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Implications Of Results From Cognitive Science Research For Medical Education

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Abstract: Recent results from the cognitive sciences provide insights into the neurobiological basis of memory formation and learning. Learning involves three steps: acquisition of information (physical encoding in the brain), its retention, and the ability to retrieve the information when needed. The results also support the concept of multiple intelligences identified by Gardner and Kolb's Experiential Learning Cycle theory of learning. Courses developed using these principles are particularly effective in facilitating formation of rich association networks of information that are critical to recall of specific information when needed. Case-based courses satisfy more important learning criteria than other instructional methods, but the effectiveness of all methods can be improved using principles derived from cognitive science research. Computers are a supplement that can enhance the effectiveness of all instructional techniques. However, their use must be integral to the instruction rather than simply being added on to existing courses.

Advances in the cognitive sciences over the past two decades have important implications for curriculum design and for instructional practice. These ideas are being widely used in grades K-16, but they have had much less effect on medical education. One reason for its lack of effect may derive from the fact that high-aptitude students succeed regardless of the instructional strategy used[1]. Since this applies to almost all medical students, many faculty conclude the effort involved in redesigning courses and instructional methods is not worth the effort in terms of increased student knowledge.

However, "success" in this situation needs to be qualified. Nearly all medical students pass the required courses and make acceptable scores on USMLE exams. The problem is that too many of them are unable to apply what they have "learned" in the basic science courses to clinical situations involving diagnosis and treatment of patients[2].

Of course, discoveries in the cognitive sciences have not been responsible for all we know about teaching and learning, nor have these discoveries overturned everything that was known about good educational practice prior to their elucidation. They have supplied the neurological basis of and support for some theories; e.g., Gardner's[3,4] theory of multiple intelligence and Kolb's[5] Experiential Learning Theory.

What Advances In Cognitive Sciences Tell Us About Learning:

Extraordinary advances have been made in the cognitive sciences in the past 15-20 years ranging from functional anatomy[6,7] to evolution[8] to consciousness[7,9-11] to learning and memory[6,12,13]. One area relevant to our discussion has been to show that the well-known lateralization of various functions to the right and left hemispheres of the brain is due to semi-independent modules for these functions[6,7]. The modules are all interconnected with and reciprocally influence other functional centers in the cerebral cortex and subcortical structures such as the thalamus, hippocampus, and basal ganglia. In addition, they are influenced by various hormones and neuropeptides many of which are central to emotional states[10]. Synchronous activity by multiple modules is often required to accomplish a given task[6]. As we shall see, these functional centers provide the physical basis for Gardner's concept of multiple intelligences.

As with other organs, the centers arose to deal effectively with the environment, so they were available to be adapted to other uses. For example, the ability to quickly process the topological features of the environment has obvious survival value, but it is then available for the sculptor to use in creating her art. Others, such as language and the ability to understand other people's moods and intentions, were expanded and refined through culturally driven feedback loops[8].

The term "learning" itself actually covers several distinct activities. The material to be learned must be encoded in the brain by altering the strength of connections between neurons (lots of neurons) which alters the dynamic pattern of brain activity[14]. This physical change has to include its associations with (incorporation into) already known material. This physical trace/dynamic pattern must be maintained until it is needed. Finally, the information must be accessible when it is needed or appropriate.

Memory Acquisition: Long-term memories (LTM) are formed in stages[6]. First, the thing(s) to be learned must catch the person's attention since we can focus on only a fraction of the sensory input with which we are constantly bombarded. Information enters working or short-term memory which is quite small (about 5-9 items) where it can be maintained for only a few seconds without rehearsal; e.g., repeating a phone number until you dial it. It is then transferred to LTM via a two-stage process. For about a day after the memory is formed, it is not "permanent." For example, head trauma often prevents consolidation of memories of events for the several hours preceding the trauma resulting in their permanent loss. Thereafter, it is consolidated into LTM.

LTM itself is more complex than it would first seem. The knowledge about how to do something [procedural memory] such as making an omelet or driving a car is diffusely spread over the brain just below the cerebral cortex in the striatum. These memories are resistant to total destruction by localized brain damage[8].

