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Learning Sciences Perspective on Engineering of Distance Learning. Part 1

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Abstract. There is an on-going debate in the literature on theoretical underpinnings of distance learning. Scholars consider different theoretical perspectives including but not limited to theory of independence and autonomy, theory of industrialization, and theory of interaction and communication through the lens of a traditional Learning Theory approach. There is a lack of discussion on a potential role of a newly emerging field of Learning Sciences in framing the theory of distance learning. Thus, in this paper we provide a theoretical analysis of the Learning Sciences as a new approach to understand distance learning in the era of Information and Communication Technology (ICT). Learning sciences is an interdisciplinary field that studies teaching and learning. This emerging innovative field includes but is not limited to multiple disciplines such as cognitive science, educational psychology, anthropology, computer science, to name a few. The Learning Sciences' major objective is to understand and design effective learning environments, including distance learning, based on the latest findings about the processes involved in human learning.

Keywords: Distance learning, Learning sciences, Constructivism, Constructionism, Connectivism, 'Engineering of learning' paradigm

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Дистанционное обучение с позиции наук об учении. Часть 1

Научная статья
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Аннотация. *В литературе продолжаются дискуссии о концептуальных основаниях дистанционного обучения. Учёные рассматривают различные теоретические точки зрения, включая, помимо прочего, теорию независимости и автономии, теорию индустриализации и теорию взаимодействия и коммуникации, через призму традиционного подхода к теории обучения. Отсутствует обсуждение потенциальной роли недавно появившейся области – науки об учении (Learning Sciences) – в формировании теории дистанционного обучения. Таким образом, в этой статье мы предлагаем теоретический анализ направления наук об учении как нового подхода к пониманию дистанционного обучения в эпоху информационных и коммуникационных технологий (ИКТ). Эта инновационная область, изучающая преподавание и учение, включает, среди прочих, несколько дисциплин, таких как когнитивная наука, педагогическая психология, антропология, информатика и многие другие. Основная цель Learning Sciences – изучение и разработка эффективной обучающей среды, включая дистанционное обучение, на основе последних данных о процессах, связанных с тем, как человек познаёт и учится.*

Ключевые слова: *дистанционное обучение, науки об учении, конструктивизм, конструкционизм, коннективизм*

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Introduction

The society is experiencing truly revolutionary changes due to the intensive implementation of new digital technologies that provide unprecedented democratization of knowledge and access to open education. According to some estimates, millions of personal computers and other mobile devices (tablets and cell phones) are now connected to the global network. We are witnessing the formation of a new phenomenon – a virtual learning community, which now includes more than a billion users. The number continues to grow. Along with the trend, the market of distance learning services is steadily increasing, which requires rethinking of traditional teaching and understanding of learning in digital environment. Expansion of these services necessitates training of "online" educators who are capable of analyzing information resources, designing distance courses, and constructing effective learning experiences and environments. Many universities around the globe have established consortia and special platforms to design and offer the MOOCs (massive open online courses) to develop new instrumentation systems in order to support distance learning, to create databases of multimedia lectures, online courses, e-books, digital libraries, etc. Along with the transfer of university disciplines, including teacher education courses, to the distance learning format, there is a need to revisit the training of school teachers. Instead of the traditional teacher training, the focus is shifting toward a new type of training for teachers who can work in the digital age, with high demands on teachers' knowledge and ability to engineer an effective online learning. Moreover, in the digital era a teacher is not just an online tutor, she becomes an analyst and manager of informational resources, a designer and a constructor of courses, modules, and lesson fragments using interactive multimedia tools.

Under these circumstances, use of the traditional Learning Theory does not provide an in-depth understanding of learning and teaching in digital environment. Moreover, the phenomenon of distance learning is a relatively new landscape which requires a solid theoretical foundation to build cutting-edge research methodologies, analyze data and interpret findings.

Why theoretical foundation is important? The need for theoretical underpinnings to study emerging phenomenon is outlined by Herek [1] and includes the following main elements: critically evaluating prior research and connecting to existing knowledge; building a basis for formulating hypotheses and providing a choice for selection of research methods: generalizing various aspects of the phenomenon under research and identifying the limitations of the study; specifying key variables that influence the phenomenon under different circumstances.

