CONCEPTUAL AND CONTEXTUAL STRATEGIES FOR TRANSFER

THE EFFECT OF CONCEPTUAL AND CONTEXTUAL TEACHING STRATEGIES FOR THE TRANSFER OF BASIC SCIENCE KNOWLEDGE IN MEDICAL EDUCATION

By

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ABSTRACT

Application of previously learned knowledge to new problems or contexts is a cognitive process known as transfer. Undergraduate medical education is optimized when learners are able to transfer basic science knowledge to clinical learning. A long history of transfer research suggests that spontaneous transfer of conceptual knowledge is not easy for learners, thus creating an educational challenge during undergraduate training. However, not all transfer tasks are equally difficult. When conceptual problems are presented in familiar contexts (e.g. similar surface details or semantic content in word problems), this *near* transfer is facilitated for learners. But when contextual familiarity does not exist, the problem is one of *far* transfer and becomes more difficult. Previous research suggests that using contextual information and focusing on conceptual teaching can improve transfer performance for novices.

This thesis investigates how emphasizing contextual information versus conceptual information can impact transfer of principles of physics relevant to physiology (the concepts) to different organ systems (the contexts). Across three experimental studies, students were assigned to different learning and practice conditions where conceptual and contextual teaching were manipulated. The results showed 1) while emphasizing conceptual information can improve transfer, contextual alignment (near transfer) between learning and problem solving had the highest performance for all students. 2) Novices use contextual information as

recognition cues for new problems but can be shifted to examine deep conceptual structure when provided with in-depth conceptual teaching as well as varying the number of contexts used to practice concepts. This shifts novices to equal success at near and far transfer. 3) Novices can revert to relying on contextual information if teaching interventions do not provide contextual variation and instead promote a close association between contextual details and conceptual information.

This research suggests that shifting novices to examine conceptual problems at the deep structure level should be a key goal for teaching basic science for transfer. Novices default to using surface details to encode and retrieve conceptual information. While in some near transfer problems this can be an effective strategy, for far transfer it can lead to errors. Basic science teaching during undergraduate training must emphasize transferability of concepts by providing more relatable ways to understand conceptual information and showing the variation of a concept's presentation.

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LIST OF ABBREVIATIONS

CBL: Case-based learning

PBL: Problem-based learning

CHAPTER 1: INTRODUCTION

This thesis is an exploration of the processes and interventions that can facilitate transfer of conceptual knowledge. Broadly defined, transfer is the application of previously learned knowledge, skills, or information to a new context, problem, or domain. While transfer has a long history of investigation in psychology (Thorndike, 1910), it remains an important focus for education (Laksov, Lonka, & Josephson, 2008) and cognitive psychology (Kaminski, Sloutsky, & Heckler, 2009; Salomon & Perkins, 1989). This is partly because transfer is recognized as a key outcome of education activities (Eva, Neville, & Norman, 1998). Material and content taught to learners is not intended to remain dormant or sequestered to the classroom. This is especially the case in health professions where different domains or types of knowledge are used in clinical practice. In medical training for example, novice trainees undergo classroom training in basic sciences such as physics, chemistry, physiology, and anatomy. Previous research suggests that when this information is transferred, it aids problem solving and understanding of more hands-on clinical activities such as diagnosis (Baghdady, Carnahan, Lam, & Woods, 2013; Baghdady, Pharoah, Regehr, Lam, & Woods, 2009; Woods, 2007). Thus, training students to transfer basic science is essential for early undergraduate training.

However, transfer is also of continuing interest to educational scholars and psychologists because it remains a difficult task for novices (Perkins & Salomon

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1989). Attempting to optimize teaching for transfer has been an ongoing program for both theoretical (Catrambone & Holyoak, 1989) and applied (Rohrer, Taylor, & Sholar, 2010) researchers in cognitive or educational psychology as well as in motor skill acquisition (Adams, 1987). While several useful suggestions for learning and practice have been identified by these efforts, some questions remain. One enduring debate in understanding the transfer of conceptual knowledge is how information acquired in the context of learning and problem solving (e.g. semantic information, surface details, and superficial features) is encoded and used by learners. Whether this information is always useful and if it impacts the utility of transfer learning interventions that attempt to focus learners on conceptual knowledge is also unknown. How each type of information – contextual and conceptual – is emphasized to the learner may impact how a learner solves transfer problems.

This sandwich thesis investigates the role of contextual information as well as the role of conceptual or structural knowledge of the concept in influencing a learner's ability to transfer. The goal of this work is to build on existing theory of transfer and suggest axes along which teaching for transfer can be improved in health professions education – particularly the teaching of basic science in undergraduate medical training. I accomplish these goals by manipulating the learning and practice of basic science concepts relevant to physiology by novice learners and examine subsequent transfer to familiar (near transfer) and unfamiliar contexts (far transfer). The chapters containing experimental data (3-5) are papers which have been published or submitted for publication in peer-reviewed journals.

In Chapter 2, I review the general literature on transfer of conceptual knowledge in psychology and in medical education. In Chapter 3, I demonstrate that providing teaching aids for physiology concepts' deep structure can improve transfer but learners still use surface details in the context of learning as cues for future problem solving. Chapter 4 examines whether reliance on contextual information can be manipulated to improve transfer and whether context variation of practice examples is an effective way to achieve this goal. The first experiment in this chapter compares contextual variation against the deep structure teaching method presented in Chapter 3 and the second experiment examines how each intervention changes how learners approach transfer problems. The experimental results suggest that while both methods have independent effects on transfer, the methods also result in the same processing changes in the learners: recognition and reliance on deep structure of transfer problems instead of contextual surface details. Chapter 5 examines the negative impact of a practice intervention intended to promote transfer when it is employed without attention to learners' tendency to encode and rely contextual surface details. In Chapter 6, I summarize and review the general results in order to suggest implications for basic science teaching in undergraduate medical education.

Chapter 2: Literature Review

Transfer describes a wide range of activities. For example, an experienced driver accustomed to sedans will use their previously acquired knowledge and skill when driving a larger vehicle such as a van or truck. Similarly, a physician encountering an atypical presentation of a disease will apply knowledge from more typical encounters to make the diagnosis and manage the illness. An aeronautical engineer designing aircraft will have to apply highly theoretical physics as well as principles of design to create a new prototype. And elementary school students learning Newton's second law of motion will apply knowledge of multiplication and division to solve physics problems. All of these tasks can be argued to require some type of transfer of learning though what is transferred in each task may be different. The broadest definition of transfer of learning is the application of learned information – be it skill, attitude, concept, strategy etc. – to a different problem or context. But as illustrated by the above examples, a broad definition hides a great deal of complexity in how transfer occurs for different tasks. To understand how transfer of conceptual knowledge in medical education can be improved, we must first clearly articulate what is meant by transfer and what is known about how learners successfully transfer knowledge. This chapter will briefly: 1) define the particular type of transfer task to be investigated 2) describe the transfer challenge in medical and health professions training 3) outline the history of transfer of learning conceptualizations and general transfer theory, 4) discuss the implications for learning interventions to improve transfer, 5) outstanding issues for current research on transfer in medical education.

2.1 Isolating and defining the Transfer task

Defining transfer and classifying or categorizing all the different activities that can be described as 'transfer tasks' is highly controversial (Bransford & Schwartz, 1999; Detterman, 1993; Haskell, 2001). Activities ranging from highly automatic motor movements such as opening doors to broad innovations in scientific thought have been described as transfer (Haskell, 2001). And as seen from the examples at the beginning of this chapter, even at the surface level, transfer tasks can involve various levels of difficulty and processing. As Myers (1992) notes: "many activities may be described in the same way, they need not involve the same process." One conceptualization of transfer argues that all learning – formal and informal – involves some type of transfer (Bransford & Schwartz, 1999). Still, an overly broad definition does not allow progress or isolation of the mechanisms that allow for successful transfer. Furthermore, it may be unreasonable to collapse activities as diverse as driving to solving complex physics problems in the same category.

One method by which to address this complexity is to sub-divide transfer tasks based on ease and automaticity vs. effort and deliberate activity. Such a model is offered by Salomon and Perkins (1982) who outline transfer as a continuum of

different activities and isolate categories of different transfer processes. In this model, transfer is divided broadly into two categories: low road and high road. In low road transfer, learners automatically apply concepts and skills that are not abstract. Transferring driving skills from a car to a truck is an example of this type of transfer. This requires minimal abstraction of knowledge and this type of transfer encompasses many different types of activities. The ease by which individuals transfer driving skills to different vehicles is captured by this type of activity. In contrast, high road transfer occurs when learners must transfer abstract concepts (Salomon & Perkins, 1989). High road transfer is further subdivided into forward reaching and backward reaching transfer. Forward reaching transfer occurs when learners can spontaneously transfer abstract concepts (thus the term "forward reaching"). This is facilitated by a high degree of concordance between the learning context and application context. For example, trigonometry is taught as a set of mathematical concepts. Its useful application includes triangulating position on a two dimensional map. The use of trigonometry for triangulation is an almost obvious application of the abstract relationships of lines and angles in triangles. Backward reaching transfer refers to the application of abstract concepts when the concordance between the concept and its application is low (Salomon & Perkins, 1989). The learner, confronted with a new problem, must review their store of concepts, abstract out the concept that needs application, and apply the concept in a useful manner. For example, increasing the unbound blood concentration of a drug requires that learners recognize that the problem requires manipulation of the law of mass action – a biochemistry concept. But how the law applies to pharmacology is not immediately obvious to novices and must be deliberately extracted for application. Most conceptual transfer of learning tasks are multi-faceted in that both forward and backward reaching transfer can be involved. However, depending on the context, one may predominate over the other. Backward reaching transfer is of special interest to medical education and the role of basic sciences.

2.2 The Transfer challenge in medical education

Learning basic sciences such as anatomy, physiology, biology, biochemistry, and physics is an important component of first year medical education in North America. The historical roots of this state can be traced to the Flexner Report of 1910 which helped created the scientific profession of medicine (Flexner, 1910). Accordingly, knowledge of basic science was seen as a fundamental competence of medical students. Recognition of the importance of basic science has also been affirmed by the 2010 Association of Faculties of Medicine of Canada's Future of Medical Education Report which includes as a major recommendation: "both human and biological sciences must be learned in relevant and immediate clinical contexts throughout the MD education."(AFMC, 2010) The report also stresses the integrated and connected teaching of basic science and clinical science (pp. 24). Clearly, a renewed mandate for basic sciences in medical education has arrived.

This establishes a need for effective teaching of basic science concepts in first year medical training as well as other areas (Spencer, Brosenitsch, Levine, & Kanter, 2008). A growing body of evidence shows the importance of basic science in preparing novices to deal with the complex task of diagnosis and management of pathology (Patel, Groen, & Scott, 1988; Schmidt, Machielts-Bongaerts, Hermans, ten Cate, Venekamp, & Boshuizen, 1996; Woods, Brooks, & Norman, 2005; Woods, Neville, Levinson, Howey, Ockowski, & Norman, 2006). A study in 2005 by Woods and colleagues taught novices pathologies using clinical symptoms and features or basic science explanations (Woods et al. 2005). Though initially there was no difference in ability to accurately diagnose pathology, a one week delay showed that those taught basic science maintained performance while the control group dropped dramatically. This effect was replicated again in further studies (Woods et al. 2006, 2007) with a larger sample of medical students with basic science continuing to show a dramatic effect over time. Baghdady and colleagues (Baghdady et al. 2009, 2012) replicated this effect in the visual domain of oral radiology and Goldszmidt and colleagues (2012) showed that this effect was robust for teaching more complex material using even more fundamental basic sciences such as physics (Goldszmidt et al. 2012). Evidently, even if learners do not access basic science routinely in practice, learning basic science seems to ease the acquisition and understanding of clinical concepts.

Taking advantage of basic science requires that learners mobilize and activate their basic science concepts in order to relate them to the learning of

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clinical tasks (Laksov et al. 2008). These transfer tasks involve abstract basic science concepts that do not necessarily have direct correspondence to learning in clinical contexts, e.g. the use of fluid dynamics to understanding asthma and blood circulation. The principles of fluid dynamics are near universal features of physics and knowledge of these principles should enable understanding of physiology and pathology in any number of human organ systems involving fluids. Asthma, heart murmurs, kidney dysfunctions, can all be conceptualized as involving fluid flow disorders (Tortora & Grabowski, 2002). Teaching a learner about fluid dynamics in the context of a respiratory disorder is no guarantee that learner can use the same principles to solve new fluid dynamics problems involving the lungs or a problem in an unfamiliar organ system (Kulasegaram, Min, Ames, Howey, Nevile, & Norman, 2012). This failure to transfer even the most highly conserved concepts is the challenge not only for medical education but almost all concept teaching. A large body of evidence suggests that learners rarely succeed in spontaneous transfer (Bransford & Schwartz, 1999; Myers, 1992, Eva et al. 1998). In multiple concept learning domains including physics, statistics, and chemistry, experimental evidence shows that spontaneous success rate is 10-30% - an effect replicated in experiments in medical education (Norman, Dore, Krebs, & Neville, 2007.). Students tend to have great difficulty in recognizing the applicability of conceptual knowledge to a new problem.

However, not all transfer tasks are equally difficult. Transfer research must still address a critical theoretical problem: the effect of context on transfer

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performance (Day, & Goldstone, 2011; Catrambone & Holyoak, 1989; Catrambone, 2002). That is, learners perform differentially on transfer tasks depending on the similarity of the transfer context to that of learning. Situations where there is a high degree of similarity between learning and transfer are termed as "near transfer" (Blessing & Ross, 1996). For example, learning the concepts of fluid dynamics in arteries and then applying them to new problems involving venous circulation is a form of near transfer (Kulasegaram et al. 2012). The context or "surface features" have not shifted greatly and in most cases, learners are able to transfer in these circumstances as they can recognize the conceptual problem. As the context moves further away from that of initial learning, the difficulty of transfer increases. When the context has sufficiently moved, the situation becomes far transfer. Transfer of fluid dynamics from learning with a blood circulation problem to regulating flow in gas pipelines is an example of far transfer. In this example, the surface features surrounding the concept of fluid dynamics have departed greatly and prevent recognition necessary for transfer.

On the other hand, the positive effect of surface similarity has been noted several times in that surface similarity greatly facilitates transfer (Ross, 1987; Gentner, Ratterman, & Forbus, 1993; Catrambone, 2002). And indeed, in other areas of medical education such as clinical reasoning, experts and novices display a strong reliance on similarity based on past experience to make decisions (Norman et al. 2007, Young, Brooks, & Norman, 2011; Dore, Brooks, Weaver, & Norman, 2012). Familiarity with even irrelevant or superficial features (e.g. age of patient, patient occupation) can have subtle influences on diagnostic decision making (Young et al. 2011).

This tension in the transfer of concept learning – ease of near versus far transfer – is reflected in historical conceptualizations of transfer theory which has struggled to articulate how broadly learners could be expected to transfer and what strategies can facilitate it.

2.3 History of Transfer of learning theory

The struggle for transfer theorists has been to define how far from the domain of learning can knowledge be feasibly transferred for problem solving. Transfer conceptualization and theory lies on a continuum from broad (formal and informal learning can be transferred across a variety of dissimilar domains) to specific or narrow (knowledge can only be applied to domains or problems that are substantially similar) (Helfenstein, 2005). Whether transfer is conceptualized as broad or specific influences how learners are taught for transfer. If transfer is theorized as being broad, then fundamental knowledge or skills can be taught to improve a wide range of faculties or abilities. If transfer is considered to specific, then learning and practice must closely align with the domain of problem solving.

2.3.1 Early Transfer theory

The earliest conceptions of transfer were broad. An early broad articulation of transfer is found in Book VII of *The Republic* where Plato's Socrates argues that

knowledge of geometry and mathematics was necessary and applicable for understanding many higher order tasks including politics or apprehending the idealized abstract forms necessary for the optimal functioning of society (Plato, Book VII pp34). This broad conceptualization dominated educational thinking for several centuries up to the early 20th century. Subjects such as Latin, mathematics, history, and literature were not only taught with the expectation that they could enable students to advance to more sophisticated disciplines but also that these subjects induced general habits of mind and dispositions (Helfenstein, 2005; Bransford & Schwartz, 1999). This training of fundamental mental faculties was expected to improve performance or aid in learning new knowledge domains. In some sense, this historical view still exerts an influence in education as even 21st century learners are taught 'critical reasoning' or problem solving skills (Synder & Synder 2008).

2.3.2 Behaviourist theory and its opponents

However, this broad view was challenged by advances in experimental psychology in the early 20^{th} century, notably by Thorndike and Woodworth (1901). Thorndike and Woodworth conducted three seminal studies in which they described the failure of learners' improvement of faculty or ability in one task to improve faculty in another within the same domain (1901). For example, in the third study, participants practiced identifying words with *e* and *s* in written passages until they achieved total accuracy while completing the task as quickly as possible. They were

then asked to mark words in a new passage but now identifying words with other letters (e.g. t and s). Accuracy on the new identification task was not improved by training on the practice task, leading Thorndike and Woodworth to conclude that "Improvement in any single mental function rarely brings about equal involvement in any other function, no matter how similar, for the working of every mental function-group is conditioned by the nature of the data in each particular case" (pp 247). This viewpoint was expanded by behavioural psychologists in their conceptualization of transfer as strictly specific (Cox, 1997). This view argued that for transfer to occur, elements of the learning and transfer setting had to be nearly identical. As with most behaviourist theories, transfer conceptualizations did not refer to mental processes that could promote or hinder transfer. Rather, transfer was described as a specific response to familiar stimuli (Cox, 1997, Lave, 1988). While this view- *identical elements* – dominated thinking in psychology and education till the early 1980s, counter-currents against, narrow, highly specific conceptualizations of transfer appeared early in the literature.

One of the earliest to argue for a compromise between overly broad and strictly specific transfer was Charles Judd (1908). His theory of generalization argued that learners can be aided in extracting general principles from one domain and application in another domain. For example, rules of grammar in a parent language such as Latin, can be generalized and applied to learn some of the rules of French. At the same time, research in gestalt psychology investigating problem solving, in particular, posthumous work by Karl Duncker (1945), suggested that some individuals indeed managed to solve novel problems by analogizing a solution from previously solved problems. Famously, Duncker tested participants in their ability to learn the "fortress problem" where participants were told:

"A general must capture a fortress. However, the most direct route that can accommodate all of his troops is mined heavily and an approach would cause too many casualties. The general decided to split his troops into smaller units and approached the fortress from multiple sides, thus capturing the fortress." (Gick & Holyoak, 1980)

Participants were then given the following "tumour problem"

"A doctor must irradiate an anterior esophageal tumour in a patient. A direct application of the necessary dose would also irradiate healthy surrounding tissue. What should the doctor do?" (Gick & Holyoak, 1980)

The correct solution is to irradiate the tumour in small doses but from multiple positions. Like the "fortress problem", the "tumour problem" involves the splitting of a large amount of force and approaching from multiple sides. Once the learner understands the principle of the "fortress problem", they can solve the "tumour problem" by analogy. Despite the relatively early emergence of a hybrid view, research on transfer was largely influenced by the identical elements view and behaviourist theory (Cox, 1997). In many ways this paradigm was self-limiting. If transfer only occurred when there was high correspondence between learning and problem solving, then the only way to teach for transfer is to familiarize learners

with every possible variation or context in which a problem may occur. Experimental evidence did support this assertion (Campione, Shapiro, & Brown, 1995) likely reflecting the ease of near transfer and the difficulty of far transfer. However, the emergence of cognitive psychology as an alternative to behaviourism would challenge the overly specific conceptualization of transfer.