Memories of specific information [knowing that] can also be divided into two types[15]. Those involving knowledge of how the world works; e.g., water is wet and dogs have fur, are called semantic memories. Episodic memories are those usually associated with a specific time, place, or people[7,8]. Their formation requires the activity of the limbic system (particularly the hippocampus) and temporal lobes. They are relatively localized, so they can be destroyed by localized brain damage or evoked by direct electrical stimulation of the area. Semantic memories start as episodic memories that are generalized through repeated exposure to new examples in different contexts until they become part of our implicit knowledge of the world. Experts are those who have developed a large store of semantic memory in a particular area.

Memory Retention: Loss of memories seems to be due to three, non-mutually exclusive processes: decay of the physical trace, interference, and lack of retrieval clues. The first probably does contribute to some memory loss, particularly during aging or from trauma, but generally is not thought to be a major factor in forgetting.

Interference is the effect that other information has on learning or retaining new material[16]. It may be proactive or retroactive. Proactive interference occurs when the new information is not consistent with what we already know. The most pernicious example of this is in stereotyping. New information that does not fit our preconceptions of a group of people is easily forgotten. Retroactive interference occurs when new information interferes with what we had already learned. This appears to be true only when the new information is similar to the first. People were shown the film of an automobile accident, then asked to estimate the speed of the red car when the two cars collided (35 mph) or when the red car crashed into the white car (47 mph).

Memory Access: Being able to retrieve information from memory when it is needed is usually the most difficult part of the learning cycle. We have all had tip-of-the-tongue experiences in which we were unable to access information we knew we possessed.

Memories are organized into categories, hierarchies, and/or schemas. The items in a group are linked in a complex network with the most similar items linked most directly and less similar items linked through intermediaries. Groups are, in turn, linked into networks. The situation is complicated by the observation that an item is often linked into multiple groups. (Interferon can be categorized via inhibition of viruses, control of helper T cell development, control of induction of immune responses, cytokines produced by T cells, etc.) Using schemas or categories to organize new information also lets us extract additional information from it by drawing inferences based on our knowledge of the category or schema. Accessing memories seems to be a matter of activating the appropriate networks[11], and the richer the associations, the more easily the memories are recalled. Access through recognition (identifying a picture of an eighth grade classmate) is much easier than direct recall (remembering the name during a discussion) because recognition automatically triggers multiple associations.

The initial stages of learning a field is more difficult because the categories/schemas are sparsely populated, so extensive associations are not possible. A major part of the difference between a novice and an expert is simply the richer association network available to the expert. Each person organizes the information uniquely; e.g., experts not only organized information differently from novices, they also organize it differently from other experts[17]. They may even activate different configurations of networks depending on how the information is to be used; e.g., diagnosis vs. explaining the underlying pathology[18]. The formation of these rich associations seems to be what is happening during the consolidation phase of learning.

The context in which the information is learned also plays a role in its accessibility. This suggests we should train students, as much as practicable, in contexts similar to those in which the information is to be used[2]. Carried to extreme, context specific training leads to the inability to transfer the knowledge to other clinical settings. Thus, students must also be helped to recognize the similarities in problems beyond the surface characteristics, so strategies previously found to be successful in one context can be applied to the new problem[2,19].

Multiple intelligences:

Gardner[3,4] postulated that there are seven, largely independent, types of intelligence. He defines intelligence as “a biological and psychological *potential*; that potential is capable of being realized to a greater or lesser extent as a consequence of the experiential, cultural, and motivational factors that affect a person.”[20] Children as young as four years old already exhibit a range of different types of intelligence. Of course, most people are strong in two or three, weak in two or three and average in the others. Statistically, it is only the rare individual who is equally strong in all types or who has only one very dominant type.

The types of intelligence and their characteristics are listed in the table below.