Analyzing theoretical underpinnings of distance learning, Anderson and Dron [2] claim that three approaches, namely cognitive behaviourism, social constructivism and connectivism closely influenced understanding the phenomenon of distance learning. Whereas cognitive-behaviorist approach attempts to explain the first generation of individualized distance learning (e.g. correspondence education), social-constructivism and connectivism aim at understanding learning as a socially enacted process. The difference between the social-constructivism and connectivism according to Siemens [3] is in understanding how learning takes place: connectivism claims that learning can reside outside of an individual (e.g., within a social network) through connection to specialized information sets which enables an individual to advance his/her current state of knowing.

Additionally, scholars proposed other theories to explain the phenomenon of distance learning such as the theory of independence and autonomy (Simonson et al.) [4] with emphasis on independent study, self-directed learning and self-regulation (Gunawardena & McIsaac) [5]; theory of industrialization (Peters) [6] with its view of distance learning as an industrial production of goods; theory of interaction and communication (Holmberg) [7].

In last two decades, scholars intensively seek for a theoretical underpinnings of the distance learning [2–4; 8–10]. However, there is a lack of discussion in literature on a potential role of a newly emerging field of Learning Sciences in framing the theory of distance learning. The Learning Sciences deserve a theoretical discourse as an emerging approach to understand distance learning in the ICT era as "an interdisciplinary field that studies teaching and learning" [11] based on the advancement in cognitive science, educational psychology, anthropology, computer science, didactics, etc. The Learning Sciences' major objective is to understand and design effective learning environments in different settings, contexts and formats.

The paper consists of several parts. First, we discuss the emergence of the Learning Sciences through the lens of guiding principles of learning. Then, we support these principles with research-based strategies of learning. Further, we discuss recent developments in two leading theories of the Learning Sciences: Constructivism and Constructionism as well as an emerging branch of Constructivism – Connectivism. Finally, we conclude the paper with discussion.

Emergence of Learning Sciences

During the last two decades the learning sciences scholars significantly advanced the research in learning theories. Within half-a-decade, the U.S. National Research Council published two major studies – "How People Learn" [12] and "How Students Learn" [13] with a focus "on three fundamental and well-established principles of learning":

1) building on students' prior knowledge;

2) connecting students' factual knowledge and conceptual understanding;

3) involving students in meta-cognitive and self-monitoring activities.

Let us briefly discuss each of the above principles.

Principle 1. In addressing students' prior knowledge, we are trying to gauge and record students' understanding of previously learned facts, concepts and procedures that would help them to learn new material. "Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for the purposes of a test but revert to their preconceptions outside the classroom" [13]. Based on the first principle, it is of major importance to continually make links between students' experiences outside the classroom/auditorium (e.g., everyday informal experiential out-of-school/college knowledge) and inside the school/college and classroom/auditorium (e.g., academic knowledge).

Building on prior knowledge requires considering certain sequences, for instance, while introducing a new topic it is helpful to start with an activity to assess students' preconceptions and keep building on students' prior understanding and experiences. How can we best do this? One way is to use a powerful instructional strategy – the "bridging context". The bridging context is a context that serves to connect student's experiences through multiple representations, for example, numeric (equations) and spatial (graphical) understandings and to link their everyday experiences to material taught. Another possibility is to engage students' everyday experiential knowledge. The experiential knowledge is a knowledge that students learn through their practical experience. Using the language strategically and as a link to more formal language use is another way to build on students' prior knowledge. Not all problems, tasks, statements should be phrased in the "student language". It is important for students to learn formal terminology and abstract symbolism. However, using the student language is a way of assessing students' knowledge on particular topic and then build on what they already know to guide them toward deeper understanding and use of formal language.

Summarizing, the first guiding principle suggests that students' prior knowledge acts as a building block for the development of more sophisticated ways of thinking. Topics and activities presumed to be challenging and difficult for students may in fact have intuitive or experiential underpinnings, and it is important to discover these and use them for formalizing student's thinking [13].

Principle 2. This principle suggests the importance of both conceptual understanding and procedural fluency, as well as an effective organization of knowledge that facilitates strategy development and adaptive reasoning [13]. In order to implement this principle in a classroom/auditorium, a teacher/instructor needs to recognize and address the following main strategies.