2.3.3 Cognitive psychology and Transfer as mental processing

Beginning in the early 1980s a renaissance of transfer research using analogical reasoning as a model began to uncover the cognitive processes that influenced transfer. The seminal studies that launched an explosion of transfer research were by Gick & Holyoak (1980, 1983). Using problems such as Duncker's fortress, this research attempted to illustrate how encouraging analogical reasoning could assist in transfer to novel problems. For example, Gick & Holyoak (1980) asked students to solve the 'tumour problem' with and without seeing the 'fortress problem' first. Students who had the benefit of seeing the 'fortress problem' previously and told that it was a source of the potential solution for the 'tumour problem' were much more likely to solve the 'tumour problem' than students without (1980). To accomplish this transfer, students had to understand the analogical relationship between the deep structure of the 'fortress' and 'tumour' problems – that despite different contexts, the problems shared a structural similarity. This work led to similar investigations exploring transfer as analogical

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reasoning, notably by Gentner (1983, 1989), Ross (1987,1989,1990) as well as others.

Analogical reasoning posited transfer as a mental process that was cued by both the environment of the problem solving and the mental abstractions of problem categories generated by the learner(Reeves & Weisber, 1994). The paradigm for this work was to examine exposure to the solution of one problem (e.g. fortress problem) and transfer of an abstracted general principle to another problem that may or may not be in the same domain as the original source problem. While analogical reasoning soon became synonymous with transfer in psychology literature (Helfenstein, 2005), reasoning by analogy is in fact only one of many specific conceptualization of the transfer of highly abstract, conceptual knowledge from 'insight problems' (Norman et al., 2007). As such, this work often had limited generalizability but expanded the conceptualization of transfer to be broader than allowed by behaviourists. In this view, transfer is recognized as difficult for learners, but still possible even in the absence of identical elements between learning and transfer (Gentner, Loewenstein, & Thompson, 2003). The paradigm shift caused by this work allowed further exploration of transfer in more complex settings of concept learning and ecologically valid learning materials.

The work in analogical reasoning focused on two key questions: 1) What type of mental processing and representation of a problem or concept was necessary for transfer? 2) What impact did the learning problem and the transfer problem have on this processing? In answer to the first question, a large body of literature converged on the idea that successful transfer required transfer appropriate cognitive processing during learning and this processing can be achieved by specific mental activities (K. J. Holyoak & Koh, 1987; K. Holyoak, 1989; Needham & Begg, 1991; Catrambone & Holyoak, 1989; Catrambone, 1996, Gentner, 1983, 1989, et al. 2003; Loewenstein, Thompson, & Gentner, 2003). Furthermore, these activities could be elicited by some types of learning interventions (Bassok & Holyoak, 1989; Goldstone & Son, 2005; Novick & Holyoak, 1991; Sloutsky, Kaminski, & Heckler, 2005). While this was considered encouraging for the possibility of teaching for transfer, research addressing the second question found that the similarity between the learning and transfer problems was still a strong predictor of successful transfer (Catrambone et al. 1989, Ross et al. 1987, 1993).

2.3.4 Schema theory and Transfer appropriate processing

The work addressing the first question settled on two main findings. Firstly, formation of problem solution schemas was essential for successful far transfer – especially across very broad contexts such as the 'fortress' and 'tumour' problem. Several different versions of schema theory were proposed. Two prominent positions: 1) structure mapping (Gentner, 1983) and 2) pragmatic schema building (Catrambone & Holyoak, 1989) viewed transfer as the result of the abstraction of underlying structural characteristics of between a learning problem and transfer problems. As the structural representation of the concept became more strongly

encoded and understood by the learner, the possibility of transfer increased (Reeves & Weisberg, 1994). While these theories differed in describing how specifically schemas for problem solution were formed, they agreed in general that access to abstract, structural information was important for the learner. These theorists also argued that contextual information such as surface details became increasingly irrelevant as learners began to build schemas. Specifically, it suggested that transfer would occur through four specific steps within the schema: 1) encoding of a target analogy and solution 2) retrieval of the analogy and solution, 3) application of the solution and 4) adaptation of the solution (Cheng & Holyoak, 1985). Learning interventions that functioned at step 1 and step 2 by helping learners understand the deep structure of the problem should ostensibly improve transfer. Several studies of learning interventions (Lowenstein et al. 2003; Paris & Glynn 2007,; Donnelly & McDaniel, 1993; Newby, Ertmer, & Stephic, 1995; Day et al. 2011) supported this view. Further support was found for this perspective as it closely reflected the emerging literature on expert categorization. A series of studies (Chi, Feltovich, Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980a,b) showed that for complex domains such as physics, experts tended to approach and classify problems on underlying structural features (e.g. Newton's second law). The contextual or surface features of the problem only served as minor cues for deep structure recognition (Larkin et al. 1983). As this literature too was converging on schema formation as a prerequisite for expertise (Chi, 2011) training on abstract,

structural information seemed a logical axis on which to design interventions for transfer.

The second finding of this work was the importance of facilitating cognitive processing during learning that would simulate processes learners had to engage in during transfer problem solving, so called *transfer appropriate processing* (Morris, Bransford, & Franks 1977). An early demonstration with teaching implications was a study by Morris et al. (1977) who had participants memorize lists of words either in a semantically appropriate context (e.g. logical sentences such as 'the train had a silver engine) versus rhyming phrases. Participants were then asked to recognize the words when presented in logical sentences or other rhyming phrases. Morris and colleagues found that participants who had congruence between the learning condition and testing condition had the highest performance. Alternative learning and memory accounts (e.g. the levels of processing theory) would contend better memorization in fact would lead to better performance. The transfer appropriate processing account argues that the congruence between the processing demands of the learning and transfer task would be more likely to facilitate transfer. Memorization - and in the education analogue, knowledge or recall - maybe necessary but not sufficient for improved transfer. In a novel demonstration of this effect, Needham and Begg examined how processing instructions changed transfer performance (1991). Psychology undergraduates in a series of studies were given sets of probability problems and the solutions by the experimenters. In the problem oriented processing condition, the experimenter asked participants to explain why

the solution was correct and think about the solution for use in solving other problems. The comparison control condition was labeled memory oriented processing condition; the experimenter asked the students to recall as much as possible of the solution for future use. The results of several experiments showed that while memory oriented processing was superior for recall (80% to 70%), problem oriented processing was markedly superior for transfer (90% to 67%). Needham and Begg concluded that even though learners were given the same set of materials, instructions for different process types changed how learners make sense of the learning materials.

Current theoretical and instructional approaches to transfer are still organized around the transfer appropriate processing principle (Butler, 2010; Leboe, Whittlesea, & Milliken, 2005; Markman & Ross, 2003;) though this account is by no means unchallenged (Rohrer et al., 2010). Transfer appropriate processing provides support for focus and teaching of deep structure. Identification and recognition of the deep structure of conceptual knowledge during initial learning simulates the same cognitive processes required to solve future transfer problems. Abstraction of conceptual knowledge early during learning would greatly facilitate learning for transfer (Reeves & Weisberg, 1994).

2.3.5 The role and manipulation of contextual information

Despite the evidence for the value of schema formation and abstract learning, a consistent finding in cognitive literature replicated the effects of the behaviourists: transfer was easiest for novices when there was strong contextual alignment (similar surface features, superficial details or semantic information) between the learning and transfer contexts (Ross & Kennedy, 1990; Ross, 1987). Furthermore, the evidence suggested that even slight variations or modifications to the transfer problem's context from the learning context caused difficulty for novices in recognizing the shared conceptual deep structure (Reed, 1989). Notable theorists in this area proposed that contextual information could have added value in solving problems and aid in future problem solving. These so-called "exemplar theorists" (Reeves & Weisberg, 1994) did not necessarily disagree that schema formation occurred as novices developed problem solving capability. But they did argue that contextual information such as surface details did not disappear from schemas and in fact this information was retained during problem identification and explanation (Reed & Bolstad, 1991; Ross, 1989).

Support for this view came from a series of studies examining how novices transferred knowledge in the presence or absence of contextual alignment. For example, Spencer and Weisberg (1986) examined the ability of novices to transfer knowledge using materials similar to the insight-analogical reasoning studies conducted by Gick & Holyoak (1983) (e.g. fortress and tumour problems). Crucially, after the learning phase, they attempted to evaluate the strength of schema formation and schema quality (e.g. degree of abstraction and reference to crucial structural elements) by asking participants to write out their perceptions of the underlying problem solving procedure for the class of problems. At transfer

testing, they found that transfer to problems with similar contextual details was highest while the transfer to problems with new contextual details was poor. Both of these findings were independent of the strength and quality of the schema. Furthermore, even students with high quality schemas have low transfer to novel problems. This led them to conclude that contextual alignment as opposed to elaborate conceptual structure was the crucial facilitator of problem solving. These findings were replicated by Catarambone & Holyoak (1989) and similar effects with other materials were reported by Reed (1989) and Cheng and colleagues (Cheng, Holyoak, Nisbett, & Oliver, 1985). Further work found that learners, often failed to use the explanation for the abstract principle or concept and instead relied on surface similarity to guide problem solving (Ross et al. 1987). Learners do represent concepts as abstract or platonic context free representations. Instead, novices used and relied on the contextual details and surface features as exemplars of the category of the problem (Ross & Kennedy, 1990; Gentner & Toupin, 1986). Thus reliance on contextual information was possibly a default strategy for the learners. This suggested that contextual information had a strong influence on how learners' approached transfer problems and that making all transfer into 'near transfer' would be necessary for training learners. The strong contextual effect was reflective of other effects reported in studies psychology of memory and retrieval (notably Godden & Baddeley, 1975) which argued that learning was context specific.

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However, further exploration of the influence of context specificity suggested that contextual details could be manipulated to promote transfer to novel problems. Specifically, contextual variation – presenting multiple examples of a concept with different sets of superficial or surface details - suggested that increasing the number of examples of problem solving contexts could facilitate both near and far transfer. For example, some studies found that encouraging comparison of dissimilar examples improved far transfer (Lowenstein et al. 2003; Gentner & Gentner, 1983; Ross, 1989; Catrambone & Holyoak, 1989). Other studies found that simply providing exemplars of the problem task was sufficient to improve transfer to problems with dissimilar surface features (Cheng et al. 1986; Avrahami, Kareev, Bogot, et al., 1997). Despite these results, there is lack of consensus of whether increasing the number of examples of conceptual knowledge promotes greater reliance on surface features and processing of new problems based on similarity (Nokes, 2009; Kaminski, Soutsky, & Heckler, 2008; Spencer & Weisberg, 1986) or whether it pushes learners to examine underlying deep structure (Ross, 1989; Gentner, et al. 1993).

2.4 Implications for teaching for Transfer

Both the schema based theories of transfer and the exemplar-context based theories of transfer have strong support. Indeed, some have argued that these positions are complementary (Reeves & Weisberg, 1994) and can be reconciled by considering the type of experimental transfer task being examined. Furthermore,
both these positions suggest that transfer interventions in more complex domains such as basic science training have to contend with two issues: 1) exposing deep structure to novices and 2) addressing the context specificity of learning and reliance on contextual information. It could be that addressing the first issue is sufficient to address the second. Several authors in the tradition of the schema theorists (Kaminski et al. 2013; Nokes, 2009; Kaminski et al. 2008; Sloutsky et al. 2005) have argued that contextual information should be de-emphasized during training and that deep structure teaching should be increased. Others contend that learners can be encouraged to examine a large number of examples of problems *and* rely on surface features when appropriate (Reed et al. 1991, Ross & Kilbane 1997).

Transfer interventions have tended to focus on structural strategies. For example, teaching analogies have been used as ways to illustrate deep structure and promote transfer. Newby and colleagues defined instructional analogies as "explicit, non-literal comparison between two objects, or sets of objects, in different context domains. which describes their structural functional, and/or causal similarities." (Newby et al. 1995) Providing relatable concepts to new or difficult material aids understanding of the unfamiliar in familiar terms as noted by Gentner et al (2003). A typical example of analogies for teaching is Donnelly and McDaniel's 1993 study. Students in the intervention condition were taught the concept of quasar activity (a rotating star that emits light in two opposed streams) by likening its appearance to that of a lighthouse while the control condition did not receive the analogy. Students taught using analogies showed similar recall to

control subjects but improved ability to transfer to inferential questions. This effect for the strength of analogies in facilitating transfer has been demonstrated in mathematics (Novick & Holyoak 1991) and in physiology (Paris & Glynn, 2007). Though the use of instructional analogies is not controversial, the manner of their deployment and the processes they promote are still being investigated. Familiar, elaborate, and explicit analogies (Paris & Glynn, 2007) seem to have value over other forms of analogy presentation. Analogies that emphasize structural or relational features of concepts can promote transfer but analogies that emphasize superficial characteristics of a concept tend to obviate transfer (Newby et al., 1995) suggesting focusing on deep structure to be an appropriate strategy. Further explanations for the success of teaching analogies point to reduction of cognitive load when attempting to learn novel concepts (Van Merrinboer, Kester, & Paas, 2006). A notable application of deep structure teaching was an instructional analogy study by Norman and colleagues (2007) in which students were taught how explain the symptoms of written clinical cases using widely applicable physiology principles. The authors manipulated whether participants were given an analogy or just a basic clinical explanation and found a general benefit for the analogy.

While analogies seem to benefit learning for transfer during concept instruction, transfer interventions have also been employed during practice. One notable example is manipulating the order in which multiple concepts are practiced: in blocked or mixed (also called interleaved) practice. In blocked practice, students learn and practice each concept separately. This form has been traditionally used: a concept is practiced before learning the next concept. As noted by Norman, this form of practice reinforces that: "t-test problems come at the end of the t-test chapter" (Norman, 2009). In contrast, mixed practice involves learners practicing all concepts together. For example students would practice ANOVA questions, ttest problems, and chi square problems in the same practice session. Rohrer and Taylor (2007), noted that though this makes practice more difficult for students, mixed practice outperforms blocked practice for solving new problems. Hatala and colleagues (2003) demonstrated the effect of mixed practice in medicine through the teaching of cardiac diagnosis by ECGs. Students taught using mixed practice were 47% successful at solving novel problems while blocked practice was only at 30%. The most likely explanation for this effect is mixed practice forces students to identify the structural features of the concept involved in the practice problem. This increases the germane load of the activity and reduces the extrinsic load of future problem solving tasks (Van Merrinboer et al. 2006). In blocked practice, students are already aware of the problem's underlying concept and structure thus receiving less practice at concept identification.

2.5 Outstanding issues for Transfer in medical training

The literature from analogical reasoning, cognitive psychology, and educational psychology provides theoretical and applied knowledge for framing training for the transfer of conceptual knowledge. However, some limitations – methodological and theoretical – prevent the ready adaptation of the literature in psychology to medical education. Methodologically, it has been argued the materials and design of most studies do not reflect the context of medical education (Norman et al. 2007; Norman, 2009). This critique most readily applies to early transfer studies (Gick & Holyoak, 1980) where the concepts taught are too simple to reflect the needs of medicine and have been termed "aha!" or "insight" problems such as the Duncker problem. Once the learner recognizes the broad features of the concept, no further adaption or work is necessary. Ross and colleagues in a series of transfer experiments, taught learners to identify the appropriate statistical tests or mathematical formulas for a given situation (Ross & Kennedy, 1993; Blessing & Ross, 1996). At transfer testing, students must recognize whether a particular problem should be solved by ANOVA or t-tests and indicate through a multiple choice response. As long as two groups with interval or ratio measurements are present, a t-test can be performed regardless of the nature of the grouping or subjects. In contrast, the conceptual task of transferring basic science concepts in medicine is much more difficult – e.h. the processes of the Kreb's cycle and their application to metabolic disorders. Basic must also be adapted to each clinical context: using fluid dynamics requires identifying the sources of pressure and turbulence in the respiratory tract, circulation, or gastrointestinal tract. Work in other domains such as physics (Newby et al., 1995), physiology (Paris & Glvnn, 2004), and even in commerce (Lowenstein et al., 2004) can provide more ecologically valid lessons. It is reassuring that, by and large, the findings of early transfer research in theoretical domains have been replicated in applied settings. However, replication studies in medical education are warranted to confirm *and extend* previous findings. In particular, there is an opportunity to advance the theory of transfer by addressing theoretical limitations of the current work.

One of these theoretical issues is the relationship between deep structure concept teaching and the reliance on contextual information by the learners. For successful far transfer, learners must learn and understand principles on a conceptual level. The difficulty of far and the ease of near transfer suggests that that surface features play a key role in encoding concepts. In medical training, surface features are often (but not always) reasonable cues for deep structure (Young et al., 2011; Norman et al., 2007) and thus reliance on contextual information can be seen as appropriate in some circumstances. Furthermore, this suggests that increasing context variation during training would achieve the transfer goals for near and far transfer. The effect of concept focusing, deep structure interventions such as teaching analogies on near versus far transfer performance is unclear. Similarly, whether context focused teaching strategies such as multiple examples have a uniform effect on near and far transfer is also unclear. And whether these strategies have similar or different mechanisms (as well as the precise mechanism of their effects) are still to be elucidated in the medical education context.

To address these issues, first the effect of deep structure interventions on near and far transfer must be examined. If near transfer performance is equivalent to far transfer for those with better deep structure instruction, then the novices' reliance on contextual features could be argued to be mitigated. If not, contextual information is still relevant and needed by learners. This question is studied in Chapter 3. Secondly, if contextual information is still primary, then context variation maybe an appropriate transfer strategy. Increasing the number of examples of contexts or surface features may be more advantageous for near and far transfer than just using deep structure teaching. Furthermore, there should be an incremental advantage for using more than just two dissimilar contexts. If this does not occur, then perhaps these interventions elicit similar processing changes in learners, likely by shifting away from reliance on contextual information. This question is addressed in Chapter 4. Lastly, if reliance on contextual information is the default mode of learners, then it may interfere with transfer interventions if they are employed without attention to this strategy and the type of processing required for transfer. This question is addressed in Chapter 5.

CHAPTER 3: THE EFFECT OF CONCEPTUAL AND CONTEXTUAL FAMILIARITY ON TRANSFER PERFORMANCE

In chapter three I replicate Norman et al. (2007)'s finding of the advantage of a common-sense analogy, illustrating deep structure, on transfer of physiology of concepts. This study also examined the impact of the analogy on transfer to near and far transfer problems. I show two key findings: first, a replication of Norman et al. (2007) and other investigations that interventions to enable learners to access deep structure can improve near and far transfer. Secondly, near transfer performance for novices is invariably higher than far transfer performance regardless of the analogy. I propose this due to an efficient use of contextual, surface details which are easier to understand and recognize in-comparison to conceptual deep structure.

Use of teaching analogies as an instructional strategy has been discussed in applied educational (Newby & Stephic 1994, Paris & Glynn 2004) and theoretical literatures (Catrambone, 2002). Norman et al. (2007) examined the impact of pairing analogies with an explanation, presenting analogies separately, and only using a clinical explanation. Though they found no significant difference between the analogy conditions, both groups outperformed students with only the clinical explanation. While this supports the use of teaching analogies it is unclear whether they have uniform effects on both near and far transfer tasks. Near transfer presents the same surface details as in the context of learning. Previous studies of transfer have shown that these problems are invariably easier for learners (Ross, 1987), especially if there is a close correspondence between concept and contextual information. Contextual similarity can be a useful method for identifying the category of the problem to be resolved in many domains but especially in medicine (Young et al. 2011, Dore et al. 2012).

Study one examined if provision of a teaching analogy can overcome reliance on contextual similarity and if there is an interaction with the analogy instruction and near versus far transfer performance. It was published in *Advances in Health Sciences Education* under the title of "The effect of conceptual and contextual familiarity on transfer performance" in October 2012, volume 17, pages 489-499. The list of authors includes: Kulamakan Kulasegaram, Cynthia Min, Kimberly Ames, Elizabeth Howey, Dr. Alan Neville and Dr. Geoffrey Norman. The design and conception of study was by myself and Dr. Norman. Dr. Alan Neville originally developed the materials for the study; I modified those materials for the present study. Data collection was conducted primarily Cynthia Min, Kimberly Ames, and myself. I also conducted the data analysis and authored the first draft of the paper. The paper is reprinted with the permission of Springer International.