Intelligence type	**Characteristics**
Verbal-linguistic	Sensitive to the meanings of words and the subtle shades of meaning between them. Master of syntax, semantics, and phonology. Enjoys word play, puns, and rhymes.
Logical-mathematical	Likes dealing with abstraction. Facile at understanding and manipulating symbols and appreciates the relationships among them. Good at discovering and applying analogies. For scientists, as opposed to mathematicians, a concern with discovery of unifying principles which apply to the real world. (Not necessarily connected with facility in computation.)
Visual/Spatial	Capacities to perceive the visual world accurately, to perform transformations and modifications upon one’s initial perceptions, and to re-create aspects of one’s visual experience.
Bodily-kinesthetic	Ability to control movements for functional [skiing] or expressive [mime] purposes. Skill in manipulating objects [sculptor].
Musical	Acutely aware of tone, rhythms, timbre [characteristic qualities of a tone], and larger musical patterns. Intuitive understanding of how music expresses or influences emotions.
Interpersonal	Good intuitive understanding of other people’s moods, temperament, motivations, and intentions. Skilled at influencing individual and group behavior. Usually well developed in political and religious leaders.
Intrapersonal	Ready access to and ability to differentiate among one’s own feelings and emotions. Ability to draw on them to guide one’s own behavior.

Subsequent research supports the validity of the intelligence types across cultures, age groups, and sexes[20]. It has been widely and productively used in education, particularly in K-12[4]. Biologically, each intelligence corresponds to a separate functional module.

- verbal-linguistic – left temporal lobe and Brocca's area
- mathematical/logical – right frontal lobe
- musical – right frontal and temporal lobes
- spatial, right frontal lobe
- kinesthetic – motor cortex
- interpersonal – under side of frontal cortex just above the eyes,
- intrapersonal – left temporal lobe. [A module in the left temporal lobe controls feelings of self-hood, but other areas may also be involved in sensitivity to one's own feelings.]

Educational Theory/Learning Styles:

Research shows that students learn best when their preferred learning style is matched by appropriate teaching methods, although the correlation is not very high[21]. Thus, a better understanding of what constitutes intelligence and how people learn should lead to improved conceptual bases for constructing curricula and selecting teaching methodologies. These, in turn, should result in "better" learning on the part of the student.

Learning-style theory attempts to understand how people screen and process the overwhelming volume of information available to which they are exposed. Many learning theories have been proposed over the last three decades, and each has been used in constructing courses in classes ranging from K-16. Some of the most widely used include *field dependence/independence, 4mat system, analytic/non-analytic conceptualization, hemispheric preference, Felder-Silverman Learning Style Method, Mastery Learning,* and Kolb's *Experiential Learning Theory*.

Kolb's Experiential Learning Theory[5] has the best experimental support for improved learning outcomes when a student's learning style is matched by the appropriate teaching methods[22]. He suggested that learning involves a cycle of four discrete steps: 1) Concrete experience leads to 2) reflective observation on that experience, followed by the 3) development of theory through abstract conceptualization. The theory is then tested by 4) active experimentation that generates new experiences. [Stage 2 may be connected to the consolidation phase of memory formation.]

Kolb proposes there are two dimensions of how people deal with the new information. The two poles of the first dimension are abstract versus concrete reasoning. The other dimension consists of reflective versus active processing. If these two continua are placed at right angles, the quadrants represent the combinations of strength in these two dimensions [Figure 1] that represents their learning style. Although everyone goes through the cycle as they learn new material, people are most comfortable with and extract the most information from the phases that correspond to their preferred learning style.

A few studies have correlated Kolb's learning styles with teaching methods and learning outcomes in medicine. First year medical students' learning styles significantly influenced development of their patient interviewing skills[23]. The different learning styles of faculty and residents in a pediatrics department of a public medical center led to less efficient learning since an instructor tends to teach using methods that would appeal to his personal style[24].