Developing Students' Knowledge Networks. This strategy requires a close link between procedural knowledge and conceptual understanding. The network of knowledge must include both new concepts and procedures. To teach in a way that supports both conceptual understanding and procedural fluency requires that the primary concepts underlying a subject domain be clear to the teacher or become clear during the process of teaching for proficiency. Due to the fact that some subjects, including mathematics – for instance, have traditionally been taught with an emphasis on the procedure, the teachers who were taught this way might initially have difficulty identifying or using the core conceptual understandings in a subject domain. Therefore, teacher training with the focus on these guiding principles is the key component of effective implementation of principles in the classroom.

Addressing Students' Learning Paths. The above networks of knowledge could be often organized as *learning paths* from informal concrete methods to abbreviated, more general, and abstract methods. The knowledge of student learning paths and knowledge networks helps teachers to direct student learning along productive lines toward valued knowledge networks. The research on learning has uncovered important information on typical learning paths and knowledge networks involved in acquiring knowledge about a variety of concepts [13]. As teachers guide students through learning paths, a balance must be maintained between learner-centered and knowledge-centered needs. The learning path of the class/group must also continually relate to individual learner knowledge.

Using Multiple Methods. The discussion of multiple methods in the classroom – drawing attention to why different methods work and to the relative efficiency and reliability of each – can help to provide a conceptual ladder that helps the students to move in a connected way from where they are to a more efficient and abstract approach [13]. This view of learning which involves different methods does not mean that a teacher or a curriculum must offer multiple methods for every domain. Alternative methods might frequently arise in the classroom, either because students bring them from their prior experiences or because students think differently about problems to be solved. Frequently, there are viable alternative methods for solving a problem, discussing advantages and disadvantages of each can facilitate flexibility and deeper understanding.

Principle 3. This principle is concerned with a way to make student's thinking visible in a learning process. Metacognition is considered to be one of the key approaches to promote student's thinking about their learning. "Learning about oneself as a learner, thinker, and problem solver is an important aspect of metacognition" [13, p. 236].

The metacognition principle suggests the following instructional strategies to support students' self-monitoring activities: involving students in debugging errors, engaging students in external and internal dialogue, and encouraging students to seek and offer help in challenging learning situations.

Debugging Errors. The National Research Council strongly recommends to facilitate students' metacognitive activities by "shifting from a focus on answers as just right or wrong to a more detailed focus on "debugging" a wrong answer, that is, finding where the error is, why it is an error, and correcting it" [13, p. 239]. Traditionally, debugging errors was primarily the teacher's activity: the teacher would grade the student's work, find errors, and report them to students along with the grade. Debugging errors should be shifted to students. Students should develop critical skills to recognize an error, identify it, locate the source of an error, fix it and check the solution for correctness.

Internal and External Dialogue. Communication is an important process that enriches student learning. The classroom culture should be built around meaningful content-focused communication and discourse whether it is a reflection on student's own learning and thinking (internal dialogue) or discussion with peers on comparing and contrasting different methods of problem solving (external dialogue). "Of course, teachers must help students to interact fruitfully" [13, p. 241] through modeling good questioning techniques, providing support structure for student learning, creating an atmosphere of subject-specific communication and collaboration.

Seeking and Offering Help. Teacher's acceptance of challenge translates to student productive attitude toward problem solving (Valverde & Tchoshanov) [14]. Therefore, it is critically important to encourage teachers to help students to be independent problem solvers and actively seek for information or assistance when they face a challenging problem. "Students must have enough confidence not only to engage with problems and try to solve them, but also to seek help when they are stuck" [13, p. 241]. At the same time, working in groups in solving challenging problems might facilitate the environment where students can collaboratively offer help to each other in "tough" situations. "Such helping can also increase the metacognitive awareness of the helper as he or she takes into consideration the thinking of the student being helped" [13, p. 242].

Along with the guiding principles of learning, it is important to consider advances of brain-compatible research in education to support student learning. In the last couple of decades, studies of neuropsychological basis of the learning processes are steadily growing as evidenced by the variety of subject domains involved and a number of papers published during this period [15–18]. That is why the decade of the 1990-ies was called the "decade of brain". One of the interesting challenges is the problem of adapting the advances in neuropsychology and brain research to teaching.