The effect of conceptual and contextual familiarity on transfer performance

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ABSTRACT

Applying a previously learned concept to a novel problem is an important but difficult process called transfer. It is suggested that a common sense analogy aids in transfer by linking novel concepts to familiar ones. How the context of practice affects transfer when learning using analogies is still unclear. This study investigated the effect of a common sense analogy and context familiarity for transfer of physiological concepts. First year psychology students (n = 24) learned three concepts: Starling's law, Laplace's law, and laminar-turbulent flow. The control group saw standard explanations while the intervention group saw an additional common sense analogy. The context of learning was the organ system used for two practice clinical cases which differed for all concepts. Testing consisted of 12 new clinical cases. Starling's law cases used the organ system from practice while the other concepts presented in both novel and familiar organ systems. Half of the sample repeated testing after 1 week delay. The outcome was ratings of explanations of cases on a 0-3 scale. The effect of analogy was significant (Mean = 1.24 with, 0.86 without, F(1,22) = 4.26, p < 0.05) but not after

delay (means of 1.08 and 0.75 respectively, F = (1,10), p = 0.06) There was significant effect for familiar context (Same = 1.23 (Starling), different = 0.68 (Laplace) and 0.73 (laminar-turbulent flow) (F(2,44) = 5.14, p < 0.01). Laplace's law and laminar turbulent flow cases in the familiar organ system had means of 1.65 and 1.77 respectively compared to novel cases with means of 0.74 and 0.68 (F(1,22) = 35.64, p < 0.0001). Similar effects were observed after delay. There was significant decay in performance after delay for all participants (immediate = 1.17, delayed = 0.91, F = 11.9 (1,10) p < 0.01). Common analogies aid conceptual understanding necessary for transfer. Despite conceptual aids, solving transfer problems is difficult.

INTRODUCTION

For a century since the Flexner report, medicine practice and the biomedical sciences have been intimate partners. Although medical practitioners must master many skills in many domains—cognitive, technical, conceptual and interpersonal, it is difficult to conceive of a contemporary practitioner who could not demonstrate some mastery of the basic concepts in anatomy, biology, pharmacology, and physiology. Indeed, one-third to one-half of the student's time in undergraduate medical education are devoted to basic science teaching, and understanding of basic science is included in licensing examinations.

It is perhaps surprising therefore that observational studies of expert practitioners reveal that they rarely explicitly use basic science concepts in solving clinical problems (Patel et al. 1986). Basic science concepts remain "encapsulated" where they may occasionally be retrieved for use (Boshuizen and Schmidt 1992).

What, then, is the developmental role of basic science in the education of a practitioner? One insight has come from a series of studies by Woods (2005, 2007) in which she showed that biomedical knowledge provided a conceptual "scaffold" that aided remembering of relationships between symptoms and diseases and consequently had demonstrable effects on diagnostic skill. It is self-evident that basic science concepts can only serve this central role if they are sufficiently understood and are seen as relevant to the clinical problem. This condition was not tested in the Woods studies, as the concepts were deliberately straightforward. However, there is reason for concern that, while students may appear to understand

concepts and may demonstrate recall, they will not be able to recognize when a problem situation demands application of a particular concept.

The act of applying conceptual knowledge learned in one context to solve a problem in an unfamiliar or novel context is called transfer by psychologists (Ross 1987). Research has shown that transfer is a difficult process; learners faced with new problem scenarios in which previously learned concepts yield a solution only succeed in recognizing their applicability 10–30% of the time (Norman et al. 2007). Successful transfer requires the recognition of the structure of the abstract concept that lies below the surface details of the problem. However, often surface similarity provides a strong cue to the nature of the problem and learners may unconsciously rely on surface similarity to decide on the nature of the problem (Gick and Holyoak 1980; Holyoak and Koh 1980; Ross and Kennedy 1990). This strategy will be effective when the new problem is sufficiently similar to the context in which the abstract concept was learned; this type of transfer is referred to as near transfer. By contrast, if the problem to be solved presents with surface features sufficiently different from the learned example, transfer can be difficult, a situation called, by extension, far transfer. As Ross showed, novices tend to mistakenly look for similarity of contextual details and thus will invoke the wrong solution strategy (Ross 1987; Ross and Kennedy 1990). By contrast, as Larkin et al. (1980) showed in their classic studies of expert and novice physics problem solvers, experts classified problems by deep structure (e.g. conservation of momentum) whereas novices classified by problem details (inclined plane).

The challenge, then, is to devise instructional strategies that encourage learners to classify and understand concepts at the level of the deep structure, so that they can identify problem similarity at this level. One can envision several stages of the process that may be amenable to interventions. At the time of initial learning of the concept, invoking an everyday analogy may serve to enhance understanding as well as to decouple surface and deep structure. Newby et al. showed that the use of analogies can be effective if the analogy is in-depth enough to allow for easy comparison by the novice (Newby et al. 1995). This has also been demonstrated using medical materials by Norman et al. (2007) who showed an advantage of about a factor of two for learners who saw a mechanical analogy in the course of learning physiological concepts.

Most studies in psychology have intervened during practice, where students are given one or more problems that exemplify the concept. Several studies have shown an advantage for multiple problems (Gentner and Holyoak 1997; Catrambone and Holyoak 1990). Encouraging different processing can also yield gains. Gentner showed that active comparisons between two problems illustrating the same concept led to large gains. Needham and Begg showed that students who attempted (usually unsuccessfully) the problem and were then shown the solution outperformed a control group who were taught the problem and solution. Finally, some studies have examined effect of instruction at time of test (Needham and Begg 1991). Encouragement to "think about other problems like this" has some benefit.

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While the psychology literature can provide real insight into the nature of transfer, the materials used are frequently highly artificial, and limit generalizability. As one example, many studies are based on insight problems where the learner need only retrieve, not learn, the relevant concept, so the impact of different strategies for initial concept learning is not explored. Additionally, these artificial insight concepts use superficially dissimilar analogies, which constitute the bulk of the learning material. While this is useful for exploring analogical reasoning, the generalizability of this approach to learning as it occurs in educational settings is limited. Further, the studies that systematically explore the effect of variations in surface context tend to the extreme-exactly the same problem context except for some minor wording changes or at the other extreme, completely different contexts—a medieval fortress and a light bulb (Gentner 1983). Research on transfer must move away from the analogical reasoning paradigm to embrace a more ecologically valid use of analogies and context variation during learning.

The present study is an extension of the Norman et al. (2007) study. We wished to replicate the central finding that providing a simple "commonsense" or everyday mechanical analogy could lead to substantial gains in transfer by enabling access of the conceptual relationships of physiology principles. We also attempted to elaborate on the Ross studies of the effect of context on transfer by manipulating similarity within more reasonable bounds—same versus different organ system and its interaction with learning conditions (Ross 1987; Ross and Kennedy 1990).

Finally, we included an initial exploration of the effect of a 1-week delay to see if differing learning conditions led to different patterns of decay.

METHODS

This study was conducted with twenty-four psychology students (N = 24) at McMaster University who participated for course credit or a small monetary compensation. The study received institutional ethics approval from the Health Sciences Review Board; all participants read and signed consent forms. Students enrolled in the health sciences and/or with a background in anatomy or physiology were excluded.

Procedures

The experiment was divided into two phases: learning and testing. During the learning phase, participants learned three physiological principles in random order: Starling's law, Laplace's law, and laminar-turbulent flow—renamed Goethe's law for consistency. Starling's law describes the elastic behavior of heart muscles and the effect on final stroke volume. Laplace's law describes the relationship between wall tension, pressure, and radius in a filled cylinder or vessel; it is applicable to the normal functioning of arteries and the gastro-intestinal (GI) tract. Goethe's law (laminar-turbulent flow) describes factors that affect the transition of fluids from laminar to turbulent flow and plays a role in the respiratory and cardiac system. The above principles converge in that they all describe various parts of the cardiovascular system, while both laminar-turbulent flow and Laplace Law have application in other organ systems. This allowed manipulation of far and near transfer during testing.

Students in the biological explanation condition saw a detailed half-page explanation of each principle approved by an expert clinician (AN). However, for two of the principles the explanation used features and terms that described the principle in an organ system other than cardiac. Laminar-turbulent flow was taught using the respiratory system, in particular airflow through the bronchioles and the effect of asthma or obstructions. Laplace's law was taught using the gastrointestinal tract. Starling's law, which served as a near-transfer control principle, was taught in the cardiovascular system. Participants in the biomechanical analogy condition learned from the same explanations but had an added common-sense analogy. For Starling's law, the stretch of heart muscle was compared to stretching a spring; laminar-turbulent flow was compared to water flow through pipes and a tap; Laplace's law was compared to a weight suspended on a string. An example is shown in Table 1.

Table 1: Laplace's law explanation and analogy

Explanation	Analogy
Laplace's law applies in many situations,	A diagrammatic way of explaining this
The intestines are tubes with a radius,	the pressures across the vessel wall is
exerted by the tube's contents: digesting	shown in the left diagram (Fig. \underline{I}). In order to maintain the same downward
food. The tension in the intestinal wall is proportional to the radius of the intestine	force (the pressure), the wall tension T must increase as the wall becomes less

Explanation	Analogy
and the pressure of the contents. This	curved. This is analogous to a weight
relationship can be explained by: $I = PR$	hanging on a string as in the diagram at
where T is the wall tension, P is the	the right. When a weight is suspended
pressure, and R is the radius. Thus,	from a string, the tension in the two ends
having a small radius decreases the	of the string increases as the string
tension in the wall for the same internal	becomes closer and closer to horizontal,
pressure. Laplace's law explains why in	because the vertical component of the
normal circumstances intestines don't	tension must equal the weight
rupture their contents and why in some	
conditions, serious complications can	
follow dilatation or an increase in the	
radius of the bowel, as occurs in	
inflammatory conditions of the bowel	

After viewing each explanation, participants were allowed to proceed to a practice session which was standardized across conditions. Participants saw two practice cases presented simultaneously and were asked to explain the how each previously learned principle explained the clinical features of the practice case. The practice cases were deemed "typical" by an expert and were situated in the same organ system used in the explanation of the principle. Thus laminar-turbulent flow practice cases only showed respiratory scenarios while Laplace's law cases showed only gastro-intestinal scenarios, and Starling's law cases showed only pathologies in the heart. After completion, participants were allowed to view the appropriate answer for each case. Upon completion of the initial learning phase for all three principles, the participants were presented with an additional practice session consisting of ten true or false questions, standardized across conditions. A score of at least eight out of ten was required to move on to the testing phase. A participant

who received a lower score repeated the practice session once before moving to the testing phase.

The standardized testing phase consisted of random presentation of twelve clinical scenarios which asked the participant to (a) identify the law that explains the scenario and (b) provide a brief explanation of how the principle explains the scenario. Laminar-turbulent flow consisted of three cases in the cardiac system and one respiratory case that differed from the practice problems. Similarly, Laplace's law had three cases in the cardiac system and one gastro-intestinal case. Starling's law was presented with all cardiac cases. This design allowed comparison of performance in near transfer (familiar organ system) in comparison to far transfer (new organ system) within laminar-turbulent flow and Laplace's law and between principles: performance on Starling's law cases (near transfer) in comparison to unfamiliar organ systems in laminar-turbulent flow and Laplace's law (far transfer). Participants in the delay condition were required to return in 1 week to retake the testing phase without viewing the learning condition. No participants were lost to follow-up. A sample case used at testing is shown in Table 2. It has similar format, but different content from the practice cases.

Table 2: Sample test case of Laplace's law

A patient complained of vomiting copious amounts at the end of each day. Investigations revealed they had a lax, poorly contracting stomach. They were given a drug that constricted the size of the stomach, resulting in more efficient emptying. Identify the law at play and explain why constricting the size impacts stomach emptying Answers were rated on a three point scale (0-3) with higher score for more complete answers as in Norman et al. (2007)'s original study (as shown in Table <u>3</u>). The scoring system rewarded adaptation and extension of the learned principles instead of simple recognition.

Table 3: Scoring criteria

Scoring	Explanation
0	Incorrect concept identified
1	Laplace's law, explanation not provided
2	Laplace's law. This can be due to a decreased radius of the stomach The drug must have dilated the pathway of the stomach, allowing the food to stay in the stomach for further digestion
3	Laplace's law. The drug might have decreased tension within the stomach walls. From the knowledge of Laplace's law, we know that as the tension decreases, so does the pressure. The drop in the pressure from the outside walls, stomach's radius increases and thus, resulting in more efficient space

Two independent raters assessed the first ten participants, resulting in inter-rater reliability (Intraclass correlation) of 0.80. Only one rater was used for the remaining participants.

Design

An overview of the design is provided in Fig. 2. Participants were randomized to learn physiological explanations using either the biological explanation with additional mechanical analogy (n = 12) or only the biological explanation (n = 12). Participants were then again assigned to only immediate testing (n = 6 for each group) or immediate plus additional delayed testing group (n = 6 for each group). Thus, there were 12 participants per group for the immediate comparison and 6 participants per group, with two testing occasions, for the (immediate + delay) group.

Fig. 1: Laplace's law analogy illustration



Fig. 2: Experimental design



There were two crossed between participant factors—Biological versus Biological and Mechanical Concept, with 12 participants pr group and Immediate test only versus (Immediate and Delayed), with 6 participants per group. A total of 12 cases were used in each testing session, divided into three laws (Laplace Goethe, Starling). Within Laplace and laminar-turbulent flow, 3 cases were from cardiovascular (far transfer) and one was from the original organ system (GI or Respiratory; near transfer). All the Starling cases at both practice and test were cardiovascular, so all were near transfer. The selection of cases for each law allowed for multiple tests of near and far transfer performance.

Analysis

We initially considered only the immediate test. Three repeated measures ANOVAs were conducted, to test different hypotheses. To examine the impact of a mechanical analogy, we treated all cases as repeated measures with two factors— principle (3 levels) and case within principle (4 levels), and examined the between subject factor—biological versus biological + mechanical. We then examined the effect of near versus far transfer with two different analyses. First, we used only the cardiac test cases nested in each principle (3 for Laplace and laminar-turbulent flow, 4 for Starling), and examined a main effect of principle looking for higher performance in Starling law, since this is near transfer (cardiac–cardiac), versus far transfer (GI—cardiac for Laplace, respiratory—cardiac for laminar-turbulent flow). Second, we looked at the 4 cases nested within Laplace and laminar-turbulent flow, contrasting the 3 far transfer cases with the single near transfer (same organ system) case.

We then repeated all these analyses with the 12 participants (6 biological, 6 biological + mechanical) who did immediate and delayed testing, exactly as above except that an additional repeated measure (delay) was introduced. Thus we had a longitudinal replication of all the previous analyses.

RESULTS

All 24 participants provided data with no loss to follow-up with the subsample of 12 asked to return after delay.

Effect of mechanical analogy

The analysis of immediate testing showed significant difference in performance between the two learning conditions. The biological explanation group had a mean performance on all cases of 0.86 versus a mean of 1.24 for the biological + mechanical analogy group (F(1,22) = 4.62, p < 0.05) (See Fig. <u>3</u>). On longitudinal testing the difference in means was of the similar magnitude (biological: 0.75 vs. analogy: 1.08) but this was not significant. The effect of time spent during learning and testing as a covariate was not significant at both immediate and delayed analyses.



Fig. 3: Difference in average performance between the analogy and biological explanation condition was significant (F(1,22) = 4.62, p < 0.05) at initial testing but not after delay

Effect of near versus far transfer

The first analysis examined the 3 far transfer cardiovascular cases in Laplace and Goethe against the 4 near transfer cardiovascular cases in Starling. The overall mean for Starling's law cases was 1.23 in comparison to 0.68 and 0.74 for Laplace and laminar-turbulent flow (F(2, 44) = 5.14, p < 0.01.) (Fig. <u>4</u>). The analysis was replicated with the longitudinal data, with means for Starling of 1.33 versus Laplace and laminar-turbulent flow at 0.64 and 0.65 respectively (F(2,10) = 5.08, p < 0.01).



Fig. 4: Performance on the 3 far transfer cardiovascular cases in Laplace's law and laminar flow compared to 4 near transfer cardiovascular cases from Starling's law used in immediate testing (F(2,44) = 5.14, p < 0.01)

Examining the near and far cases within Laplace and laminar-turbulent flow, the mean for the near transfer case was 1.17 versus a mean of 0.75 across the 3 far transfer cases per system F(1,22) = 35.64, p < 0.0001) (Fig. <u>5</u>). Respective means from the longitudinal analysis were 1.64 for near and 0.65 for far transfer (F(1,10) = 9.84, p < 0.01).





Interaction effect of analogy on near and far transfer

Analysis of immediate testing comparing performance on all far transfer cases showed the biological explanation group at 0.51 versus 0.90 for the biological + analogy group (F(1,22) = 5.90, p < 0.05). Although differences were of similar magnitude in the longitudinal analysis with the biology group at 0.33 and the analogy group at 0.79, this was not significant. Differences in near transfer cases were not significant at immediate testing with the biological mean of 1.21 and the biological + mechanical mean of 1.58 (F(1,22) = 1.78, p < 0.20). These results were replicated in the longitudinal analysis. A test of interaction between analogy and near versus far cases was not significant (F(1,22) = 0.005, p < 0.094), the result replicated after delay.

Effect of delay

The effect of delay was to reduce performance across both learning conditions (immediate mean = 1.17, delayed mean = 0.91, F = 11.9 (1,10), p < 0.01). However there was no indication that the effect of delay differed between conditions; in particular, there was no evidence that the mechanical analogy resulted in less decay.

DISCUSSION

The study replicates earlier findings demonstrating the superiority of an additional mechanical analogy in facilitating transfer. We have also shown the difficulty of far transfer, with scores in the far transfer conditions about 67% of those in near transfer conditions. Both the effects were present on both immediate and delayed testing. However, our expectation that the effect of analogy may reduce

or prevent performance loss over time was not demonstrated; instead we found a near uniform decay of performance in both learning conditions.

It is possible that simply providing an analogy, while improving the ability to transfer, does not aid retention. The analogies in this study were provided as additions to the biological explanation. Whether a qualitatively improved explanation that linked anatomical or physiological features to the common-sense analogy would improve retention bears investigation. Evidence from the study of basic science instruction for recall of clinical features suggests that linking the analogy to the clinical features and making explicit the transferability of concepts would improve both recall and transfer (Woods et al. 2005; Woods 2007).

Limitations of this study include the possibility that Starling's law cases are naturally easier to understand for novices than laminar-turbulent flow or Laplace's law. However, superior performance on the familiar organ system cases in laminarturbulent flow and Laplace's law still indicate the robustness of the effect of familiarity for transfer. Participants who returned after delay saw the same test problems as in the initial test. In this case, it can be argued that the delayed test was entirely a test of familiar problems, though the general decay of performance for both groups suggests there was considerable forgetting due to time delay. The inability to detect a significant difference between the groups after time delay was likely due to low power.

A post-hoc exploration of whether participants were correctly categorizing test cases by principle revealed that on average, the biomechanical analogy group labeled 50% far transfer cases correctly while the biological explanation group correctly identified these cases only 33% of the time. Conversely, the biomechanical group and biological explanation group were almost equivalent in correctly identifying near transfer cases at 79 and 76% respectively. In light of our other results, this suggests that surface feature matching can be sufficient for near transfer cases at least to the extent of recognition of problem type.

Therefore, there are two major findings of this study. First, provision of easily understood analogies consistently enhanced transfer. Second, despite the fact that they demonstrated mastery of the concepts, novice learners still found far transfer to be a difficult task. Paradoxically, regardless of intervention status, they did use surface feature matching to resolve near transfer cases successfully. Understanding how these conflicting situations can arise can allow educators and learners to take advantage of them.

