research method**	**Topic explored in the intervention**	**Learning outcomes**
Abid[53]	2010	Embryology	2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember, Understand
Adibi[54]	2007	Anatomy	2	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Integration of basic and clinical sciences	Remember
Al-Khalili[55]	2014	Anatomy	1	Veterinary	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Allen[56]	2006	Anatomy	1	Dentistry	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember, Apply
Alnassar[57]	2012	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Videos	Remember
Antepohl[58]	1999	Pharmacology	3	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Problem-based learning	Remember
Anyanwu[59]	2014	Anatomy	2	Medicine, dentistry	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Gaming	Remember

Appaji[60]	2010	Anatomy	1	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Integration of basic and clinical sciences	Remember
Azer[61]	2011	Anatomy	1	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Drawing	Remember
Bachman[62]	1998	Anatomy	1	Dentistry	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember
Baghdady[41]	2013	Anatomy	NA	Dentistry	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	Conceptual coherence	Remember, Apply
Baghdady[63]	2009	Anatomy	2	Dentistry	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	Conceptual coherence	Apply
Balemans[64]	2015	Histology	1	Medicine, sciences	How the concept is introduced - Relation between problem context and concept	Pure applied research	Drawing	Remember
Beerman[65]	2010	Anatomy	4-5	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Understand
Bogacki[66]	2004	Anatomy	1	Dentistry	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember
Boreham[45]	1984	Biochemistry	2	Medicine	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	Problem-based learning	Remember
Brinke[67]	2014	Anatomy	1-6	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Dissection	Remember

Bryner[68]	2008	Anatomy, physiology	1-2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember
Carlson[69]	2014	Physiology, histology	2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Images	Apply
Cendan[70]	2011	Physiology	2	Medicine	How the concept is introduced - Multimedia: Contiguity effect	Pure applied research	Simulation	Remember
Davis[71]	1994	Microbiology, immunology	2	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Supervision	Remember
Devitt[72]	1999	Anatomy, physiology	2	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Computerized modules	Remember
Diaz-Perez[73]	2014	Pathology	3	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Integration of basic and clinical sciences	Apply
Donnelly[74]	2009	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Estevez[75]	2010	Anatomy	1	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	3 Dimensional technology	Understand
Finn[76]	2011	Anatomy	1	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Body-painting	Remember
Fritz[77]	2011	Anatomy	1-4	Medicine, dentistry, physical therapy	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember, Understand

Garg[36]	2002	Anatomy	1	Medicine	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	3 Dimensional technology	Remember
Garg[35]	1999	Anatomy	NA	Medicine	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	3 Dimensional technology	Remember
Gauthier[78]	2015	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Gaming	Remember
Gonzalez[79]	2008	Physiology	2	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Concept maps	Remember, Apply
Griksaitis[80]	2012	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Images	Remember
Hampton[81]	2010	Anatomy, physiology	3-4	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Hariri[82]	2004	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Simulation	Remember, Apply
Hisley[83]	2008	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Ho[84]	2014	Physiology	1-2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Concept maps	Remember, Understand
Janssen[85]	2014	Anatomy	1	Medicine, physical therapy, physician assistant	How the concept is introduced - Relation between problem context and concept	Pure applied research	Experiential learning	Remember
Ketelsen[86]	2007	Anatomy	2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Information delivery	Remember, Apply

Knobe[87]	2012	Anatomy	2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Images	Remember, Apply
Kockro[88]	2015	Anatomy	2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Kooloos[89]	2012	Anatomy	2	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Supervision	Remember
Kulasegaram[34]	2015	Physiology	1	Psychology	Problems Practice - Blocked versus mixed practice	Use inspired basic research	Transfer	Remember, Understand, Apply
Kulasegaram[42]	2015	Anatomy, physiology	1	Medicine, nursing, physician assistant	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	Conceptual coherence	Remember, Apply
Kulasegaram[21]	2012	Physiology	1	Psychology	How the concept is introduced - Use of analogy	Use inspired basic research	Transfer	Remember, Understand, Apply
Levinson[37]	2007	Anatomy	1	Psychology	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	3 Dimensional technology	Remember
Li[90]	2014	Pharmacology	3	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Experiential learning	Remember, Apply
Lim[91]	2015	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
MacFadyen[92]	1993	Pharmacology	4	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember

Maggio[93]	2012	Anatomy	1	Dentistry	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember
Marsh[94]	2008	Embryology	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Miedzybrodzka[95]	2001	Genetics	4	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember, Understand
Mueller[96]	2005	Pharmacology	3	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Simulation	Remember
Mylopoulos[97]	2014	Anatomy, physiology	1-2	Medicine	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	Preparation for future learning	Remember, Apply
Ng[98]	2015	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Nicholson[99]	2006	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Nolte[100]	1987	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember
Nouns[101]	2012	Biochemistry, physiology	1-5	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Problem-based learning	Remember
Pai[102]	2014	Physiology	1	Medicine	How the concept is introduced - Multimedia: multi versus single media	Pure applied research	Self-directed learning	Remember, Apply
Prakash[44]	2010	Physiology	2	Medicine	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	Constructivism	Understand

Qadir[103]	2011	Pharmacology	2	Dentistry	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Concept maps	Remember
Richardson[104]	2013	Pharmacology	2	Pharmacy	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Apply
Roberts[105]	2005	Anatomy, physiology	1	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Problem-based learning	Remember
Roon[106]	1983	Biochemistry	1	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Cooperative learning	Remember
Sanprasert[107]	2005	Microbiology	3	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember
Schwartz[108]	1980	Biochemistry	3	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Personalized instruction	Remember
Scoville[109]	2007	Histology	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Images	Remember
Seixas-Mikelus[110]	2010	Anatomy	NA	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember
Sherer[111]	2014	Physiology, histology	1-2	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Integration of basic and clinical sciences	Remember
Singh[112]	2009	Microbiology	NA	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Inquiry-based learning	Remember
Solyar[113]	2008	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	3 Dimensional technology	Remember

Stanford[114]	1994	Anatomy	1	Medicine	How the concept is introduced - Multimedia: multi versus single media	Pure applied research	Computerized modules	Remember
Stirling[115]	2014	Anatomy	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Computerized modules	Remember
Sultana[116]	2001	Anatomy	3	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Videos	Remember
Surapaneni[117]	2013	Biochemistry	1	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Concept maps	Remember
Takkunen[118]	2011	Anatomy	1	Medicine, dentistry	How the concept is introduced - Multimedia: multi versus single media	Pure applied research	Problem-based learning	Remember
Vollebregt[119]	2005	Pharmacology	3	Medicine	How the concept is introduced - Relation between problem context and concept	Pure applied research	Experiential learning	Remember, Apply
Wong[120]	2007	Physiology	2	Medicine	How the concept is introduced - Multimedia: effect of the medium	Pure applied research	Simulation	Remember
Woods[39]	2007	Physiology	NA	Psychology, sciences	How the concept is introduced - Relation between problem context and concept	Use inspired basic research	Conceptual coherence	Remember, Apply

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VITA

NAME	Jean-Marie Castillo
EDUCATION	M.D., University of Nantes, France, 2014
PROFESSIONAL MEMBERSHIPS	French-speaking International Society for Medical Education Association for Medical Education in Europe International Association of Medical Science Educators
PUBLICATIONS	Castillo JM, Agard C, Artifoni M, Brisseau JM, Connault J, Durant C, Espitia O, Masseau A, Neel A, Perrin F, Pistorius MA, Planchon B, Ponge T, Hamidou M, Pottier P. ”Qualitative and quantitative evaluation of an internal medicine assistance line dedicated to the diagnosis and treatment of diseases for general practice”. Rev Médecine Interne. 2016 May;37(5) :321-6. Pottier P, Buffenoir K, Castillo JM, Etienne J, Richard I, les membres de la Commission pédagogique de la Conférence des doyens des facultés de médecine de France. “Research in medical education in medical schools in France. Status report from a systematic review of published scientific papers”. Pédagogie Médicale. 2015 May;16(2):91-103. Pottier P, Hardouin JB, Dejoie T, Castillo JM, Leloupp AG, Planchon B, Bonnaud A, LeBlanc VR. “Effect of extrinsic and intrinsic stressors on clinical skills performance in third year medical students”. J Gen Intern Med. 2015 Sep;30(9):1259-69.