The traditional popular image of the distinction between the functions of the left and right hemispheres is still strong among practitioners and some scholars, particularly, the fact that the left hemisphere is a domain of languages, numbers, logic, analysis, and the right hemisphere is a domain of images, shapes, intuition, synthesis, etc. However, in the light of modern advances in brain research, this view occurs to be limited and incomplete (Posner and Raichle) [19]. Still there are scholars who use these outdated ideas to propose teacher training on brain-based education [20; 21]. For instance, for the development of the left hemisphere functions, Sousa [21] suggests using different methods of reading, writing, and arithmetic. The development of students' imaginative right hemisphere, according to the same author, requires intensive use of visualization strategies.

In part, this distribution of functions between the hemispheres is based on the structure of the human brain. This simplification cannot be abused and overgeneralized. In fact, the brain functions as a whole and performs certain tasks (verbal or visual) in conjunction with the neural structures located in both left and right hemispheres of the brain. Posner and Raichle [19] used the following example to study the human brain in the process of solving basic visual spatial problems: "Specify the location of the given two points based on the questions below:

- which point is located higher than the other one?
- is the distance between the points greater than 1 meter?"

According to the traditional theory, it is a typical "right-brain" problem. However, the experiment showed that the first part of the task is dealing with the categorical spatial reasoning and mostly carried out by active zones of the left hemisphere of the brain, and the second part of the task, directed by interposition of objects, stimulated the neuron populations of the right hemisphere. Moreover, the study showed that the left hemisphere of the human brain may do as good job as the right one in "solving" visual spatial tasks. Based on the results of the study, Posner and Raichle [19] also claim that the traditional opinion on creative thinking as a function of the right hemisphere of the human brain is inaccurate.

Another revealing example: in accordance with the traditional theory, the elementary school task "What is greater 2 or 5?" is a left-hemispheric arithmetic task. However, research conducted by Dehaene [18] suggests that in dealing with such problems the human brain functions as a bilingual learner: it "speaks" descriptive language when we say the names of the numbers "two" and "five" and it "speaks" numeric language when we use the symbolic representation of "2" and "5". In the first case, the areas of the left hemisphere are activated, and in the second case – neuronal populations of both hemispheres of the human brain are engaged.

These examples show that depending on the specific conditions of the task, whether it is verbal or numeric, arithmetic or visual, different areas of the hemispheres could be involved in solving the problem. The distinct separation of functions of the right and left hemispheres of the brain is one of the examples of the "myths" that was debunked by the advanced research in the field during "the decade of brain".

The next myth is the scientific cooperation in the study of the brain among neuroscientists and psychologists. For a certain period of time, two seemingly related branches of the scientific knowledge – neuropsychology (the science of brain) and psychology (in this particular case, cognitive science) – have evolved quite separately. Neuropsychology, to put it in computer terms, explored the "hardware" (structure and function) of the brain, whereas psychology independently studied the "software" of the brain (mental mechanisms of cognitive activity). Meanwhile, the educational scholars attempted to use fragmentarily the results of each of the disciplines as a scientific basis for interpretation of the learning process. Only by the end of the XX century researchers managed to merge the advances of these disciplines in integrative brain-compatible education (Bruer) [15]. The emergence of the combined field made it obvious that most of the previous attempts were nothing but the application of a simplified version of neuropsychology achievements to understanding of learning. At the same time, this approach brought forward an opportunity to formulate a set of principles about brain functioning during the learning process in traditional face-to-face and online learning. This set includes the following principles [22; 23].

Brain is a parallel processor. The human brain is able to perform multiple functions simultaneously. Thinking, emotions, imagination, and other complex processes may occur in the brain at the same time, along with the mechanisms of information processing and socio-cultural interaction (communication) with other people. Based on this principle, the teacher could provide opportunities for the involvement of students in a variety of content and learning activities using different teaching methods and techniques.

Learning is a natural mechanism for the development of brain. Learning is as natural for a human body, in general, and for a human brain, in particular, as respiration. Nature has endowed a human brain as capable of learning and, therefore, curiosity and desire for knowledge are key intellectual needs for brain development. Didactics as a science, engineering, and art of teaching and learning should provide conditions and environment to meet the critical intellectual needs.