One explanation for these findings is provided by the dual processing theory of cognition which posits that there exist two separate sets of cognitive processes that operate in parallel (Evans 2008). The first process is called System 1 thinking and has been described as unconscious, automatic, swift, non-analytic, intuitive, and most salient for our purposes: context specific. System 2 thinking is described as conscious, deliberate, slow, analytic, logical, explicit and independent of context. Because System 1 processing is domain specific, this may be invoked when learners successfully use surface or contextual features for near transfer tasks. Reliance on

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contextual features to varying degrees has been shown as an almost ubiquitous phenomenon during problem solving.

However, this strategy may fail for far transfer, which requires recognizing that surface features do not provide sufficient information about the problem to be solved. An important challenge for educators is to overcome naïve reliance on surface features. Initial learning must encode not only the potential contexts and surface features associated with concepts but also the deeply conserved abstract notions at the heart of most concepts. This would require more effortful System 2 processing forcing learners to recognize the distinctness of concepts from surface features. Carried forward to problem solving, learners must also become comfortable with "going below" the surface features and reframing the problem in terms of its essential deep structure. The challenge then in developing manipulations to improve transfer is to engage System 2 processes and reorient the learner to the deep structure of concept. Education for transfer is a situation where the term "active learning" is not just rhetoric, but rather a strategic goal that guides how educators can operationalize their teaching. Whether particular manipulations do in fact engage active System 2 processing warrants future research.

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Conclusions

This study demonstrated that the effect of analogies and familiar case presentations can improve transfer of concepts to new problems by novices. Future research on transfer should consider the effect of an actively compared analogy over time and other strategies of engaging System 2 processes for far transfer. Despite gains in transfer, context specificity during learning is still a challenge for novices. Further exploration of the effects of context specificity and differential performance on near and far transfer problems is also needed.

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CHAPTER 4: RELATIVE EFFECTS OF TEACHING ANALOGIES AND CONTEXT VARIATION ON NEAR AND FAR TRANSFER OF CONCEPTUAL KNOWLEDGE

In chapter 4, I examine how teaching interventions that illustrate deep structure (teaching analogies) and expose learners to context variation (practice with multiple organ systems) have positive effects on transfer performance and promote examination of problems' deep structure instead of contextual information.

The previous chapter discussed the impact of providing a common-sense, structure- illustrating analogy on near and far transfer. There are multiple reasons why analogies provide might benefit for transfer instruction, including reducing the cognitive load when acquiring novel concepts and contextualizing unfamiliar terminology. The most significant advantage is providing an illustration of the concept's deep structure thereby allowing better understanding of the conceptual features that must be transferred and minimizing the use of surface details. Focusing on deep structure is a favoured strategy in transfer training (Norman, 2009) and relates directly to the early transfer studies (Gick & Holyoal, 1980; Catrambone & Holyoak; 1989) that highlighted the importance of building abstracted schemas for analogical reasoning.

However, the results of the previous study also showed that surface details and contextual information still exert considerable influence on learners' ability to transfer knowledge. While some theorists would suggest minimizing reliance on surface features, our results show that contextual surface information can aid in correctly recognizing near transfer problems. Other literature in expertise development suggests that surface features are an important part of exemplar-based reasoning (Dore et al. 2012, Young et al. 2011,). It is possible surface features and other contextual information actually aid novices when solving transfer problems. This view is reflected by exemplar theorists who studied transfer processing (Ross, 1989, Reeves & Weisberg, 1994) and suggested that contextual information plays an important role in cuing recall of concept categories.

The debate regarding analogical reasoning is reflected in discussions around how to train learners to accomplish transfer tasks. One class of strategies would be to provide greater in-depth teaching of deep structure, for example by providing an analogy for the deep structure of a concept. An alternative suggested by the exemplar view, would be to increase the number of exemplars (i.e. contexts) with which the concept is illustrated or practice. While both strategies may be effective, the mechanisms by which each strategy facilitates transfer is unknown.

In study one, I examined only one potential method of promoting transfer: use of deep structure teaching in the absence of contextual variation during learning and practice. The following study examines a) whether each teaching strategy – exposing deep structure of the concept versus increasing the number of contexts used during teaching – has independent and additive effects on near and far transfer performance and b) if similar mechanisms are behind each strategy's success. Using

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similar materials and methods as study 1, I investigated this question in two separate experiments.

The results will be submitted to the *Journal of Education Psychology* under the title *Relative effects of teaching analogies and context variation on near and far transfer of conceptual knowledge* and co-authored by Zarah Chaudhary, Nicole Woods, Kelly Dore, Alan Neville, and Geoffrey Norman. The design and conception of study was by myself and Drs. Woods, Dore, and Norman. Dr. Alan Neville developed and edited the materials for the study. Data collection was conducted primarily Zarah Chaudhary and myself. I also conducted the data analysis and authored the first draft of the paper in consultation with the co-authors.

Relative effects of teaching analogies and context variation on near and far transfer of conceptual knowledge

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ABSTRACT

A critical learning outcome is transfer: applying and adapting knowledge to new contexts. Transfer is facilitated during instruction by use of structural aids like analogies but disagreements exist regarding the role of the context of practice on transfer success. One theory (abstract-structure) suggests that content at practice must be de-contextualized to enable efficient abstraction of deep structure. The exemplar view highlights the necessity for exposure to multiple contexts at teaching. These views reflect a tension in the literature regarding the importance of contextual information during learning on later transfer.

Experiment 1 tested these theories against each other in a 2x3 design where students learnws three physiology concepts with or without an analogy and by means of one, two or three organ systems (the contexts) during practice. Transfer to familiar organ system (near transfer) and unfamiliar organ system (far transfer) cases was evaluated during immediate and delayed testing. Experiment 2 examined the changes in categorization caused by both interventions by examining how

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learners exposed to analogies and two organ systems of practice made similarity judgments between problems.

Results of Experiment 1 showed that increasing context variation improved far transfer performance but there was no difference between two and three organ systems while the one organ system group had lower performance than both. Similarly the analogy group outperformed the non-analogy group for far transfer. For near transfer, the one organ system group had the highest performance. Experiment 2 showed that without teaching analogies or context variation learners used organ systems matching to make similarity judgments. But provision of teaching analogies or practice with two organ systems shifted learners to making similarity judgments on the conceptual structure, not organ systems.

The results of the study support the schema formation view. More relevant for transfer teaching is that both deep structure teaching and variation of contextual information during practice shift learners to use structural information of the concepts for categorization. Teaching for transfer should be wary of learners' tendency to use contextual information incorrectly.

INTRODUCTION

Transfer is broadly defined as the use and application of previous knowledge in a new problem or context. Uncovering the processes by which learners transfer conceptual knowledge has been a perennial issue in learning and cognition research (Salomon & Perkins 1989). Thus, transfer processing is the underlying intent of virtually all learning interventions and strategies for novice learners. To date, most research efforts have focused on analogical reasoning or analogical transfer – the resolution of a new problem based on information gathered from a previously solved problem – as a model from which to examine transfer processing (Day et al. 2011; Goldstone & Son, 2005; Gick & Holyoak 1983)

An enduring debate in this literature is the role and value of contextual information (also termed surface details, semantic domain, problem content, superficial details) that is not necessarily related to the structural features of the underlying concept to be understood by the learner (Kaminski et al. 2013, Blessing & Ross 1996; Reeves & Weisberg, 1994). For example, the teaching of a statistical concept (e.g. conditions in which ANOVAs are appropriate) can occur with any number of contexts (health research, education etc.) and surface features (patient groups with various drug interventions, students assigned to classrooms etc). Transfer requires that learners successfully recognize the statistical concept and apply it in a wide variety of contexts. The debate among transfer theorists is how learners incorporate surface details from the contexts of learning. A subsequent

question is how learning interventions should manipulate the contextual information to optimize transfer.

Earlier studies of analogical reasoning and transfer processing coalesced around two positions on the relative importance of contextual surface details. The first position advanced by Holyoak and colleagues (1983, 1989, 1997) as well as Gentner and colleagues (1991, 1999) argues that while content information and surface details can be important in early stages of learning, these surface details become increasingly irrelevant as learners develop abstract representations of the concept. This abstract-structure view proposes that as learners begin to develop more advanced schema for a concept, they begin to focus on the highly conserved structural features of the concept (Goldstone & Son, 2005; Reeves & Weisberg, 1994) as opposed to contextual information. In this view, contextual information has limited value and is less important than assisting learners in identifying abstract deep structure (Catrambone & Holyoak, 1989). The notion that over-emphasizing contextual information can hinder transfer has some support in other studies (Kaminski et al. 2013, 2008). Discussion of transfer in applied settings such as health professions education (Eva et al. 1998; Norman, 2009), mathematics (Kaminski et al. 2009), and skills training (Lowenstein et al. 2003) as well as other domains (Barnett & Ceci, 2002) have tended to accept this view. In general, the ideas proposed by *abstract-structure* theorists been influential in guiding research on learning interventions that improve transfer (Reeves & Weisberg, 1994). For example, teaching analogies have been paired with concept explanations in order to allow learners to access the deep structure and further build structural schemas (Norman et al., 2007; Paris & Glynn, 2004; Newby et al., 1995). Similar interventions during practice (van Merrinboer et al., 2006; Rohrer et al., 2010) and other phases of learning (Needhman & Begg, 1991) have supported structureemphasizing learning interventions.

An alternative view argues that contextual information retains its importance even in later stages of schema formation and can be harnessed to further facilitate transfer (Reeves & Weisberg, 1994). The so-called exemplar view (Ross & Kennedy, 1990) argues that contextual information and surface details continue to be stored and recalled by learners even when they begin to explicitly (Spencer & Weisberg, 1986) recognize structural features of concepts. It is argued that surface features retain their importance in all stages of transfer because abstract information about a new concept can only be understood, represented, and stored in the form of the surface details used to illustrate the deep structure (Ross, 1989). Intuitively, this idea has some merit. Abstract relationships can be hard to grasp when presented in a decontextualized manner. Providing a more concrete example can reduce the load necessary to grasp the concept (Van Merrinboer et al. 2006) and allow the learner to see how the concept can be applied or used to solve problems (Ross & Kennedy, 1997). This also means that the surface details are encoded simultaneously with the first example of the concept. This may have advantages when surface details can be expected to repeat themselves in new problems. A series of studies (Ross 1987;

Ross & Kennedy, 1990) showed that surface detail correspondence between target problems and analogues was much more likely to result in recall and application of analogues. Furthermore, these studies (Ross & Kennedy, 1990) showed that increasing the number of examples from different contexts tended to increase transfer of conceptual information. Reliance on contextual information as a cue to the category of problem to can be efficient and effective strategy for transfer in some domains and transfer tasks (Kulasegaram et al. 2012). As an example, use of contextual similarity forms the basis of categorization and problem solving in complex cognitive tasks such as medical diagnosis (Brooks, Norman, & Allen, 1991; Young et al. 2011; Dore et al. 2012). This would suggest that successful transfer can be achieved by simply increasing the store of exemplars, i.e. the number of contexts in which a concept is presented during learning. Contextual variation during learning and practice can teach learners which surface features are significant cues to recall concepts. This also gives novices an indication of the variance of the presentation of the concepts and builds practice in applying and adapting knowledge which reflects the conditions of expert performance.

If the abstract-structure view is accurate, emphasizing deep structure during teaching and practice maybe more effective and efficient in teaching for the transfer of conceptual knowledge. In contrast, the exemplar view suggests that the same gains in transfer processing demonstrated by strategies emphasizing conceptual structure can be achieved by exposing learners to exemplars with multiple contexts for problem solving While, there is evidence for the effectiveness of both strategies

(Rohrer et al. 2010; Paris & Glynn 2004; Sloutsky et al. 2006) there are no head to head comparisons of these strategies to our knowledge and few studies have specifically identified if each class of interventions activate similar or different processes. It is possible that both emphasizing deep structure and presenting multiple context exemplars teach learners similar lessons about the importance of contextual information (Genter et al. 2003; Harding et al. 2004). For example, the abstract-structure view would predict providing a teaching analogy during learning would provide equivalent gain in transfer as providing two exemplars with dissimilar contextual details. Both interventions would lead learners to focus on structural features. While the teaching-analogy is an explicit provision of the deep structure of the concept, the dissimilar exemplars could teach novices a) teach novices that surface details are inconsistent and thus unreliable for concept identification and/or b) which features of the concept's structure are conserved and possible variations they can expect for future problems. The abstract-structure view would also predict a third exemplar with an additional context would have marginal value as learners have already understand the deep structure. On the other hand, if the exemplar view is correct, providing a third context in which to practice problem solving will increase the store of surface details from which to generalize the concept and would allow a stricter, rigorous schema for future problems involving the concept. A previous investigation of this question by Genter and colleagues (1983) in analogical reasoning showed that while having three and two contexts during learning provided similar transfer outcomes, both groups outperformed

learners with only a single context. However, this study did not test if the processing induced by multiple contexts was similar to increasing structural teaching.

Furthermore, studies to date have not explored how the interventions suggested by each model affect near and far transfer. Near transfer occurs when context of learning and problem solving are similar whereas in far transfer, the context is dissimilar to that of learning. It is repeatedly found that that near transfer is easier for learners to accomplish hinting at a benefit provided by contextual familiarity (Kulasegaram et al. 2012; Catrambone & Holyoak, 1989; Ross, 1989). Whether context variation and abstract teaching have differential improvements on near and far transfer needs to be established.

Previous efforts to address these questions have primarily framed the issue as determining whether 'concrete' surface details help or hinder learning processes. It has been repeatedly argued that that surface details divert attention from the deep structure (Goldstone & Sakamoto, 2003; Markman & Gentner, 1993) and become over-associated with conceptual deep structure (Bassok & Olseth, 1995; Bassok, 2001). Some have noted that while surface details can improve learning of a concept in one domain, reliance on them can hinder transfer to isomorphic or unfamiliar domains (Kaminsky et al. 2013). While this research has provided some useful perspectives from which to understand transfer processing, the direction question of the benefit of context variation during learning and practice is still to be resolved. Secondly, many previous studies used artificial stimuli or concepts that have a fairly orthogonal relationship with the contextual information. For example the classic Dunker paradigm of analogical transfer using the "Fortress" and "Tumor radiation" problem presents a concept with no real association with the context of problem solving. In contrast, in applied settings such as medical or physiology problem solving, contextual information is an important and useful cue to problem solving. For example, the surface features of a medical diagnostic task or a physiology problem are often relevant clues to the underlying conceptual structure of a problem (Norman et al., 2007). In these types of transfer tasks, reliance on surface details and increasing the store of a learner's exemplars can be the key to developing expertise and the requisite ability to transfer knowledge. Contextual variation can be an effective approach to teaching learners to transfer since in applied domains, reliance on surface details maybe an appropriate transfer strategy.

This study is an evaluation of the relative efficacy of focusing on deep structure teaching versus contextual variation during learning for transfer in physiology. In experiment one, we examine the efficacy of each learning strategy by manipulation of the amount of structural instruction for novel concepts as well as the number of contexts in which practice occurs. In experiment two, we examine the mechanisms by which these interventions may lead to improved transfer, specifically they result in classification of new problems based on structural instead of contextual characteristics.

EXPERIMENT 1

Experiment one evaluated learning interventions suggested by the abstractstructure view versus the exemplar view on near and far transfer. Participants were asked to apply physiology concepts to explain the signs and symptoms of written medical cases. Near and far transfer cases were created in the clinical cases by involving organ systems which learners had been exposed to during learning (near transfer) and organ systems which they had not been exposed to (far transfer).

The abstract-structure intervention was providing a teaching analogy during instruction. The analogy was an accessible, common sense illustration for the deep structure of for each physiology concept. Teaching analogies have been used previously in many experimental studies of mathematics (Richland, Zur, & Holyoak, 2007), physics (Newby & Stephic, 1995), and physiology teaching (Paris & Gynn, 2004; Norman et al. 2007). The exemplar view was manipulated during practice in which learners had the opportunity practice applying concepts to three clinical cases that all involved the same organ system, two organ systems or three different organ systems. This allowed us to manipulate contextual variation via the number of surface details used to practice concepts.

We hypothesized that:

1) If the abstract-structure view is accurate, then participants provided with the teaching analogies would have superior transfer performance 2) If the exemplar view is accurate, then participants in the three organ systems of practice will have superior transfer performance to those in two and one organ systems of practice. If the abstract-structure view is correct, the organ systems of practice will have superior performance to one, but adding a third organ system will have no additional advantage.

Methods

McMaster University undergraduate students taking a first year psychology course were recruited into this study for course credit. Recruitment was on a volunteer basis and advertised to all first year psychology students using the Department of Psychology's website. The study received ethics approval from the Faculty of Health Sciences Research Ethics Board at McMaster. Procedures and methods are similar to those of previous studies of transfer in medical education (Norman et al., 2007; Kulasegaram et al., 2012).

Design

Participants were randomized in a 2x3 design to two instruction and three practice conditions. Each participant in this study learned three physiology concepts using a standard clinical explanation and diagram provided by an expert clinician (AN) or with the standard explanation and a deep structure illustrating analogy. Participants were also randomized to practice two of the physiology concepts with one, two, or three organ systems. Following learning and practice, participants were given a transfer test immediately after testing and returned after a one-week delay to complete a new transfer test. The delay condition was included to examine the durability of the interventions over time. All materials in the study were designed by an expert clinician collaborator (AN).

Procedure

The entire study was conducted on a computer using Runtime Revolution programming software. The study was conducted in 2 phases: learning and testing.

Phase 1: Learning

In Phase 1 participants had the opportunity to read explanations for three physiology concepts (Laminar and turbulent flow, Laplace's law, and Starling's law) as well as practice applying these concepts to explain the signs and symptoms depicted in clinical vignettes.

Laminar/turbulent flow illustrates the principles of flow dynamics which have application in multiple organ systems including the respiratory, cardiovascular, gastrointestinal, and urinary tract. Laplace's Law describes tension in the walls of cylindrical vessels as it relates to the radius of the vessel and pressure of the contents; it applies to the same organ systems as the principles of laminar and turbulent flow. Starling's law describes the elastic 70ehavior of the heart in response to filling of the ventricles and volume of the ejected blood. Starling's law was included as a near transfer control. Explanations included a detailed outline of the concept, its relevance to physiology, a brief example of its application, and emphasized that the concept applied in multiple organ systems (see Table 1). Explanations were also randomized for order of presentation.

Each concept was practiced using three practice cases. Cases were presented sequentially and immediately after viewing each concept's explanation. Cases were structured as brief clinical encounters involving disorders of a specific organ system. An example of a practice case is given in Table 2. The participants were asked to read each case and explain how the concept they had just encountered applied to and explained the features of the patient in the case. Feedback was given in the form of the correct answer to how the previously learned concept applied to the case.

After completing the learning and practice, all participants were asked to complete a 10 question true or false quiz on the concepts they previously learned as additional practice. Participants had to achieve a score of 8/10 or greater to move onto testing or they were asked to repeat the before moving onto transfer testing.

Manipulation of instructional condition

Participants were randomized to instructional conditions in which they were presented with either a basic clinical explanation of the physiology concepts or with the clinical explanation and an additional deep structure teaching analogy that illustrated abstract deep structure of each concept in addition. Laminar turbulent flow (called Goethe's law for simplicity) was explained using water flow through faucets, Laplace's law by weight suspended on a taut string, and Starling's law by likening the stretching of the heart to the stretching of a metal spring. These analogies were previously used in studies of transfer (Kulasegaram et al. 2012; Norman et al. 2007) and were shown to increase transfer performance at testing. An example of a teaching analogy is presented in Table 1.