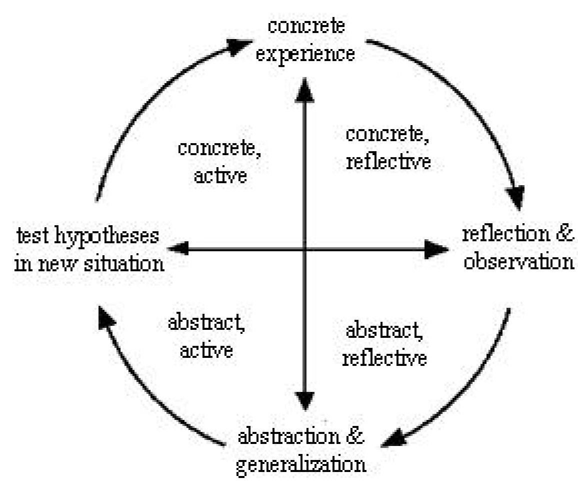

Figure 1: Kolb's Experiential Learning Cycle

It is well to end this section with a caveat. Not all material can or should be taught using all the learning styles [of whatever theory] or to appeal to all types of intelligence. For example, combining Kolb's four learning styles with Gardner's seven intelligences yields 28 potential categories with which the instructor must deal. However, this is ameliorated by the fact that most students, particularly those as bright as medical students, have several (but not all) intellectual strengths and can use more than one style. Thus if one keeps in mind the multiple learning styles and types of intelligence when designing a course, one can consciously include several approaches and modalities which should reach the vast majority of the students.

Implications for Medical Education:

All of the above considerations support the general concept that has been known and used by good teachers since time immemorial – students learn best when they are actively engaged by material that is presented in a variety of ways and formats[27]. How can the instructor or curriculum committee use these insights to design a course or curriculum that more effectively prepares students to diagnose and care for patients?

GENERAL CONSIDERATIONS: Teaching strategies must take into account all three aspects of learning: memory formation, maintenance, and retrieval or access. The course must be structured to catch and keep the student's attention, minimize retroactive interference and deal with potential proactive interference, and provide guidance in forming associations while allowing for consolidation of newly formed memories. Multiple intelligences and learning theory probably function mostly at the latter stage by facilitating the rich associations needed for easy retrieval.

Acquisition: Recognition of the fact that the material to be learned must capture the students' attention leads to the conclusion that appealing design of the material is not just a nice touch, but rather is the first critical step in the students' learning the material. The use of color, graphics, white space, fonts, layout, etc. in printed material keeps the student focused on the material. Similarly, the use of multimedia in the form of slides, interactive computer applications, sound, music, etc. all serve to keep the student engaged. Surveys of students using the *Essentials of Physiology* computer-based application (Gold Standard Multimedia, www.gsm.com) report students spend longer lengths of time at the computer than they do studying the same material from the printed syllabus (T. Nosek, personal communication).

Interference: Proactive interference is probably more of a problem than retroactive interference in medical education. During their undergraduate education, students may have learned information from animal studies that does not apply to humans. Unless the instructor makes a point of emphasizing the difference, the old material may interfere with retention of the human specific information. Retroactive interference can come from students being exposed to different approaches to material that overlaps two or more courses. Information from the subsequent course may interfere with retention of some subtle distinctions made earlier.

Retrieval: Retrieval, whether recall or recognition, involves activation of association networks. Thus, the presentation should aid students both in forming connections among new concepts, examples, and concrete experiences and in developing rich connections between the network of new material and networks of what is already known[19].

Since new information is organized into hierarchies, categories and/or schemas, the material should be organized to help students recognize appropriate groups in which to include the new material. Some experiments have shown that prototype examples are an important component of how people organize categories. The category into which new information is placed depends, in part, on how closely it matches the prototype[13]. The use of concrete examples provides prototypes for a new category or makes it easy to compare to existing prototypes. Thus, simplified clinical cases in the basic sciences are not just to show the students that they will eventually need this information. They provide guidance as to how the students can organize the material.

Multiple intelligences: Gardner[20] cautions that the intelligences themselves are not the same as learning styles. That does not mean that they do not have important implications for course design. Since almost all students have several intellectual strengths and others they use adequately, all students benefit from having material structured such that they can use more than one type of intelligence in trying to understand it. It helps them to form the rich association networks so important in retrieving the information when it is needed.

As educators, we too often focus on trying to correct our students' defects rather than building on their strengths. As sports coaches have long known, using a player's strong points is often the most effective means of overcoming, or at least ameliorating, deficits. If material is presented such that a student can use several intelligences to process the information, major understanding will come via his or her strongest intelligences. However, the understanding will be supplemented and enhanced via insights gained through lesser intelligences. In addition, to the multilevel understanding gained, the student learns to trust other ways of information gathering/processing. The latter encourages him/her to use these intelligences in other situations.