Building on prior experience and the search for meaning are innate qualities of the human brain. Brain is always functioning in the communication mode between the previous experience and a new situation. Understanding and comprehension of the new situation occurs when the brain finds a support in the prior knowledge and ideas. Hence, it is critically important to engage students' prior experiences in order to acquire new knowledge (see Principle 1 above). This principle also supports the Vygotskian conception of the zone of proximal development (ZPD) – the distance between what a learner knows and what s/he could potentially learn with the help of "a more knowledgeable one" (Vygotsky) [24].

Brain looks for a pattern. Confusion and chaos complicate the productive functioning of a human brain. In any given situation, no matter how random it is, the brain "tries" to find patterns. The following task illustrates this principle – "You have a minute to memorize the given number 1123581321345589. After a minute write it down on a piece of paper." At the first glance, the task is meaningless because it seems to have no pattern. However, there is a hidden pattern. In mathematics, this numerical pattern is called the Fibonacci sequence where each successive number is the sum of the two preceding numbers. According to this principle, learning aimed at mere memorization is not productive for the brain development. At the same time, learning aimed at finding patterns is a good "food" for brain. In other words, learning is effective when a student's brain is developed by overcoming intellectual difficulties in searching for a pattern.

Emotion is a necessary factor in the brain development. Surprise, indignation, inspiration, a sense of beauty, and even a sense of humor, to name a few, are permanent "companions" in the process of productive functioning of a human brain. Neuropsychologists claim that emotion and cognition are inseparable. This principle emphasizes an obvious need for inclusion of the emotional background in the learning process via contradictions, paradoxical situations, elements of literature, poetry, music, humor, etc. regardless of the subject specific content, whether it is mathematics, history, language or any other discipline. Subjects learned in a supportive emotional atmosphere are better remembered and understood, as they have more stable relations with the corresponding emotional state. Moreover, the emotional factor stimulates thinking and creativity of the student.

Brain is capable to simultaneously analyze and synthesize an incoming information. The results of neuropsychological studies show that brain has a unique ability to "see" an object as a whole and "recognize" its parts. Brain can learn to divide and multiply at the same time. In other words, the execution of mutually inverse operations is another natural ability of the human brain. Analysis and synthesis are two important and constantly interacting cognitive processes in learning.

Learning aimed at developing students' analytical skills only, or as it is otherwise called – "learning by steps" blocks the natural potential of the learner's brain, its innate ability to simultaneously analyze and synthesize the information. The same is true about the so-called "holistic learning", which underestimates the development of students' analytical abilities. With this principle in mind, the learning materials should be presented in a constant interaction between the whole and a part, analysis and synthesis, induction and deduction, direct and inverse methods of solving problems.

Brain is able to operate simultaneously with a focused attention and peripheral perception. A human brain can absorb the information that lies not only in the immediate field of attention, but also beyond it. Thus, a student in the classroom (both physical and virtual) perceives teacher's words and sounds outside the classroom. In a well-organized classroom, a teacher can use the features of a student's peripheral perception as a constructive factor of learning. For example, producers and designers use the background music to enhance the context of the movie. At the same time, if this principle is ignored, the mechanism of peripheral perception could act as a destructive element in the learning process.

Conscious and subconscious processes in the learner's brain occur simultaneously. In a learning process, we receive a lot more information than we can imagine. It could be compared to an iceberg where the underwater part can be associated with the processes that occur in learning at a subconscious level. Peripheral signals (sounds, words, images, etc.) are often fed into brain "without permission" of our consciousness and submerge into the deepest layers of the subconscious. Reaching the subconscious, these signals can rise to the level of consciousness with a certain delay or indirectly act on the human mind from the inside through the inner motives, unconscious desires, feelings and states. In the learning process, this principle should be taken into account in conjunction with other neurophysiological principles. A student is impacted not only and not so much by what a teacher said but also by the full range of internal (prior experience, emotional state, level of motivation, individual characteristics, etc.) and external (atmosphere in the classroom, sound, light, etc.) factors of the learning environment.