<<Table 1: Examples of Standard Clinical Explanation and Teaching Analogy>>

Context variation in practice manipulation

Individuals in the one organ system of practice condition saw three cases that involved the same organ system. For laminar/turbulent flow the cases all involved respiratory disorders and for Laplace's law they involved gastrointestinal disorders. In the two organ systems of practice, laminar/turbulent flow involved 2 cardiovascular cases and 1 respiratory disorder and Laplace's law involved 2 cardiovascular cases and 1 gastrointestinal disorder. In the three-organ systems of practice, laminar turbulent flow was practiced with 1 respiratory, 1 cardiovascular, and 1 gastrointestinal case. Laplace's law was practiced with 1 gastrointestinal, 1 cardiovascular, and 1 respiratory case. Starling's law only applies to the cardiovascular system, and was practiced only with cardiovascular cases in each condition. Starling's law served as a distracter and near transfer control.

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<<Table 2: Example Practice Vignette>>

Phase 2: Testing

Transfer testing consisted of 15 short, written clinical cases. Participants were required to correctly identify the concept that best explained the features seen in each vignette and provide an explanation of how the concept did so. Cases involved organ systems that were familiar and unfamiliar to all participants regardless of condition to create near and far transfer cases. Six cases involved laminar/turbulent flow, six involved Laplace's law and 3 involved Starling's law. The cardiovascular organ systems were common to all three concepts; the gastro-intestinal and respiratory systems were common to laminar/turbulent flow and Laplace's law. Far transfer cases for laminar/turbulent flow and Laplace's law were also presented using the urinary tract, spinal cord, and reproductive systems.

Responses were scored on a scale of 0-3 with more marks awarded for more accurate and in-depth explanations as used in previous studies with these materials (Kulasegaram et al. 2012; Norman et al. 2007). A sub-sample of responses was coded in duplicate by two raters to determine inter-rater reliability for consistency of scoring.

See Table 3 for an example of a test case and scoring rubric.

<<Table 3: Sample test vignette and scoring guide>>

Test vignettes were presented in random order. After completing the initial transfer test, participants returned after a 1-week delay to complete another transfer test with 15 new vignettes.

For a summary of the design, see Figure 1.

<< Figure 1: Design Summary>>

Outcomes

Average performance per case was calculated separately for near and far transfers scores.

Analysis

The primary analysis was a 2x2x3 repeat measures ANOVA with near vs. far transfer as the repeated variable and instruction condition (analogy vs. no analogy) and practice condition (one vs. two vs. three organ systems of practice) as the between subjects variables. We replicated these analyses with scores on the delayed transfer test and a repeated measures analysis with time to account for the impact of delayed testing. The alpha value for all analyses was 0.05 two-tailed.

Results

Ninety undergraduate students (n=90) were recruited into the study with 15 participants per group. Two students were excluded from final analyses for not completing the transfer test. Participants on average took 2678.43 seconds (SD=345s) in the learning phase. Average time between conditions did not differ significantly. Time spent in learning did not correlate significantly with performance on immediate and delayed transfer. Inter-rater reliability for consistency of scoring was 0.83 suggesting high consistency.

Immediate Testing

A repeated measures of performance on near and far transfer showed a general main effect for near transfer (F(1,82)=5.92, p<0.017) with average performance on near transfer cases at 1.09 (SD=0.51) compared to far transfer at 0.96(SE=0.45). Significant interactions were also found with instruction group (F(1,82)=7.35, p<0.01) and practice condition (F(1,82)=13.87, p<0.0001). There was no interaction between instruction and practice condition.

Specifically, performance on near transfer was higher for the non-analogy condition but dropped for far transfer while the analogy condition maintained similar performance on near and far transfer (see Figure 2). Far transfer performance was higher for the analogy group (1.06 (0.50)) compared to the no

analogy group (0.86 (0.37)). Post-hoc testing showed this difference to be significant (F(1,82)=4.6, p=0.035).

<<Figure 2: Near and Far Transfer Performance for Analogy vs. No Analogy Instruction at Immediate Test>>

Similarly, the one organ system group had high near transfer scores but dropped for far transfer while the two and three organ systems of practice maintained performance across both transfer tasks (see Figure 3) The one organ system group had the highest near transfer performance (1.28(0.57)) compared to the two (0.94(0.41)) and three organ system groups (1.04 (0.47)). In contrast, the highest far transfer performance was seen for the two (1.03(0.48)) and three organ system groups (1.07(0.46)) compared to the one organ system (0.78(0.34)). Posthoc testing showed that there were no significant differences between two and three organ systems but both groups had significantly higher far transfer scores compared to the one organ system group.

<<Figure 3: Near and Far Transfer Performance for Practice Condition at

Immediate Test>>

To examine the cause of these effects, we determined what percentage of each type of transfer case was correctly identified at testing. The no analogy group correctly identified on average 57% of far transfer cases compared to 63% of cases for the analogy group. While the one organ system group on average correctly identified the concepts in 70% of the near transfer cases, their success was only 45% for far transfer. The two and three organ system groups on average correctly identified 58% and 60% of far transfer cases respectively.

Delay

Fifteen students (n=15) did not return for delayed testing limiting sample size for delayed analysis to 75.

A significant effect of time delay was seen for far transfer performance (F(1,69)=8.06, p<0.006) with immediate far transfer performance at 0.98 (0.41) and delayed performance at 0.85 (0.38). The one week time delay did not significantly decrease near transfer performance (F(1,69)=0.051, p<0.82)).

The same pattern of results was seen as immediate test with significant interactions with instructional condition (F(1,69)=7.78,p<0.007) and near vs. far transfer performance and practice condition and near vs. far transfer (F(2,69)=5.72, p<0.005).

Once again, the analogy condition experienced a smaller difference in near (0.99(0.43) and far transfer performance (0.91 (0.53) compared to the no-analogy group (1.21(0.52)) vs (0.77 (0.42)) (see Figure 4). As at immediate test the one organ system group had high near transfer performance but lowest performance for far transfer while the two and three organ system practice groups maintained similar

scores for both types of transfer tasks (see (Figure 5). The far transfer scores between the two and three organ system groups were not significantly different.

<<Figure 4: Near and Far Transfer Performance for Analogy vs. No Analogy Instruction at Delayed Test>>

<< Figure 5: Near and Far Transfer Performance for Practice Condition at Delayed

Test>>

Experiment 1: Discussion

Experiment one attempted to examine the relative effects of in-depth structural instruction via a teaching analogy as well as the impact of increasing the number of practice contexts by varying the number of organ systems used to practice physiology concepts. We hypothesized that if the abstract-structure view was correct, providing a teaching analogy to teach the deep structure of physiology concepts would have an added benefit for near and far transfer performance compared with increasing the number of organ systems used to practice each concept. While this effect was not seen for near transfer, learning physiology concepts with the teaching analogy improved far transfer performance. We also hypothesized that, if the abstract-structure view was correct, there would be no advantage of 3 vs. 2 contexts; conversely, if the exemplar view was correct, 3 contexts would have an advantage over 2. The results showed that that practicing with two organ systems was superior to practicing with a single organ system for far transfer, there was no added benefit from a third organ system during practice. These results suggest that interventions to promote far transfer should focus on developing understanding of structural characteristics. This can be achieved by using interventions to illustrate deep structure and by presenting examples in as few as two contexts with dissimilar surface details. The highest transfer performance was seen for groups with the benefit of contextual variation and the analogy suggesting independent effects on transfer.

Furthermore, providing three problem contexts did not seem to elicit greater transfer compared with two contexts performance. It is possible that contextual dissimilarity during learning simply facilitates greater structure abstraction (Genter et al. 2003) and two sufficiently dissimilar examples were sufficient fort this. Thus for far transfer, the predictions of the abstract-structure view were more accurate. This suggests that while context variation can be used to promote transfer, it does by teaching learners that contextual information may not be a reliable cue for concept retrieval.

Performance on near transfer did not conform to the predictions of either transfer model. Participants in the one organ system group displayed high near transfer performance possible because of additional practice they received with the exemplars for near transfer cases. The advantage for near transfer has been repeatedly shown in other transfer studies (Kulasegaram et al. 2012; Kaminsky et al. 2009; Catrambone & Holyoak, 1989). But, superior performance on near transfer

in comparison to far transfer was found for only the one-organ system and noanalogy groups. In contrast, individuals with benefit of context variation and indepth teaching had similar near and far transfer scores. A further exploration of our data showed that these differences between near and far transfer and interactions with learning conditions were driven by how learners classified or identified the concept in the transfer cases. The groups with benefit of structural teaching and context variation were less likely to miscall or incorrectly classify a case involving an unfamiliar organ system. One possible explanation is that participants in these groups shifted from reliance on surface details as a marker or cue for the deep structure of the problem. The one organ system group on the other hand seemed to rely on the association between contextual and conceptual information during learning. While this surface driven strategy would be reliable for near transfer, it can be misapplied for far transfer. Whereas learners' default strategy is to rely on surface and contextual cues to recall concepts for transfer, it is likely that successful transfer requires learners to shift to structural cues to classify transfer problems.

Evidence from other studies tends to support the utility of multiple contexts: encouraging active comparison across dissimilar sets of surface features proves superior to providing a principle explanation and a single example of a problem context (Gentner, 1989; Gentner et al., 1993). It is possible that learners can integrate both structural/conceptual cues as well as match on contextual surface detail similarity to solve transfer problems.

This view is consistent with earlier studies of transfer that argued that learners developed abstract schemas for problem solving (Hummel & Holyoak, 1997; Reeves & Weisberg, 1994). A similar model is proposed by studies of categorization which argue that problem exemplars are reclassified on abstract, structural features as expertise is developed (Chi, 2011; Larkin et al. 1980). This body of literature labels the general process *representational shift* (Chi, Slotta, & de Leeuw, 1994). Though the specific mechanisms by which representational shift for rule-based and exemplar-based categories is debated (see Johansen & Palmeri 2002 for review)), a shift from an orientation to surface details to structural features seems to be necessary prior to successful far transfer.

Recognizing and using abstracted deep structure is necessary for mastery of conceptual knowledge and is understood as a marker of expertise (Larkin et al. 1980). While the experimental procedures did not allow for the participants in the previous experiment to become true experts, participants with the learning interventions were more likely to solve far transfer problems and behave like experts. Learning interventions that support the transition to structural details and aid in representational shift will likely improve transfer performance and support the building of expert schemas for problem solving.

To test these possibilities, experiment two examined if a representational shift to categorization based on structural features occurred due to exposure to structural teaching via teaching analogies and/or context variation due to practice with more than one set of surface details for a concept. We hypothesized that

learners would be more likely to classify problems on structural, conceptual bases if exposed to either teaching analogies or contextual variation. We also included a more robust test of conceptual recall in the form of a multiple choice knowledge test to determine if the interventions used improved transfer independently of knowledge recall.

EXPERIMENT 2

Methods

Undergraduate students taking a first-year psychology course were recruited into this study for course credit. The study received ethics approval from the Faculty of Health Sciences Research Ethics Board at McMaster.

Design

We used similar design, procedures, and materials in experiment two as in first experiment with three major changes. In a 2x2 design participants, were randomized to learn physiology concepts with a basic clinical explanation or basic clinical explanation with a deep structure illustrating teaching analogy and practice with one or two organ systems for laminar flow and Laplace's law. The first change was that the third organ system manipulation was eliminated since it did not improve transfer performance and in order to reduced participation time. Second, after completing learning, participants completed a recall multiple-choice test and a similarity categorization test, which required them to make similarity judgments to classify written medical cases. Lastly, the delay condition was eliminated to make participation more convenient for participants and since delay did not impact the pattern of results in experiment 1.

Procedure

Phase I: Learning

The learning phase used the same materials as in Experiment 1 with the exception that participants only practiced with two practice cases with feedback in the form of the correct answer. Participants completed a 10 question true or false quiz prior to testing; they were required to achieve minimum score of 8/10 required to move on or they were asked to repeat the test

Phase II: Testing

In the testing phase, all participants were first given a 15 question multiplechoice test that tested their recall of the concept explanations to assess. Questions were focused on solely on their understanding of the explanations given of each concept. Participants were not given feedback on their performance before moving on to the similarity classification test.

Similarity classification test

The similarity classification test was framed as a forced-choice recognition task (Gentner, 1993). Participants were asked to view a clinical case designated the target case. Participants were not told which concept was involved and given instructions to read and think about the vignette but were not required to explain the features or answer any questions. After completely reading the case, they proceeded to view 3 new cases and were asked to select the case that was most similar to the previous target case. Participants were not given any instructions on what constituted similarity. Time per target and match decision was limited to 5 minutes.

The three choices were manipulated to have a) surface similarity to the target, b) structural similarity to the target, or c) both surface and structural similarity or no similarity. For example, if the target case involved a gastro-intestinal disorder explained by Laplace's law then the possible matches could be a) a gastro-intestinal disorder explained by laminar turbulent flow, b) a cardiovascular disorder explained by Laplace's law or c) a gastro-intestinal disorder explained Laplace's law/a cardiovascular disorder explained by Starling's law.

Participants using contextual, surface information to identify similarity select case a) while those matching on conceptual, structural features could pick case b). The third case was used as a distracter or control and typically involved Starling's law cases. Participants had to complete 10 classifications with 4 involving laminar flow cases from various organ systems, 4 involving Laplace's

law and 2 involving Starling's law. Clinical cases were similar to those in experiment 1.

The outcomes from the similarity-classification test were the 1) **context matches:** the number of times the selected case had the same organ system (i.e. contextual surface detail) as the target case but a different concept (i.e. structural features) explaining the clinical presentation 2) **concept matches:** the number of times each participant selected a matching case that had the same concept involved but had different organ system from the target case; 3) **double hit:** the number of times a match had the same concept and organ system and 4) **double miss:** had neither the same concept or organ system.

Analysis

Analysis of the multiple choice recall test was by a 2x2 ANOVA with analogy/no-analogy and one/two organ systems as the between subjects factor. Each type of match on the similarity categorization test was also analyzed using 2x2 ANCOVA.

Results

Forty undergraduate students were recruited into the study with 10 students per group. Participants on average took 2523.45 seconds (SD=400s) in the learning phase. Average time between conditions did not differ significantly.

Multiple-choice knowledge test

There were no significant differences between any groups on MCQ testing. Mean score (SD) score for the no-analogy and one organ system group was 10.22 (2.10), for two organ systems 9.27(1.61). Mean score for the analogy with one and two organ systems were 9.3(1.76) and 8.45(2.06) respectively. MCQ scores had a significantly negative correlation with the number of context matches (r=-0.36, p<0.020) and non-significant positive correlation with concept matches (r=0.11, p<0.48). MCQ score was used as a covariate in the analyses of the similarity categorization test.

Similarity Categorization test

Analysis of the number of context matches (when the matched case had a similar organ system but different concept from the target case) showed a significant main effect for instruction condition (F(1,35)=4.6, p<0.04). Individuals in the no-analogy condition made more context matches than those in the analogy condition (see Figure 6). While those in the one organ system of practice group tended to make more context matches than the two organ systems of practice, this difference was not significant. MCQ score was a significant covariate (F(1,35)=9.7, p<0.004). On average, the no-analogy with one organ system group made 3 matches on contextual similarity while the analogy with two organ systems made 1 match.

<< Figure 6: Number of Context Matches by Condition >>

Analysis of the concept matches showed two significant main effects for instructional condition (F(1,35)=12.8, p<0.001) and for practice condition (F(1,35)=5.9, p<0.02) with no significant interaction. Individuals in the analogy and two organ systems of practice conditions were more likely to match on conceptual, deep structure features even when the matched case and the target case had dissimilar organ systems (see Figure 7). MCQ score was also significant covariate (F(1,35)=4.35,p<0.04). On average, no-analogy with one organ system group made 2 matches on conceptual similarity while the analogy with two organ systems made 5 matches.

<<Insert Figure 7: Number of Conceptual Matches by Condition >>

Analysis of double hits (matching on both concept and context) and double misses (missing both conceptual and contextual similarity) showed no significant differences between groups. All groups on average matched one case on the double miss. MCQ was not significant in predicting number of double hit or double miss matches.

Experiment 2: Discussion

Experiment 2 attempted to examine if provision of deep structure teaching via teaching analogy and contextual variation through increasing the number of practice contexts would lead to a representational shift in how novice learners classified problems. We hypothesized that if these interventions led to learners relying on conserved deep structure, then they would be more likely to make similarity judgments between problems based on conceptual similarity even if the context or surface features were different. The results showed that the participants in the analogy and two organ systems of practice condition were indeed more likely to make matches on conserved deep structure of the underlying concept. Furthermore, learners without the benefit of the deep structure analogy or an additional organ system of practice tended to be more likely to make similarity judgments on contextual surface similarity. Interestingly, MCQ score was a significant covariate and negatively predicted context matches suggesting conceptual, deep structure knowledge inhibits dependence on surface details.

The results suggest that reliance on surface similarity is the default strategy for unaided learners. Learning interventions that rely on deep structure illustration such as teaching analogies or context variation push learners away from the default strategy by highlighting the inaccuracy of contextual cues. Interventions informed by deep structure teaching as well as context variation are effective at causing representational shift and both strategies should be employed to improve transfer of conceptual knowledge. These findings support previous work which suggests analogies and context variation result in learners forming abstract comparisons between examples instead of relying superficial similarity (Gentner & Medina 1998; Markman & Gentner, 1993)

GENERAL DISCUSSION

The purpose of study was to examine the processes and interventions by which transfer of conceptual knowledge can be optimized. Specifically, we examined the relative of impacts of structural teaching as suggested by the abstractstructure view and context variation as suggested by the exemplar view on near and far transfer. In experiment one, the results showed that each of interventions had independent effects on improving transfer though increasing the number of contexts during learning had limited benefit after two contexts. The results support the abstract-structure and suggested that transfer processing was optimized by focus on structural features instead of contextual surface details. In experiment two, we showed that both classes of interventions did indeed lead to learners classifying problems based on conceptual similarity. Overall, the results suggest that representational shift is necessary for successful far transfer and that unaided, learners will default to reliance on surface features.

The results of the study however do not necessarily negate the importance of contextual information during learning for transfer. Near transfer problems were quickly and effectively identified using surface details. Furthermore, contextual variation allowed learners to extract deep structure and shift from reliance on surface details. Previous studies have suggested contextual information can hinder transfer (Kaminski et al. 2013, Sloutsky et al. 2006). Instead, our results suggest combining context variation and deep structure teaching promote transfer processing. It is likely that the abstract teaching better encodes the deep structure of the concept while context variation makes it more likely that learners will be able to search and recognize it in new problems.

The challenge for transfer teaching then is to prepare the learners to make the best use of both conceptual and contextual information to guide problem solving. Both the abstract-structure model and exemplar model argue that learners must form strong schemas for future problem solving and the transition to expertise is largely a matter of novices focusing on the relevant structural details of concepts.

There are two general limitations to the experiments in this study. Firstly, prior knowledge of concepts was not explicitly assessed though the low transfer performance in all groups suggests that learners were novices to these sophisticated clinical concepts. Secondly, while far transfer tasks presented concepts in unfamiliar contexts, our results do not directly address the transfer of conceptual knowledge that can present in multiple domains. The concepts of laminar/turbulent flow and Laplace's law can be applied to multiple domains and future work should address the extent to which the instructional strategies facilitate further transfer.

CONCLUSION

Transfer of conceptual knowledge can be aided by interventions that make abstract deep structure explicit and by context variation using examples with dissimilar surface features. Both strategies encourage categorization and recognition of concepts at the deep structure level and de-emphasize reliance of surface features. This representational shift is necessary for successful far transfer. Learning interventions should manipulate contextual information to promote representational shift for transfer.

EXPERIMENT 1 – FIGURES

Figure 1: General Design of the Study



Figure 2: Near and Far Transfer Performance for Analogy vs. No Analogy Instruction at Immediate Test



Fig 2. Mean score for near and far transfer for the Analogy and No Analogy conditions, significant interaction (F(1,82)=7.35, p<0.01). The analogy condition maintained similar performance across both transfer tasks while the no analogy instruction group dropped significantly for far transfer.