Learning theory: It is a natural tendency for instructors to present the lesson/course via structures and modalities by which they would find it easiest to understand. That is fine for those students who share the same intellectual strengths and learning styles, but makes it difficult for those with different preferences. If the material is structured such that it leads students through all four phases of the learning cycle, it provides each of them with the opportunity to deal with the material using the style by which he or she gains the most information.

The third phase of the learning cycle, abstraction and generalization, is the key to dealing with ability to transfer information learned in one context to application in a different setting. Two approaches help students in this phase of learning[19]. 1) The material must be structured so students have the opportunity to “manipulate” the material in a variety of ways, to build on it, and incorporate it into multiple categories and schemas. 2) Information must be used repeatedly in a variety of problems and situations. Students must be required to retrieve and use the information in contexts similar to that in which it will commonly be used and in novel or unexpected situations. For example, information about control of the immune response could be the key concept in a discussion of a case of a child with a suspected immune deficiency. The same knowledge is also necessary in interpreting an epidemiological review of the incidence of cancers in people living near high power transmission lines. We have seen that this facilitates formation of the rich association networks needed to be able to retrieve and apply information in a context independent manner.

Computers in Education: Computers are tools to implement instructional strategies not a technique in themselves[25]. It is essentially a waste of resources to use computers in situations where the unique capabilities of the computer are not employed. Handouts are more easily portable and do not require a power source.

Shank and Cleary[26] have shown that computers can be a powerful tool in reaching students with a variety of learning styles. The ability of computers to combine words [written or spoken], pictures, animation, interactivity, and online communication appeals to verbal, visual/spatial, kinesthetic, and interpersonal strengths. In addition, the self-paced nature of computer-based applications and the use of hypertext to find individual paths through the material are important aspects of learner control that is important in retention and student satisfaction[27].

The best computer based applications make it possible for students to learn the material 1) at their own time and pace and 2) in the order that makes the most sense to them. They 3) incorporate approaches and materials that appeal to a variety of cognitive strengths and learning styles and 4) use the unique capabilities of the computer. These will be discussed in the context of the teaching methods described below.

The most important variable influencing student use of computer-based instructional materials is the comfort level of the instructor with computers[25]. If he or she has found the computer useful, even indispensable, in his or her work, students will pick up on that and use the resource accordingly. Instructors who use computers in their other work are also more likely to integrate the computer in the course rather than simply adding it on to one that was developed without considering the use of computers.

LECTURES: Traditional lectures do have a place in well-designed curricula. They are very efficient of the teacher’s time, indicate what the teacher thinks are the key points, and provide students with a structure for learning that material. They appeal to those with strong verbal/linguistic skills. When combined with slides or figures drawn on the blackboard, they also accommodate those with strong visual/spatial intelligence. Most medical students fall into these two classes simply because they probably would not have had the grades to get into medical school otherwise.

However, the effectiveness of lectures alone is limited because students are passive recipients of information rather than actively engaging it. Lectures discourage curiosity by limiting the student’s ability and incentive to explore areas of interest not directly covered. Perhaps most importantly, lectures do not address the development of higher order cognitive skills.

Computers can enormously expand the potential of the lecture. They can show any combination of text, sound, tables, full color pictures, graphics, and animations. This serves to both keep the students' attention and allow them to process the information via multiple intelligences. Good design dictates that the use of the computer's capabilities must serve specific purposes. For example, elaborate text animation, dissolves between slides, and complex backgrounds on PowerPoint (or other) presentations can easily become distracting. On the other end of the spectrum, an entire lecture using slides containing only text would probably be more effective using handouts and the chalkboard.

The lecturer needs to also be aware of the need to process the information and allow for preliminary consolidation. Break the lecture up by requesting questions and asking the class questions. (Rule of thumb – pause three seconds before answering a question to allow time for the students to process the question.) Take a minute in the middle of the lecture to have the students write down the main points covered so far. Four, one-hour lectures during the week allows more time for abstraction/generalization and consolidation than two, two-hour lectures.