Brain memorizes information at different levels: at the level of visual-spatial memory and rote memorization level. The first level is a more natural way of memorization. The second one produces high cognitive load. For example, we have no or little difficulty of restoring a picture of where and how we spent the previous evening. It does not require special ways of storing information, because it is located and coded in our visual-spatial memory system. This system is closely linked with the natural ability of human brain to sensibly perceive and encode the information. The second level is called a rote memorization and it provides us with invaluable assistance in cases when we need to remember isolated pieces of information such as certain dates, names, phone numbers, phrases, etc. The more information is disconnected from our previous knowledge the greater the cognitive load is. The disadvantage of this system is obvious: knowledge based on rote memorization is not stable and unproductive. In contrast, visual-spatial memory systematizes the information in a brain as in the library and keeps it organized and connected. In this case, one can easily store the information and quickly retrieve it. This implies the following sub-principle: brain understands and remembers best when information is "imprinted" into the visual-spatial memory (the principle of visualization).

Brain functioning is stimulated by freedom and creativity and suppressed by the atmosphere of coercion and threat. It is known that a creative persons cannot tolerate any violence on themselves or on others. Neuropsychologists believe that to become a creative person one should be led by another creative person, or a person who is able to create a learning environment that provides freedom for creativity. Some teachers in an

Table 1

Application of the brain-compatible principles in distance learning

Principles of Brain-Compatible Education	Application in Distance Learning
Brain is a parallel processor	Variability of teaching and learning methods Learning in small groups using breakout rooms Multiple representations and connections
Learning is a natural mechanism of brain development	Learning at an optimal level of complexity Use of discovery/inquiry learning Constructive learning experience
Building on prior experience and the search for meaning are innate qualities of human brain	Use of practical applications and real-life examples Interdisciplinary connections Problem-based learning
Brain looks for a pattern	Patterns and algebraic reasoning Proofs and refutations Use of counter-examples and contradictions
Emotion is a necessary factor in the brain development	Gamification strategies Use of aesthetic elements in learning Paradoxes, surprise situations, riddles
Brain is capable to simultaneously analyze and synthesize an incoming information	Use of inverse operations Inductive and deductive reasoning in problem solving Systemic thinking
Brain is able to operate simultaneously with a focused attention and peripheral perception	Creating productive and engaging online atmosphere Ergonomics Screencasting technique
Processes of conscious and subconscious in the learner's brain occur simultaneously	Build on previous knowledge and experience Individualized learning trajectories Students' self-monitoring
Brain memorizes information at different levels: at the level of visual – spatial memory and rote memorization level	Use of computer-based dynamic visualization Verbal, symbolic, numerical, visual and other forms of representation Virtual labs Cognitive maps
Brain functioning is stimulated by freedom and creativity and it is suppressed by the atmosphere of coercion and threat	Creative projects Cooperative learning using breakout rooms Use of creative thinking techniques (e.g., brainstorming)
Brain of every human is unique	Individualized learning trajectories Constructivism in learning Learner-centered pedagogy

effort to maintain strict discipline in the classroom could unconsciously suppress the atmosphere of creativity. Of course, this does not mean that the classroom management contradicts the development of students' creativity. Rather, a creative learning environment naturally eliminates an issue of discipline in the classroom.

The brain of every human is unique. The brain of each human being has its own individual characteristics in terms of information processing, predominance of certain system of memorization, flexibility of mental processes, etc. That is why every human being has his/her own individual style of learning, own unique understanding of the world, own original style of thinking. The task of a teacher is to maintain the uniqueness of each student via recognizing and supporting student's way of seeing, reasoning, and learning. This principle is particularly evident in the philosophy of constructivism (to be further discussed).

Application of the principles of the brain-compatible education in distance learning is presented in *Table 1*.

Neuropsychologists argue that education which is not supported by brain-based principles is "blind" [22; 23]. It could lead to weakening of the natural mechanisms of cognitive development. In this case, the recovery of these mechanisms or re-teaching will take longer than the process of "natural" learning consistent with the brain-compatible principles. The "decade of brain" is gradually transitioning into the "decade of mind", which provides educators with an ample opportunity to design face-to-face and online learning experiences and environments in accordance with the scientific mechanisms of brain's functioning.

Research-Based Strategies in Engineering of Distance Learning

Engineering of distance learning depends on many factors including but are not limited to the knowledge of Learning sciences that will inform outcome-oriented design of learning objectives, engineering of content, and assessment toward creating effective online learning environment. Along with the guiding principles of learning discussed earlier, Learning sciences inform a teacher/instructor about research-based strategies to support learning. Below we consider research-based strategies to address the guiding principles of learning in engaging students' prior knowledge, connecting factual knowledge and conceptual understanding, and fostering students' meta-cognitive and self-monitoring abilities.