Figure 3: Near and Far Transfer Performance for Practice Condition

Fig 3. Mean score for near and far transfer for practice with one, two and three organ systems (F(1,82)=13.87, p<0.0001). The one organ system had the highest near transfer performance but performance dropped for far transfer. The two and three organ system groups had similar near and far transfer scores; average far transfer score was higher for the two and three organ system groups compared to the one organ system group.

Figure 4: Near and Far Transfer Performance for Analogy vs. No Analogy Instruction at Delayed Test



Fig 4. Mean score for near and far transfer for the Analogy and No Analogy conditions, significant interaction (F(1,82)=7.35, p<0.01). The analogy condition maintained similar performance across both transfer tasks while the no analogy instruction group dropped significantly for far transfer.
Figure 5: Near and Far Transfer Performance for Practice Condition at Delayed Test



Fig. 5 Mean score for near and far transfer for practice with one, two and three organ systems (F(2,69)=5.72, p<0.005).Near transfer was highest for the one organ system group and lowest for the two organ system group. The one organ system group had the lowest far transfer score while two and three had similar scores.

EXPERIMENT TWO

Figure 6: Number of Context Matches by Condition



Context Match

Fig. 6

Number of matches on contextual similarity between target and cases with structural dissimilarity. A significant main effect for non-analogy (F(1,35)4.6, p<0.04,) over the analogy group. The difference between one and two organ systems was not significant.



Concept Match



Number of matches on conceptual similarity between target and cases with surface dissimilarity. A significant main effect for the analogy over non-analogy F(1,35)=12.8, p<0.001; and for two organ systems over one (F(1,35)=5.9, p<0.02)

EXPERIMENT 1: Tables

Table 1: Examples of Standard Clinical Explanation and Teaching Analogy

Explanation	Analogy
When a passageway – for example any of the airways in your lungs, including your bronchioles and trachea – is open, it allows fluids such as air to flow in an obstructed manner. The air travels in discrete layers called 'laminae.' This is the most unobstructed way for the air to travel. However, a perturbation or disturbance can cause the layers of air to mix and individual particles to collide. This changes the flow from smooth and laminar to turbulent and chaotic. This property of fluids is called Goethe's Law. The factors affecting flow and the transition between laminar and turbulent flow are: velocity, smoothness of the passageway, the thickness or viscosity of the fluid, diameter of the passageway, and density of the fluid. In the lungs for example, narrowing of the air passageways or mucus build-up can change air flow from laminar to turbulent, thus creating difficulties in breathing. This change from laminar to turbulent can be detected physically by the presence of noise – in our lungs, this is called wheezing. Asthma for example is characterized by wheezing which is a flow problem as the constriction of the air passageways causes air to move from laminar to turbulent flow (accompanized by wheezing). Goethe's law applies in many situations.	A good analogy would be noise – gurgling – caused in water pipes due to mineral buildup or calcium deposits. The buildup disrupts laminar flow and decreases the speed of the water as well as pressure. There are other factors that affect flow. Any pathology that causes narrowing or obstruction of an airway will produce turbulent flow just as if you pinched a garden hose in the middle, you will lose water pressure.

Case (repiratory)	A 3-year-old infant presents with
Case (repiratory)	A 3-year-old infant presents with a 4-week history of progressively worsening cough, shortness of breath following feeding and an unusual musical high-pitched sound with noisy breathing. He is the first born to a nurse and an accountant, born 3-months premature but otherwise through normal delivery. A chest x-ray revealed a slightly compressed trachea by a foreign body, which seemed to have disrupted the regular smooth flow of air particles. The effect of only a small amount of narrowing of the child's airway resulted in a significant (many-fold) increase in airway resistance as manifested by the abnormal breathing symptoms the child was experiencing. Explain how the obstruction caused the infant's breathing difficulties?
Explanation provided to students	The obstruction's main function is to change laminar air flow in the lungs to turbulent flow. By occluding or restricting the airway, the obstruction forces layers of air to collide with one another. This forces the student to generate more force per breath changes breathing into a wheezes. Goethe's law explains the symptoms in this case.

 Table 2: Example Practice Vignette: Goethe's Law

Table 3: Sample test vignette and scoring guide

Far transfer Goethe (laminar flow) case

A patient with cancer receives radiation treatment to his abdomen which unfortunately includes his kidneys in the treated radiation field. While his cancer treatment is successful, several years later he returns to the hospital complaining he cannot produce urine. He develops chronic kidney failure and the physicians admit him for investigation. A kidney biopsy shows that scaring has caused consistent severe narrowing of around 60% where the filtering parts of the kidney join to the kidney's urine carrying tubules. It's shown there is virtually no fluid going down the tubules even though the tubules are not actually blocked. Which law best explains the findings and why?

Score	Law Selected	Written Response	Rationale
0	Starling's law		Incorrect selection of law
1	Goethe's Law	The restriction is a caused by the radiation which causes a block.	Incorrect explanation or weak explanation
2	Goethe's Law	The persistent narrowing of the kidney is an issue of blocking flow – this causes a changing of the flow from laminar to turbulent and prevents smooth flow of urine	Correct law selected, some use of learning terminology
3	Goethe's Law	With this degree of reduction of kidney tubules radius, what's happing is a reduction of the flow due to change in the velocity. The block changes flow from laminar to turbulent and this reduces the ability of the urine to actually move through the tubule. Additionally, the blockage itself an impediment to flow though the main is issue is the force of the urine.	Correct law selected, good use of learning terminology

CHAPTER 5: ALL MIXED UP: THE IMPACT OF CONTEXT VARIATION AND PRACTICE STRATEGY ON TRANSFER OF BASIC SCIENCE

In chapter 5, I demonstrate how inattention to learners' default strategy of relying on contextual cues and surface details can limit the efficacy of proven learning intervention. In this chapter, I examine how these aspects of the materials can alter the effectiveness of proven educational strategies.

One such strategy is mixed or interleaved practice, which has been repeatedly shown to increase the retention and transfer of concept and skills knowledge. It requires that learners practice multiple concepts together instead of each concept separately as in most traditional practice strategies (known as blocked practice). The effect of mixed practice is to increase the ability of learners to discriminate between concepts. However, this makes mixed practice more difficult for learners. Indeed, mixed practice has been described as increasing the desirable difficulty or germane load of the learning task by forcing learners to actively find structural details that distinguish concepts.

In this study, I show how mixed practice can backfire and *increase* reliance on inadequate surface details and contextual cues if it is structured without attention to how learners encode the context of problem presentation during learning. Specifically, mixed practice under conditions in which each concept is sequestered to a single context of presentation or set of surface details will increase reliance on surface details. The surface details are more easily extracted and serve to distinguish each type of concept. Thus learners over-learn the association between surface details and concepts, mistakenly associating the surface details of a new transfer problem as an accurate guide to the appropriate category of that problem. This can occur even with the provision of other learning interventions to illustrate the deep structure such as teaching analogies used in Chapter 3 and Chapter 4 to increase transfer performance. On the other hand, even traditional blocked practice with multiple contexts or sets of surface details per concept can decrease over reliance on surface details as a cue. Thus implementing 'best practice' learning interventions without understanding how learners assimilate and encode information can lead to undesirable outcomes. The results of the study reinforce the importance of combining in-depth illustration of the concept along with appropriate context variation to shift learners from reliance on contextual details to conceptual deep structure.

This study was submitted to the journal *Advances in Health Sciences Education* on under the title of "*All Mixed Up: The impact of context variation and practice strategy on transfer of basic science*" and was co-authored by Cynthia Min, Alan Neville, and Geoffrey Norman. The design and conception of study was by myself and Dr. Norman. Dr. Alan Neville originally developed the materials for the 2007 investigation; I modified those materials for the present study. Data collection was conducted primarily Cynthia Min, and myself. I also conducted the data analysis and authored the first draft of the paper.

All Mixed Up: The impact of context variation and practice strategy on transfer of basic science

Kulamakan Kulasegaram, Cynthia Min, Allan Neville, and Geoffrey Norman ABSTRACT

Background and Purpose: Applying a previously learned concept to a novel problem is an important but difficult process called transfer. Effective practice of concepts improves transfer performance in novices. Practicing all concepts together (mixed practice mode) has been shown superior to practicing concepts separately (blocked practice mode) for transfer. Other studies have shown practicing concepts in multiple contexts is beneficial compared to practice in one context. How practice context affects practice modality for transfer is still unclear. This study examined the effect of single and multiple practice contexts for both mixed and blocked practice modalities on transfer performance. We looked at performance on near transfer (familiar contexts) cases and far transfer (unfamiliar contexts) cases.

Methods: First year psychology students (n=42) learned 3physiological concepts in a 2x2 factorial study (one or two practice contexts and blocked or mixed practice). Each concept was practiced with two clinical cases; practice context was defined as the number of organ systems used (one system per concept vs. two systems). In blocked practice, two practice cases followed each concept; in mixed practice, students learned all concepts before seeing 6 practice cases. Participants completed a 10 question short answer and MCQ knowledge test. Transfer testing consisted of correctly classifying and explaining 15 clinical cases. The outcome was ratings of explanations of cases on a 0-3 scale. Analysis was by factorial ANCOVA.

Results: Significant interaction was found for far transfer (F(1,38)=20.3,p<0.001). Mean score for blocked practice with one organ system was: 0.71, blocked with two systems: 1.15, mixed with one system: 0.42, and mixed with two systems 1.22. No significant difference was found on near transfer cases but overall near transfer cases were easier (mean sore 0.91) compared to far transfer (0.88). No difference was found between groups on the knowledge test.

Conclusion: Using only one practice context during practice significantly lowers performance even with the usually superior mixed practice mode. Novices should be exposed to multiple contexts and mixed practice to facilitate transfer.

INTRODUCTION

Arguably, a central role of medical education is to provide students with the knowledge they will need to solve clinical problems presented by their patients. However, there is an abundance of evidence from other domains that even if students possess the knowledge needed to solve a problem, they may have difficulty accessing that knowledge to solve a new, unfamiliar problem (Ross, 1987). This phenomenon, accessing old knowledge to solve new problems, is called "transfer". In undergraduate medical training, the issue of transfer is particularly serious as many different domains of knowledge are taught with the expectation of future utility for problem solving. For example, basic science disciplines like physiology and anatomy, as well as epidemiology, ethics, and other disciplines are often integrated into medical school curricula. The success of this teaching is dependent on students' ability to transfer this knowledge into the clinical domain. Basic sciences are of a special concern; several studies have established (Goldszmidt et al. 2012; Baghdady et al. 2009; Woods et al. 2006, 2005;) that use of basic sciences knowledge enables students to more accurately and efficiently grasp clinical skills such as diagnosis and interpreting examination findings.

The benefits of mastery of basic science are not simply dependent on retention, however. Learners must recognize that their previous knowledge from basic science can be used to understand the clinical skill or task they are learning, and must be able to retrieve the particular knowledge they require to understand the

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clinical situation. In other words, the transfer of basic science knowledge to the clinical task is essential if learners are to derive benefit from basic science teaching.

However, over a century of research supports the view that transfer is a difficult cognitive process for learners (Eva et al. 1998). This is not domain specific concern, but rather a near universal feature of human cognition (Salomon & Perkin, 1989). Accommodating this difficulty in teaching basic sciences during undergraduate training is necessary but often not planned for in the curriculum (Kulasegaram et al. 2012; Laksov et al. 2008).

Developing strategies to teach learners to transfer requires an understanding of why students find spontaneous transfer difficult. One of the most significant reasons for failure to transfer is context specificity (Eva et al. 1998; Kulasegaram et al. 2012). By and large, learners tend to associate the learning of abstract concepts to the context in which they learn those concepts. For example, fluid flow dynamics could enable learners to understand physiology and pathology in several different organ systems. However because of limited transfer, illustrating the application of fluid flow with an example from the respiratory system (e.g. asthma or bronchitis) may enable learners to solve problems involving the respiratory system. But when presented with a fluid flow problem in a different organ system (e.g. cardiovascular), learners often fail to recognize that the new problem is simply another context to which the previously learned concepts can be applied (Kulasegaram et al. 2012). This is because learners tend to classify and retrieve concepts based on the superficial or surface level information similarity (Gick & Holyoak, 1980; Holyoak & Koh, 1980; Ross & Kennedy 1990). Problems for which the context of learning and that of transfer have similar surface details are *near transfer* (e.g. respiratory to respiratory) and are invariably easier than *far transfer*, which occurs when the surface details are different between the context of learning and transfer (e.g. transfer from respiratory to cardiovascular). Optimizing transfer performance involves switching learners from over reliance on superficial contextual details to the structural features of the concept (Kulasegaram et al. 2012).

A simple strategy that facilitates this switch is practice in multiple contexts i.e. multiple examples with *dissimilar* surface details (Ross &Kennedy, 1990), which forces learners to discount superficial surface features and focus on conserved features of the concept in present in both contexts. Practice in multiple contexts has shown dramatic improvement in transfer performance for novices (Ross & Kennedy 1990; Catrambone & Holyoak, 1989) in several domains.

The structure of practice can also be manipulated to promote transfer. Traditional practice involves learning a concept followed by practice with multiple examples of the concept. This strategy is known as *blocked* practice. An alternative method is *mixed or interleaved* practice which involves practicing on examples of multiple concepts together. For example, students learning statistics in blocked practice would learn t-tests followed by practice with t-test problems, then would learn chi-squared and practice with chi-squared problems. In mixed practice, after learning about t tests and chi-square, students would be given a practice session involving both types of problems. Originally developed and studied in motor skills learning (Lee, Magill, & Weeks, 1985; Magill & Hall, 1990) mixed practice has been extensively investigated for concept and procedural skills learning (Helsdingen, Gog, & Merriënboer, 2010; Rohrer, 2008; Hatala, 2011;Taylor & Rohrer, 2010)

Head to head studies of transfer performance for mixed and blocked practice have consistently demonstrated an advantage for mixed practice (Rohrer & Taylor, 2007; Rohrer, 2008). In traditional blocked practice, learners do not have to identify the *type* of concept to complete the practice problems; it is already known that the concept is the one from the preceding lesson (Rohrer, 2008; Rohrer & Pashler, 2010). In contrast, mixed practice requires that learners must actively learn to distinguish which concept correctly applies to each problem. As Rohrer (2008) notes: whereas blocked practice requires students to know how to perform a procedure, it does not require them to know which procedure is appropriate. Mixed practice can facilitate learning of both the ability to recognize the concept and understanding of procedural steps. While it is more difficult for learners initially, it fosters better category learning. Evidence for the benefit of mixed practice has also been found for clinical learning. Hatala and colleagues (2003) studied diagnosis of ECGs by novices. Participants were asked to learn to interpret ECGS of three different types of disorders and then given practice in either blocked or mixed fashion. Transfer testing showed participants in the mixed condition successfully diagnosed nearly half the cases while in the blocked condition accuracy was less

than a third of the new cases.

While the evidence for the benefit of mixed practice is robust, what is still unclear is how practice of concepts in multiple contexts affects its impact on transfer performance by novices. For example, a physics concept relevant to physiology can occur in the context of any number of different organ systems. Learning to transfer this concept would require that learners recognize that a particular concept is applicable to a novel problem in an unfamiliar organ system. Thus, the learner must understand the conserved structural features of the concept are more important cues than the mutable surface details which are bound to the context in which the problem or concept is occurring. Practicing several concepts together as in mixed practice should theoretically increase extraction of structural features. Learners will be required to find the distinguishing features of each concept they are practicing. However, one could expect this beneficial process can be affected by the number of contexts and sets of surface details in which a concept presents itself in. Previous research in transfer (Ross & Kennedy, 1990) have shown that learners tend to encode surface details strongly when learning novel conceptual information. While mixed practice involves practicing multiple concepts, it is unclear what effect varying or mixing the number of surface details (contexts) for each concept will have.

To our knowledge, few studies have examined learning multiple contexts and the impact of blocked and mixed practice. The studies that have (Simon, 2008) have not examined the impact on transfer but on outcomes more closely related to

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recall or memory for taught concepts. Furthermore, these studies did not examine the impact on near and far transfer.

In this study, we examined the relative efficacy of mixed and blocked practice strategies when practice occurs in either single or multiple contexts for concepts. We tested performance in both near and far problems separately to determine if benefits of practice strategies vary based on type of transfer task.

METHODS

This study was conducted with forty-four (N=44) first year undergraduate students in the Department of Psychology at McMaster University during 2010-2011. Participants received either \$10.00 in compensation for participation or course credit. The study received institutional ethics approval from the McMaster University Ethics Board. Procedures, materials, and other aspects of the design are similar to those used in previous studies (Kulasegaram et al. 2012, Norman et al. 2007).

Procedures

In a 2x2 design, students were randomized to learn and practice 3 physiology concepts with either mixed or blocked practice as well as practice with either 1 or 2 organ systems. This study was conducted in two phases, Learning-Practice and Testing, which occurred in the same session.

Phase 1: Learning and Practice

During the first phase, participants read explanations written by an expert clinician (AN) for three physiology related principles: fluid dynamics, Laplace's Law, and Starling's Law. Fluid dynamics illustrate the principles of laminar and turbulent flow, which has application in multiple organ systems including the respiratory, cardiovascular, gastrointestinal, and urinary tract. Laplace's Law describes tension in the walls of cylindrical vessels as it relates to the radius of the vessel and pressure across the wall; it applies to the same organ systems as the principles of laminar and turbulent flow. Starling's law describes the elastic 113ehavior of the heart in response to filling of the ventricles and volume of the ejected blood. Because it only applies to the heart, Starling's law was used only as a near transfer control. All explanations included a detailed outline of the concept, its relevance to physiology and a brief example of its application, and emphasized that the concept applied in multiple organ systems. Each explanation was also augmented by the provision of teaching analogy, which illustrated the basic principles of the concept. For example, the relationship of tension, pressure, and vessel radius described by Laplace's law was illustrated using the analogy of a weight suspended in the middle of a string. The increase in vessel wall tension due to increasing the radius of a cylindrical vessel is akin to the increase in the tension of the string as the ends of the string are pulled apart. We have previously used teaching analogies to improve transfer performance (Kulasegaram et al. 2012, Norman et al. 2007) and all of the participants in the study were given teaching analogies for each concept (see Table 1). Order of presentation was randomized.

<<Table 1: Example of Explanation: Laplace's Law & Teaching Analogy>>

Practice for each concept consisted of two clinical vignettes written by an expert clinician (AN). Participants were asked to provide an explanation of how the concept explained the signs and symptoms - in other words, how the concept applied to the problem. They were then provided with the correct answer as deemed by expert (AN,). See Table 2 for an example.

<<Table 2: Example of Laplace's Law's Vignette>>

Manipulation of Practice Strategy

In the blocked practice conditions, practice cases followed each explanation such that a participant starting with Laplace's law would read the explanation for the concept and would then complete the two practice cases before moving onto the next concept. In the mixed practice condition, participants read all three explanations prior to any practice; in the practice phase, participants were presented with 6 practice cases in random order.

Manipulation of Practice Context

Practice contexts were manipulated using organ systems involved in the vignettes depicted in the practice cases, which could involve the same or different organ systems. In the single practice context condition, fluid dynamics cases involved only respiratory disorders and Laplace's law cases involved only gastrointestinal disorders. In the multiple practice context condition, fluid dynamics had one respiratory and one cardiovascular case while Laplace's law was practiced with a case from the gastrointestinal and one from the cardiovascular system. Starling's law only applied to the cardiovascular system and was included to increase the difficulty of the learning and transfer tasks.

Figure 1 summarizes the design and procedures of the experiment for each condition.

<<FIGURE 1>>

Consolidation

After viewing the explanations and completing practice with feedback, all participants were asked to complete a 10 question True / False quiz on the concepts. Participants were required to obtain a minimum score of 8/10 to move on to a knowledge test or were asked to repeat the quiz before moving onto Phase 2: Testing.