Computers can also supplement the lecture outside of class. They can make visual material used in the lecture available to students. Communication via a class bulletin board encourages students to reflect on the material and interact with other students and the instructor without the constraints of place and time. It allows shy students or those with poor English skills time to formulate their inquiries or comments. Email access to the instructor has the same advantages but is more private.

CASE-BASED LEARNING: A number of themes characterize the best case-based learning[25].

1) Learning is an active process in which students reconceptualize both the new material and old information by forming new mental maps: – Case-based problems force students to actively engage the material, to reflect on it, form hypotheses, and test the hypotheses by obtaining additional information; i.e., go through Kolb's learning cycle. The extent of reconceptualization and mental map formation that occurs depends on the care with which the cases are developed.

2) Conceptual understanding is at least as important as knowledge of processes: – Cases are generally chosen to illustrate critical concepts. Active engagement and discussion reinforces understanding.

3) Connect the information to information from other classes and to the larger world outside the classroom: – One definition of a realistic case is how well it matches the context in which the students will actually use the new information. Thus, when they see a patient for whom particular basic science material is relevant, they will more easily recall the relevant material because the associations formed when they first learned it are triggered by the actual patient.

4) Help students recognize that they have developed a number of learning strategies and techniques that can be applied with different efficiency in various situations or different types of material: – Even a moderately complicated case encourages the students to employ several strategies and intellectual strengths. The reporting and debriefing period can include evaluation of strategies used, sources of information, method of presentation of information to other group members, etc. Tennyson[27] showed that problem-oriented, computer-based simulations support development of higher-order thinking strategies.

5) Incorporate self-directed learning to prepare students to become life-long learners: – This can be accomplished by requiring students to find the relevant material from a variety of sources.

Depending on how the case is presented; e.g., inclusion of graphs, pictures, micrographs, radiograms, etc., students may use verbal/linguistic, logical, visual/spatial, interpersonal, and intrapersonal skills and strengths. Also by following the false clues and blind alleys, students learn which approaches are less likely to be productive.

Computers are a natural medium for presentations of case modules. Information can be available to the student "on demand." The program can keep track of the information requested and provide feedback whether the requested "lab test" was appropriate and how much it cost. Appropriately constructed cases can let student groups work almost autonomously, if groups are assigned cases with each student responsible for a portion of a structured written report. Applications are available and in development that provide "virtual patients" with which the student can interact.

DRILL AND PRACTICE: Some material simply must be memorized. The names of RNA vs. DNA viruses do not have any logical basis, but it is important for the physician to know which is which. Similarly, communication among surgeons in the operating room depends on their knowledge of the names of the various nerves and muscles. Learning theory provides support for practices developed long before writing. Music and rhythm does aid in recall. (How many children have learned the alphabet and even the names of the presidents or states with the aid of simple tunes? Sesame Street even animates the letters.) Computers have served as expensive, automated flash cards to help students review. However, if one added music/rhythm/rhymes to the program; e.g., the bouncing ball effect used in movies years ago, it could make computers much more effective as learning aids.

Students do find test banks helpful in checking their progress and preparing for class exams or boards. Test questions become a powerful teaching tool when the answers are annotated. Computers handle this task much better than books because it is feasible to annotate each answer. Often the instructor knows the conceptual mistake involved in certain wrong answers and can correct it immediately. The question can also be linked to didactic material for students who are really at a loss about the information.

Conclusions:

Learning is a multi-step process: acquisition, retention, retrieval. The most difficult part of the process is retrieval. Not only retrieval of information but also the ability to apply it in novel situations is facilitated by structuring courses to let students gather and process information via multiple intelligences and a variety of learning theories. Lectures, independent study, memorization, and case-based instruction can all benefit from application of these cognitive principles. Among the instructional techniques, case-based learning satisfies more of the criteria for effective learning, so we should support an increase in its use in our curricula.

Our goals as educators are to graduate physicians who are competent to care for patients and who will maintain their skills through self-directed, life-long learning. Courses and curricula developed using principles derived from the cognitive sciences facilitate students' achieving this standard.

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