Phase 2: Testing

Recall and Knowledge Test

Knowledge of the concepts was tested using 6 multiple choice and 4 short answer questions for a total score out of 10. Questions directly elicited information presented about the concepts in the explanations. Participants only completed the test once and were not given feedback.

Transfer Testing

All participants were presented with 15 clinical vignettes similar to those in the practice session. Vignettes came from a mix of near transfer organ systems (familiar) and far transfer (unfamiliar) organ systems. Flow dynamics was tested with 6 cases involving the respiratory, cardiovascular, and urinary tract systems. Laplace's Law was tested with 6 cases involving the gastrointestinal, cardiovascular, and reproductive tracts. Cases in the reproductive and urinary tract systems were the common far transfer cases for all participants. Starling's Law was tested with 3 cases. Thus, near and far transfer cases were created for all conditions. Participants were asked to identify the concept involved in the vignette, then provide an explanation for how the concept accounted for the clinical signs and symptoms. Responses were scored on a 0-3 scale with 1 point awarded for correctly identifying the concept involved and additional points for accuracy and depth of explanation. This scoring system was used in previous transfer studies (Norman et al. 2007, Kulasegaram et al. 2012). A sub-sample of cases was scored by two raters to determine inter-rater reliability. See Table 3 for an example of the test cases and scoring. For a summary of the design, see Figure 1.

<<See Table 3: Example of Laplace's law case and scoring>>

<<Figure 1: Design Summary>>

Analysis

A 2x2 ANOVA was conducted on the knowledge test with practice strategy and number of practice contexts as the between subjects factors. The transfer test was analyzed using average score on case (0-3) as the outcome and using 2x2 ANCOVA with practice strategy and practice context as the between subject factors and scores on the knowledge test as a covariate. Separate analysis was conducted for near and far transfer. A repeated measures analysis of near vs. far transfer was also performed. Additionally, we conducted a sub-analysis on recognition of concepts (correct identification of transfer cases by concept) using the proportion of cases correctly identified by concept as the dependent variable. Doing so allowed us to determine whether the impact of practice strategy and practice context was limited to recognition, or if there was an additional benefit for understanding.

RESULTS

Forty-two students completed the study. One participant did not complete the test phase and another randomized to the Blocked practice with 2 organ systems scored 0 in all transfer cases; these were excluded from analyses. Inter-rater reliability for rating of explanations was high (ICC=0.85). Participants on average took 2378.54 seconds on the learning phase (SD:202s); participants in the mixed condition took longer (mean time 2734.60, SD: 190.2s) than in the blocked

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condition (2023.41, SD: 134.1s). Time spent during learning and practice did not correlate with scores on knowledge test or on transfer cases.

Knowledge Testing

Scores on the multiple choice and short answer knowledge tests are shown in Table 4. Analysis showed no effect of practice strategy (F(1,38) 0.993, p=0.35) or number of organ systems during practice (F(1,38) 2.3, p=0.21) as well as no significant interaction (F(1,38) 2.1, p<0.19). Scores on knowledge testing did not correlate significantly with performance on transfer cases overall (r=0.35, p<0.15) or with near transfer cases (r=0.19, p<0.43) and far transfer cases (r=0.33, p<0.18) separately.

<< Table 4: Average Total Score on MCQ and Short Answer Knowledge Test by Condition>>

Transfer Testing

Near transfer

Analysis of near transfer cases is presented in Figure 3. There were no significant differences between groups though the highest average performance was for the mixed practice group with two organ systems. Scores on the knowledge test was not a significant covariate.

<<FIGURE 2: Average Score on Near Transfer Cases>>

Far transfer

Analysis of far transfer cases showed no effect of practice strategy but a main effect for number of organ systems (F(1,38)=20.3, p<0.0001). Blocked and mixed practice with two organ systems had similar performance for transfer (see Figure 4). Both of these groups outperformed practice with a single organ system; mixed practice with a single organ system had the lowest average score on far transfer. Scores on the knowledge test was not a significant covariate.

<<FIGURE 3: Average Score on Far Transfer Cases>>

Near vs. Far Transfer

A significant near vs. far by organ system interaction was found with (F(1,38)=3.4, p<0.002)) with individuals practicing with a single organ system showing lower far transfer scores than near transfer (0.58 (0.37) to 0.83 (0.37)) compared to the two organ systems of practice group which had similar far and near transfer scores (1.19 (0.50) to 1.01 (0.38)).

Recognition

The proportion of near transfer cases correctly identified by all groups was similar, with participants in blocked practice identifying 62% of cases and those in mixed practice correctly identifying 70% of the cases. Interestingly, participants

practicing with 1 organ system identifying 71% of cases while those with 2 organ systems identified 60% of cases. The difference was significant (F (1,38)=4.1, p<0.045).

Far transfer cases showed the opposite pattern with the 1 organ system group identifying 44% of cases correctly and the 2 organ system group identifying 66% of cases correctly (F(1,38)=12.2, p<0.001). Participants in the blocked and mixed groups identified 56% and 55% of the cases respectively. Overall, near transfer cases were more likely to be correctly identified (66%) compared to far transfer cases (55%) with the difference being significant (F(1,41)=5.2, p<0.029).

DISCUSSION

This study examined the impact of varying the number of practice contexts on practice strategies for transfer of concept knowledge. We found that there was a significant interaction between the type of practice strategy and the number of practice contexts for far transfer. Specifically, the effectiveness of mixed practice is dependent on the number of practice contexts used during learning. As the number of practice contexts increased so did transfer performance in both practice strategies. The advantage of practice with multiple contexts appears to result from improvement in the ability to recognize concepts in new contexts and therefore discount the context as a cue to problem type. Consistent with this view, while mixed practice with multiple organ systems had the highest overall transfer performance, mixed practice with a single organ system per concept had the lowest far transfer performance suggesting that in single organ system condition, mixed practice increases incorrect reliance on context for the single system practice.

The explanation for these results is likely the advantage conferred by exposure to multiple contexts in changing the way participants used context to guide problem solving. Previous studies of transfer have shown that learners tend to rely heavily on the surface features of a problem for categorizing problems. A classic study by Larkin et al. (1980) found that novice learners categorize physics problems based on the superficial characteristics (e.g. pulley problem, inclined plane problem) while experts categorized problems based on theoretical constructs (e.g. conservation of momentum, force dynamics etc.). This approach to problem solving reflects critical difference in the problem schemas of novices and experts (Salomon & Perkins, 1989) and is one of the reasons why transfer is difficult. Learners do not create abstract representations or schemas. That is to say, Laplace's law when initially presented is not represented as a decontextualized ideal by the learner. Instead, it is associated with the example used to teach the concept. It is the example that is called to mind when recalling the concept (Reeves & Weisberg, 1994). The exemplars used to illustrate concepts will exert a strong effect on how the learner classifies concepts (Reeves & Weisberg, 1994). Use of a single context in practice reinforces the confounding of concepts and contexts while multiple contexts serves to deemphasize the importance of the context in recognizing the concept at play. This occurred in our participants despite the provision of a deep structure teaching aid – the teaching analogies – which have previously been shown to decrease reliance on contextual cues (Kulasegaram et al. 2012).

Studies of mixed and blocked practice typically find an increase in performance for mixed practice with delayed testing (Helsdingen et al. 2010). Thus, the absence of a delayed test is a limitation for this study but it is likely that the results will not be significantly different based on previous studies with delayed testing using these materials (Kulasegaram et al. 2012). The sample used in this study consisted of psychology students generally naïve to the physiology and clinical conditions that were used in testing. However, we did not control for prior knowledge using a screening test. Still, other studies using these materials (Norman et al. 2007, Kulasegaram et al. 2012) found transfer effects with this type of sample. Furthermore, the overall low transfer performance reinforces that the concepts were unfamiliar to most participants.

There are several explanations for the benefits of mixed practice. Generally, these explanations argue that mixed practice poses additional processing requirements for learners in that they must not only process the solution to the practice problems but must also attempt to distinguish the type of problem (Rohrer, 2008). This extra processing activity has been characterized as desirable difficulty (Schmidt & Bjork, 1992) or increase of germane load (processing relevant to problem solution and learning) (Pass et al. 1994). Regardless, this extra effort draws the learner to process the discriminating abstract features and form richer mental representations of the concept (Helsdingen, 2010). Many transfer theories and

teaching strategies emphasize the importance of fostering increasing abstraction of concepts in order to promote transfer (Holyoak et al. 1989; Lowenstein et al. 2003; Norman et al. 2009). However, in this study, the mixed practice condition with a single organ system removed the need for additional processing since in mixed practice, participants could rely on the organ system as a surface marker for the concept in the case. In fact, it appears that the participants in mixed practice over-learned the association between concept and organ system resulting in the worst transfer performance of all groups. On the other hand, the mixed and blocked practice groups with two organ systems learned during practice that organ system was an imperfect marker of the concept involved in a case.

Still, while far transfer performance seems to be improved by context variation, near transfer scores were not significantly different between groups. Furthermore, practice with a single organ system per concept had very slight advantage for the ability to recognize near transfer cases. One possibility for this difference could be that the single organ systems groups received additional practice for Flow dynamics respiratory cases and Laplace's Law gastrointestinal cases. However, a post-hoc analysis showed that both groups correctly classified similar proportions of these cases (66% for single organ system, 65% for two organ systems during practice). Alternatively, it is more likely that for near transfer cases, reliance on surface features is an effective and efficient method that minimizes cognitive load. While this surface feature strategy can be efficient, it can be erroneous for far transfer. The mixed practice with two organ systems group had

the greatest difficulty during practice. The additional processing or germane load – distinguishing structural and surface features during practice – likely forced them to recognize and use structural features during problem solution. This in turn reduces reliance on surface features and possibly decreases the intrinsic load of future problem solving. Accordingly, this group had the highest near and far transfer performance and the difference between near and far transfer performance was lowest for this group.

More generally, these results reinforce the continuing difficulty of transfer and support the need for extended practice in multiple contexts and focus on teaching deep structure. Most transfer interventions (Norman, 2009) focus on enhancing the abstraction of concepts – for example using teaching analogies, active comparison, mixed practice etc. Exposure to multiple contexts during practice forces learners to rely on more abstract, conserved features of concepts and possibly aids their ability to adapt knowledge to new contexts. A judicious mix of deep structure teaching aids that allow abstraction and practice with multiple contexts can push learners to more readily extract the essential features of concepts. This will likely prepare them to recognize these features in future transfer problems and ease the recall and application of that knowledge. Teaching of basic science concepts in undergraduate medical training should find ways to supplement learning along these axes.

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CONCLUSION

This study demonstrated that the benefit of mixed practice for transfer of conceptual knowledge was dependent on the number of practice contexts. Learners use the surface details of problems as cues to recall the appropriate concept for solution. Teaching for transfer in medical education should use concept-teaching strategies such as mixed practice combined with contextual variation during training to enhance transfer.

FIGURES

Figure 1: Summary of manipulation and general design





Figure 2: Average Score on Near Transfer Cases

Average score on near transfer cases for each group. No significant differences by group though the mixed practice group with two organ systems had the highest transfer score.



Figure 3: Average Score on Far Transfer Cases

Figure 3: Average score on far transfer cases by condition. The groups that practice with two organ systems had the highest transfer score regardless of the type of practice strategy. Mixed practice with a single organ system had the lowest average score on far transfer cases.

TABLES

Table 1: Example of Explanation: Laplace's Law & Teaching Analogy



Table 2: Example of Laplace's Law's Vignettes

The patient complains of increasing abdominal pain. On examination, his abdomen is distended and an abdominal x-ray shows a dilated colon. The patient complains of being unable to move his bowels for the past four days and of previously severe pain the area. The doctor is concerned that the patient might suffer a bowel perforation and prescribes anti-inflammatory drugs. He recommends surgery to constrict the size of the stomach. Explain why these measures may help and what the risk is to the patient?

The dilation of the colon is an increase in the radius of the gastric tube. While the pressure of the contents may stay the same, the increase in the radius will increase the tension of the colon (T=PR). If the tension continues to increase the colon's walls might actually rupture from the excess stress. While this is a rare possibility, it is severe. Similarly, the increased size of the bowel reduces the ability of the muscles to generate enough force to push through the contents. Reducing the radius or size should eliminate this difficulty.

Table 3: Example of Laplace's law case and scoring

A patient complained of vomiting copious amounts at the end of each day.						
Investigations revealed they had	Investigations					
that	u lux, poorty contracting s	tomach. They were given a drug				
constricted the size	constricted the size of the stomach, resulting in more efficient emptying.					
Explain why						
constricting the si	constricting the size impacts stomach emptying.					
Score	Selected Principle	Explanation				
	*	-				
0	Goethe / Starling					
1	Laplace	Not Provided or Incorrect				
1	Lupiace					
2	Laplace	This can be due to a				
		decreased radius of the				
		stomach.				
		the nathway of the				
		stomach, allowing the food to				
		stay in the stomach for				
		further digestion.				
3	Laplace	The drug might have				
		stomach walls. From the				
		knowledge of Laplace'slaw.				
		we know that as the tension				
		decreases, so does the				
		pressure. The drop in the				
		pressure from the outside				
		walls, stomach's radius				
		in more efficient space				
		in more enterent space.				
Practice	# of	Mean	Std. Deviation			
----------	---------	------	----------------			
type	Organ					
	systems					
	1	7.50	0.32			
Blocked	2	8.10	0.45			
	1	7.30	0.44			
Mixed	2	7.66	0.56			

Table 4: Average Total Score on Multiple Choice and Short Answer Knowledge Test by Condition

Means and standard deviations for total score on the knowledge test by condition.

Maximum total score was 10 points.

CHAPTER 6: GENERAL DISCUSSION

6.1 Summary of findings

Transfer of conceptual knowledge in health professions education and especially in medicine is a significant issue during undergraduate training. Basic science can aid the understanding of clinical problems as well as promote retention of clinical conceptual knowledge (Woods, 2007). While this is an increasingly accepted principle (Kulasegaram et al. 2013), finding ways to ensure basic science is available for problem solving is a transfer issue. The main purpose of this work is to outline organizing principles for improving transfer of basic science knowledge. To further this goal, the three presented studies addressed the issue of the relative importance of contextual and conceptual information for transfer in medical education.

This was achieved by manipulating learning and practice by a) teaching physiology concepts in one or multiple contexts and b) illustrating the conceptual structure using teaching analogies or mixed practice for transfer of knowledge to problems in near and far transfer contexts. Chapter 3 showed that the illustrating the deep structure of concepts using a teaching analogy improved near and far transfer and also that near transfer was significantly easier for learners. The results suggested contextual information such as surface details of transfer problems can have utility for problem categorization and solution. Furthermore, despite learning interventions, students relied heavily on contextual information.

These findings were consistent with earlier work in analogical reasoning that suggested contextual information such as surface details had a strong influence on novices during problem solving. Manipulating the variation of contextual information such as the number of different surface details presented during practice is an alternate strategy to improve transfer. Experiment one of Chapter 4 showed increasing the number of surface details used to present a single concept could improve far transfer. The impact of this contextual manipulation was independent of improvement derived from a teaching analogy. However, both interventions together led to high far transfer performance. The results of the first experiment also suggested that there was little benefit to increasing the number of examples of surface features beyond just two dissimilar examples. This supported the abstract schema based theoretical accounts of transfer. Interestingly, participants in the analogy condition and in the two and three organ system groups had similar near and far transfer scores. In contrast, the one organ system group had very high near transfer but very low far transfer scores. Experiment two showed that this was because teaching analogies and multiple organ systems shifted learners towards processing structural features for problem categorization instead of relying on surface details. This shift was necessary for successful far transfer and learners applied this strategy to all transfer problems. Both sets of studies confirmed that the default novice strategy was to use surface details as a cue for category recall and classification in the absence of structure illustrating learning interventions. While surface reliance is efficient and accurate for near transfer, it led to errors for far

transfer. This confirmed findings from Chapter 3 and suggests that effective strategies for transfer must work against this tendency.

Chapter 5 showed that the efficacy of a transfer learning intervention (mixed practice) was reduced when learners were able to revert to their native reliance on surface details as a cue to problem solution. Mixed practice with a single organ system reinforced learners' processing of surface features to categorize concepts. On the other hand, blocked and mixed practice with two organ systems had similar far transfer scores though the mixed practice group had the highest average performance for near and far transfer overall. This study suggests that carefully aligning learning to promote the processing necessary for transfer is most likely to lead to success. This requires engaging learners to process structural informational instead of superficial contextual information which is what learners do by default.

6.2 Transfer Appropriate Processing Accounts of Near versus Far Transfer

The results confirm that far transfer even within a limited domain such as physiology, is difficult for novices. This was the case even when the basic clinical explanations identified the transferability of physics principles such as Laplace's law and laminar flow. Problem solving was most successful when surface detail correspondence or contextual similarity existed between learning and transfer. The near transfer effect has been explained in many ways including the identical elements theory, inability to disassociate contextual information from conceptual information (Eva et al. 1998) and holistic pattern recognition (Reeves & Weisberg, 1994). The results of studies in Chapter 3 and 4 suggest that surface details are often recognized accurately to cue recall of conceptual knowledge because of strongly entanglement in the representations of the concept during teaching. As suggested by Ross (1987), novices have no other method of representing the concept in a way that is useful for problem solving. For the novice, the surface details are the core of the concept. This is likely to be effective for near transfer as the surface details of the transfer problem are easily apparent and extractable. While this could also be achieved by using the deep structure, as suggested in Chapter 3, surface detail matching is likely faster and efficient for all learners.

Obviously, in some domains with close alignment between context and concept as well as little overlap between concepts, reliance on contextual information such as surface details is sufficient for accuracy. Perhaps it is one of several appropriate strategies on a spectrum of strategies that could be to be taught to novices to aid in problem solving (Ark et al. 2007). However, the concepts used in this study and in general basic sciences for medical education do not lend themselves to continuous surface detail matching (e.g. Laplace's law). Reliance on surface details led to negative transfer on far transfer problems for groups without deep structure teaching such as teaching analogies or practice with multiple contexts. When contextual overlap is high between different concepts, contextual information will be an imperfect marker of deep structure. But while shifting to conceptual information can be accurate for near *and* far transfer problems, this was not an easy shift to make for participants in any of the studies presented earlier.

Several authors have offered explanations for why far transfer poses a difficulty for learners (Nokes, 2009; Barnet & Ceci 2002; Eva et al. 1998). A transfer appropriate processing account would again argue that transfer is difficult because learners often use surface details to represent concepts and manipulate future problem information at the level of the contextual details. The results of the previous studies suggest that this is indeed the case. Successful transfer requires aligning the cognitive processes used in the context of learning and the context of problem solving (Rajaram, Srinivas, & Roediger, 1998; Roediger, 2007). Interventions that give learners the chance to practice extraction and mental manipulation of deep structure enhance far transfer as learners are prepared to recognize cues of deep structure in transfer problems. Evidence from the similarity classification task from experiment two of Chapter 4 suggests that the learning interventions based on structural illustration and context variation changed the information participants processed to solve problems leading to a representational shift of the concepts. Interestingly, context variation during practice was a useful technique in focusing learners on structural information. The debate around the utility of surface details and contextual information is ongoing (Kaminski et al. 2008) but the results of these studies suggest that appropriate manipulation of surface details during practice can foster transfer. Most likely novices abstract out a conceptual deep structure from multiple examples instead of pattern matching based on familiarity. Thus, the results support a schema abstraction account of conceptual transfer instead of a strictly exemplar based one. The formation of the schema was

strengthened with the addition of deep structure teaching and practice strategies such as the analogy or mixed practice. The experimental groups in Chapter 4, Experiment 1 (two and three organ systems of practice with analogy aided instruction) and in Chapter 5 (mixed practice with organ systems as well as a teaching analogy) had the highest far transfer performance and similar near transfer hinting at a wholesale shift in the way participants represent the concepts. In fact, the mixed practice group with two organ systems of practice and the instructional analogies had consistently high near and far transfer performance even though this group likely had the highest cognitive load during learning (though this also includes high germane load which assists in transfer appropriate processing).

The experiment in Chapter 5 tested both knowledge/recall as well transfer. The results generally supported a disassociation between recall and transfer. That is, learners can have high levels of knowledge of the domain or concept but still fail to process the deep structure or recognize further instances of the concept in new contexts. While study 2 of Chapter 4 showed an individual level association between conceptual knowledge and categorization based on deep structure, the experimental groups all had similar concept test scores. Similarly, in Chapter 5, there were no significant differences between the groups on recall multiple choice questions and short answers. These results suggest that simply presenting deep structure for learners is not sufficient. Passive memorization or recall might increase familiarity with the concepts, but for transfer to occur, learners must represent and understand the concepts at the deep structure level in. This is

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consistent with results from previous studies with simpler materials (Needham & Begg 1991). This disassociation supports the transfer appropriate processing account where recall for the conceptual knowledge is necessary but not sufficient for transfer.

6.3 Other factors influencing transfer performance

Early theoretical transfer work often used very basic materials (e.g. Thorndike 1910, Gick & Holyoak 1980) in order to eliminate many converging effects in the learning materials. However, multiple factors may play a role as research in problem solving becomes more sophisticated and experimental settings begin to have greater ecological validity. While by no means a replication of a classroom, the materials and methods in this study were noisier than basic theoretical experiments. This means other converging factors beyond processing shifts likely synergistically aid in improving near and far transfer.

The first of these factors alluded to in Chapter 3 was shifting the type of mental process during learning to active, effortful processing – so called system 2 processing (Evans et al. 2008). Many explicit learning activities bear a superficial alignment with the language used to describe system 2 processing: active learning, deliberate etc. But the literature in dual process theory is equally clear that learning can also happen automatically and unconsciously (Evans et al. 2008). Without a doubt, active processing of the conceptual information is necessary for learning and transfer but the type or class of process used to solve problems will also depend on

learner expertise (Norman & Eva, 2010), the environment of problem solving (Evans, 2003), as well as other factors (Bos, Dijksterhuis, & van Baaren, 2012). While it is likely dual processing changes are involved in transfer, the theory itself is too broad to apply usefully to these results.

More relevant, to these data is the theory of cognitive load. Cognitive load has been well articulated in many settings and is parceled to intrinsic, extrinsic, and germane load (Van Merrinboer et al. 2006). Load describes the amount of effort and use of working memory during the mental activity (Sweller, 1994). Load theorists argue increasing useful mental activity (germane load) while reducing the extrinsic load or extraneous mental processing (Sweller, Van Merrienboer, & Pass, 1998) will improve learning. Many interventions have been designed around cognitive load principles and the general theory aligns with the interventions used in these studies as well as transfer appropriate processing theory (Van Merrinboer et al. 2006). For example, teaching analogies may minimize the intrinsic load (inherent difficulty) of learning and mixed practice might increase germane load. Changes in intrinsic load during learning also explain the slight differences in outcomes for the analogy group from the study in Chapter 3 to the first study in Chapter 4 as the number of practice examples increased from 2 to 3.

The provision of feedback in the form of the correct response for practice problems likely impacted the ability to transfer. While all groups received the same correct response, it is possible that individuals in the structure-emphasizing intervention conditions were more able to take advantage of feedback. An experiment manipulating the type of feedback given (e.g. just the correct answer versus a detailed explanation) and the learning condition (e.g. analogy or no analogy) may help clarify this issue. Previous work in transfer have outlined that feedback can benefit transfer (Eva et al., 1998) but how this feedback should be provided is still unclear.

6.4 Limitations

There are several limitations to this work. Foremost is that participants' prior knowledge of the physiology concepts was not controlled for. Prior experience with problem solving in physiology or expertise in the subject matter would have aided problem solution at testing. However, the low average scores in all studies and lack of high performing outliers suggests that the lack of control did not impact the outcome. Psychology students were deliberately chosen as a population as they are not taught the sophisticated knowledge of physiology that would usually be taught in first or second year medical schools. Still, future studies should attempt to screen or control for this. Another factor is that the participants were given a short period of time to learn and practice the materials. Though knowledge testing generally showed adequate acquisition of the concepts, further time for training and testing would allow the results to be more generalizable. Lastly, the materials in this study consisted of physiology concepts informed by physics. Thus, they have a strong deep structure characterized by the relationship of abstract variables (e.g. pressure, tension in Laplace's law) as well as wide applicability. As mentioned earlier, transfer appropriate processing can be conceptualized differently for domains in which surface features are adequate for problem solving.

6.5 Implications for Medical Education

The purpose of this work was to explore how to improve transfer of basic science and the relative importance of contextual and conceptual strategies for teaching for transfer. This work shows that in fact, contextual and conceptual information have a close relationship during initial learning. As long as the transfer teaching strategy pushes learners to process appropriately (i.e. manipulate features that must be examined during actual problem solving), then it will facilitate transfer. Both contextual and conceptual teaching strategies can be used to accomplish this if used carefully and with awareness that learners can easily default back to reliance on inappropriate information as seen in Chapter 5.

These results must be contextualized within the challenges of knowledge and skills training for health professionals and in particular physicians. Several converging lines of research have suggested that diagnostic clinical reasoning and other forms of problem solving in medicine are largely based on exemplars and prior experiences with the problem (Norman, 2005; Young et al. 2011). Novices who lack an extensive store of experiences must rely on formal knowledge. Thus, successful transfer of conceptual, formal knowledge such as basic science is necessary for problem solving and learning.

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Unfortunately, this is not at the forefront of medical education planning (Laksov et al. 2008). Transfer of basic science is either taken for granted or ignored during undergraduate curriculum development (Laksov et al. 2008). This means that learners are often denied the opportunity to make connections between different bodies of knowledge and forced to relearn the applicability of basic science within the context of clinical learning.

The experimental materials in this study used interventions such as teaching analogies and multiple, varied examples of concepts to improve transfer performance. While these interventions have validity for improving learning and transfer of basic science concepts, this does not necessarily mean that teaching analogies need to be developed for every basic science concept in the curriculum. Rather, interventions that can aid the understanding of deep structure – however defined for the domain and concept to be taught – will improve the transfer of conceptual knowledge within the domain. Similarly, the experiments in the previous studies used organ systems as surface context and created conditions in which widely applicable concepts were taught sequestered to one or two organ systems. While real world classroom teaching may rarely take this form, analogous contextual information and less relevant contextual information are present in most teaching situations. Inattention to how learners manage this information can lead to sub-optimal learning and transfer outcomes. A notable example of this is the use of problem-based learning (PBL) and case-based learning (CBL) in pre-clinical training. PBL and CBL use trigger problems or cases to engage students in the

learning of conceptual knowledge by contextualizing the concept. PBL has been touted as a platform from which to teach for transfer (Norman, 2009) and has been incorporated into early undergraduate medical training to teach and contextualize basic science concepts. PBL cases often have in-depth descriptions of patient history, social circumstances, and clinical presentation to add realism and complexity that simulate medical problem solving. While these 'authentic' details may motivate learners to solve problems, they also provide a whole host of contextual information that may be more or less appropriate for novices. However, while attempting to manage this additional information, novices may lose sight of or fail to extract the key basic science concepts as they attempt to resolve the details of the case itself. While it is assumed that probing questions and PBL tutors will guide learners back to the essential concepts, this is not always the case (Neville, 1999). Instead, early experimental work suggested learners often had inaccurate understandings of basic science (Patel et al. 1991) after undergoing a PBL curriculum and only weak evidence of successful transfer of concept knowledge (Norman, 2009). As Kirschner and colleagues (2006) note, the goal of problem solving in instruction is not simply to search for information or solve problems: rather "The goal is to give learners specific guidance about how to cognitively manipulate information in ways that are consistent with a learning goal, and store the result in long-term memory." Focusing learners on solving problems taxes limited cognitive resources and directs attention to problem solving instead of actively engaging with the relevant concepts for learning (Pass, Renkl, & Sweller,

2003). Ross and Kilbane (1997) showed that practicing problem solving in itself can be insufficient for transfer. Rather, students who had access to practice problems clearly illustrating the underlying deep structure – so called concept illustrating problems – were less likely to make conceptual errors at transfer tasks. PBL and CBL curricula intended to teach basic science must allow learners to access the deep structure of basic science if it they are to transfer this knowledge as intended.

While learning interventions must change, there must also be a synchronous change in assessment if transfer is to be optimized in undergraduate training. Testing for transfer as opposed to just recall or memory has been shown to improve further transfer of conceptual knowledge (Rohrer et al. 2010). This again aligns with transfer appropriate processing and the disassociation between recall of material and ability to apply knowledge (Needham & Begg, 1991). However, if the assessment system in undergraduate training emphasizes memorization, then it is no surprise that learners practice towards that goal. Assessment should challenge learners with transfer tasks that require them to adapt and apply concepts. This not only promotes transfer appropriate processing and deeper learning of concepts, it also reflects the reality of clinical practice.

Similar principles would likely operate in teaching for transfer in other areas of medical education. While what counts as deep structure and superficial, contextual features, may change, training for transfer of basic science in medical education is a matter of focusing learners on conceptual information. Teaching and

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learning interventions that facilitate appropriate transfer processing should be adopted in undergraduate medical training. Doing so will enable novice learners to fully take advantage of basic science instruction and facilitate the development of expertise.

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Concept	Explanation	Analogy
Laminar/Turbulent	Air flows into your lungs	There are many
Flow (Goethe's Law)	through the trachea	examples of laminar
	(windpipe) and bronchioles	and turbulent flow in
	and eventually into alveoli	the world. For example,
	where the oxygenation of	in an old house, calcium
	the blood occurs. The air	and other mineral
	travels in the trachea and	deposits can build up in
	bronchioles in discrete and	the copper pipes in the
	separate layers: the air	plumbing. Water can
	molecules do not deviate	be heard gurgling
	from these layers and bump	through the removed
	into each other. These	pipe, and the pressure of
	honos the term leminer	the top is reduced
	flow The flow is	the top is reduced.
	unobstructed and generally	
	silent Irregularities in the	
	flow such as a change in	
	velocity, narrowing of the	
	bronchioles, a thick or	
	rough mucus lining around	
	the passageways, or in	
	some cases, extremely	
	'thick' or viscous air (i.e.	
	smog) causes the molecules	
	of air to collide thus	
	disrupting the laminae. The	
	flow of air changes from	
	laminar to turbulent, often	
	accompanied by noise and	
	a decrease in flow rate. Any	
	pathology that causes	
	narrowing or obstruction of	
	an airway will produce	
	turbulent flow.	
Laplace's Law	Laplace's Law applies in	A diagrammatic way of
	many situations.	explaining this
	particularly in the	relationship of wall

	gastrointestinal tract. The intestines are tubes with a radius, intestinal wall tension, and a pressure exerted by the tube's contents: digesting food. The tension in the intestinal wall is proportional to the radius of the intestine and the pressure of the contents. This relationship can be explained by: T=PR where T is the wall tension, P is the pressure, and R is the radius. Thus, having a small radius decreases the tension in the wall for the same internal pressure. Laplace's Law explains why in normal circumstances intestines don't rupture their contents and why in some conditions, serious complications can follow dilatation or an increase in the radius of the bowel, as occurs in inflammatory conditions of the bowel.	vessel tension and the pressures across the vessel wall is shown in the left diagram. In order to maintain the same downward force (the pressure), the wall tension T must increase as the wall becomes less curved. This is analogous to a weight hanging on a string as in the diagram at the right. When a weight is suspended from a string, the tension in the two ends of the string increases as the string becomes closer and closer to horizontal, because the vertical component of the tension must equal the weight.
Starling's Law	To pump blood, the heart has to generate sufficient pressure in the left ventricle to open the valve that lets blood flow into the aorta and the rest of the body. As the ventricle fills, the filling blood exerts a force stretching the myocardial muscle fibres. This increases the sensitivity of the fibres to calcium and the subsequent contraction of the muscle fibres is	It's very like what would happen if you took a spring out of a cheap ball point pen, and stretched it. As you stretch the pen, it exerts more and more tension – it responds to the stretching force wit h an equal and opposite tension force. However if you keep going, you reach the point that the spring is overstretched.

enhanced. Therefore, a situation that increases ventricular filling – such as increasing diastolic pressure – will improve the output of the heart during systole. The space around the heart is not tense or tight in normal conditions allowing the stretching muscles to expand. There is in fact an optimal muscle fibre length beyond which excessively high filling pressures which over- stretch the muscle fibres will depress rather than enhance the pumping capacity of the ventricles. In this case, the heart muscle pumps less efficiently and decreases output as it cannot always generate sufficient pressure to open the ventricular valves.	At this point, your additional force will no longer result in increased tension resistance, and the spring no longer returns to its original shape. If we graphed spring tension against elongation of the spring, it would show a similar relationship, with the tension increasing more or less linearly with amount of stretch, until at some point the string loses elasticity and the tension decreases.
generate sufficient pressure to open the ventricular valves.	

APPENDIX B: Sample Practice Cases

Goethe's Law (Flow)

A man with allergies to pollens and grasses begins to cough, get short of breath and wheeze. His symptoms worsen till he is extremely exhausted and rushed to hospital. On examination, the medical student is surprised to find no wheezing coming from the chest. Explain why there is no audible wheezing. (RESPIRATORY)

A patient presents with a high fever and shortness of breath. Wheezing is noted after listening to the chest and looking at a chest x-ray. The diagnosis is acute bronchiolitis with swelling of the small airways. Explain why the wheezing occurred. (RESPIRATORY)

A patient develops sweating and palpitations and goes to the doctor. On examination, the pulse is 96 per minute (normal pulse is 60-90 while resting), and is found to have an enlarged thyroid gland as well as a soft murmur over her aortic and pulmonic heart valves. She is diagnosed with hyperthyroidism which is known to speed up the heart rate. Explain why the patient has a heart murmur. (CARDIOVASCULAR)

Laplace`s Law

The patient complains of severe abdominal pain. She is found to have a distended gangrenous appendix at surgery. Explain why the blood vessels in the wall of the appendix had been compromised, thereby starving the appendix of blood and causing it to become gangrenous. (GASTRO-INTESTINAL)

The patient complains of increasing abdominal pain. On examination, his abdomen is distended and an abdominal x-ray shows a dilated colon. The doctor is concerned that the patient might suffer a bowel perforation and prescribes anti-inflammatory drugs. Explain why the bowel was at risk of perforating. (GASTRO-INTESTINAL)

A patient receives deep lacerations to his left forearm and right thigh. When assessing and treating the patient's wounds, it is discovered that there is only one size of bandage available. Explain whether or not the same amount of stretch is required on each bandage to staunch the bleeding in each of the two limbs. (CARDIOVASCULAR)

Starling's Law

A hypertensive patient presents with swelling of feet and ankles and occasional faintness. Investigations include an echocardiogram which shows a mildly enlarged heart with thickened muscle (hypertrophy) from the longstanding hypertension. Explain how this finding could produce symptoms like faintness. (CARDIOVASCULAR)

A patient is admitted to hospital because of some chest pain. On examination, a loud murmur is heard down the left side of the sternum suggesting a leaking aortic heart valve and the echocardiogram shows left ventricular thickening. Explain how the heart valve problem has produced chest pain. (CARDIOVASCULAR)
APPENDIX C: Sample Test Cases

Goethe

1. A patient is seen to have high cholesterol and risk of myocardial infarction or stroke. A physician notices a slight heart murmur. Angiogram results show severe plaque buildup in the coronary arteries and aorta. The physician suggests angioplasty to increase the diameter of the coronary arteries. What will this do to the heart murmur?

2. A patient is being investigated for shortness of breath and episodes of apparent fainting attacks or blackouts on attempting to exercise. They are diagnosed with a congenital narrowing of the outflow tract of the left ventricle to the aorta. Explain why they appear to drop in blood pressure and faint when they attempts to exercise.

3. A patient, previously well, goes to her doctor complaining of fatigue and shortness of breath after a bout of severe bleeding. On examination she is pale and found to be anemic. The resting pulse is 84, and on listening to the heart, the physician notices a soft murmur over the aortic and pulmonic valves. Explain why the patient has a heart murmur.

4. A patient is being investigated at the respiratory clinic to establish the severity of his respiratory illness. One of the tests involves blowing as hard as he can into a spirometer which measures how much they can breathe out in one second as a proportion of the maximum expired volume. Their "one-second" expiration is far below that predicted. Explain this finding and describe a possible cause.

5. A patient with cancer receives radiation treatment to his abdomen which unfortunately includes his kidneys in the treated radiation field. While his cancer treatment is successful, several years later he returns to the hospital complaining he cannot produce urine. He develops chronic kidney failure and the physicians admit him for investigation. A kidney biopsy shows that scaring has caused consistent severe narrowing of around 60% where the filtering parts of the kidney join to the kidney's urine carrying tubules. It's shown there is virtually no fluid going down the tubules even though the tubules are not actually blocked.

6. A middle aged woman presents with abdominal pain of several hours duration. She has had several prior abdominals surgeries. On examination, her physician notes that her bowel sounds are much louder than normal. During subsequent emergency surgery, scar tissue is noted to be compressing a piece of the small bowel. Explain why her bowel sounds are louder than normal and the abdominal pain

Laplace

7. A patient with shortness of breath is found to be suffering from heart failure. His chest x-ray shows a dilated left ventricle. He is offered a experimental drug to decrease the size of his heart. How will this improve the shortness of breath and heart failure?

8. A patient has been diagnosed with an aneurysm (bulging) of the aorta. He is followed for three years by a surgeon, who tells him that if it grows to 5 cm in diameter he will need surgery to prevent it leaking or bursting. What will the surgery do and how will it help?

9. A patient complained of vomiting large amounts at the end of each day. Investigations revealed she had a lax, poorly contracting stomach. She was given a drug that constricted the size of the stomach, resulting in more efficient emptying. How did the drug improve emptying?

10. A patient suffers a number of small heart attacks over a period of years, resulting in thinning and enlargement of the left ventricle. The family physician notes that the heart is pumping less blood compared to when the patient was a healthy young man. The heart surgeon decides to remove part of the ventricle. The patient asks the surgeon why his heart is not able to generate the same output for each heart beat even though his ventricle size has increased. What explanation would you give the patient?

11. After a car accident, a young man suffers spinal damage, severing nerves to his bladder. This led to a shrunken bladder prone to infections because of increased intra-bladder pressure. He undergoes an operation where a piece of the small intestine is sewn into the bladder as a patch graft increasing the effective volume of the bladder. Explain why this might reduce his risk of recurrent infections.

12. A 35 year old woman undergoes a Caesarean section for the delivery of her second child having delivered the first child without any surgery. Post surgery, she develops an infection in her uterus that responds quickly to antibiotics. Her obstetrician advises the woman that should she have a third child, the scar she now has on her uterus because of the c-section would necessitate another Caesarean section for the safe delivery of the child. The woman is confused and asks why this is the case. Why did the obstetrician give this advice?

Starling

13. A patient suffers a small heart attack which results in damaged and scarred heart tissue. The patient is discharged after a short stay with a treatment plan. He returns

in a week complaining of feeling faint and weak. Surgery reveals rigid heart muscle. Explain how the rigid heart muscle causes symptoms.

14. A hypertensive patient presents with swelling of feet and ankles and occasional faintness. Investigations include an echocardiogram which shows a heart with thickened muscle (hypertrophy) from the longstanding hypertension. The physician concludes that the heart is weak and prescribes drugs known as vasodilators which enlarge blood vessels and decrease systemic blood pressure. Explain why the hypertrophy caused weakness in the heart and how the vasodilators will improve heart function.

15. A patient has previous damage to the full thickness of her left ventricular wall, which has resulted in a blood leak through a rupture in the ventricle into the pericardial space around the heart. He becomes progressively faint and eventually loses consciousness. Explain how the rupture causes faintness.