Strategies to engage students' prior knowledge

In order to build on students' prior knowledge and experiences, a teacher should design and construct teaching products and select instructional materials according to the following strategies to ensure:

- right level of difficulty,
- signaling,
- varying content and complexity,
- contiguity,
- minimizing cognitive load.

Let us consider the strategy which suggests the use of learning materials at the right level of difficulty. The '*right level of difficulty*' means that the learning material should not be too easy or too complex. If the learning material is too easy, a student is not challenged enough. If the material is too complex, a student may give up. In both cases, student motivation, attention, and engagement will be significantly decreased [25–27]. The learning material should be at a level of the student's zone of proximal development (Vygotsky) [24], so that s/he could learn and understand new material with some support and scaffolding. The same strategy should be applied while designing assignments and assessments. Assignments should not be too difficult or too easy. The 'right level of difficulty' in case of assignments and assessments means that students cannot complete the assignment effortlessly. However, they can successfully complete it with some cognitive effort, support and/or scaffolding. If assignments/assessments are too difficult or too easy, students may get frustrated or bored [25].

Along with the right level of difficulty, before starting a lesson, a teacher-engineer should provide an overall structure and highlight the organization of the lesson. This strategy is called '*signaling*' and includes using outlines, section headings, bullets, which draw students' attention to the most important points in the lesson [28–30]. Moreover, the learning material should be presented in a way that the points that require attention are highlighted, trying to avoid irrelevant information (even if it might be artistically and aesthetically appealing). Appealing but irrelevant information (e.g., text and graphics) distracts students' attention and they could miss important points [31].

Opportunity to work on problems that *vary in content and complexity* will help students to develop multiple layers of knowledge including facts, procedures, concepts, and models, and to connect these layers [32; 33]. Moreover, a teacher-engineer should design a learning environment where students could work collectively on challenging, real-world problems. In a cooperative problem-solving activity, student's prior knowledge should be linked to challenging real-world problems, which will motivate student and facilitate learning by applying multiple levels of knowledge and skills [34–36].

The *contiguity* strategy suggests introducing closely in time and space the concepts and ideas that need to be connected. By implementing this strategy, a teacher-engineer will make associations stronger, for instance, when corresponding words and images are presented simultaneously rather than successively [30].

The '*minimizing cognitive load*' strategy recommends to divide complex learning material into smaller parts, thus students learn better. This strategy is increasingly important in designing materials for flipped instruction and other multimedia learning environments. While designing narrated screencasting or animation, a teacher-engineer should present it in segments rather than a single continuous unit, so that students could control it at their individual pace; this will help to avoid overwhelming students with too much information at once [30; 37].

Strategies to develop students' procedural fluency within the conceptual framework

The strategies to connect students' factual knowledge and conceptual understanding include but are not limited to:

- desirable difficulty,
- cognitive conflict,
- adaptive fading,
- in-depth questioning,
- multiple representations,
- engaging in reading and writing,
- generation strategy,
- timely constructive feedback.

The '*desirable difficulty*' strategy requires effortful cognitive processing by students in learning new knowledge. The learning material at the desirable level of difficulty will make it more memorable. Therefore, rather than introducing the learning material in the same order as it is in a textbook, a teacher-engineer should modify the material presentation to facilitate students' active information processing. Moreover, learning is enhanced when students put additional effort to organize the material themselves, which promotes long-term memorizing of information [38; 39]

The '*cognitive conflict*' strategy suggests that in-depth learning is often achieved by engaging students in problem solving situations that are non-routine, paradoxical, and/or counter-intuitive to their current knowledge. When students encounter situations that are in dissonance with their existing schemata, a cognitive conflict occurs that could lead to a conceptual change in student's learning and understanding. A teacher-engineer should design situations of cognitive conflict by presenting paradoxes, refutations, and/or asking students to predict an answer, knowing that students' responses would be most likely conflicting with the solution [40–43].

A teacher-engineer should alternate examples (that illustrate a solution) and problems (that students have to solve on their own). Illustrative examples are helpful for low-achieving students. Research shows that fading (or gradual elimination) of examples depending on student performance (*adaptive fading*) leads to better knowledge retention, compared to fading of examples in the same manner for all students (fixed fading) [31; 44–46].

Another research-based strategy in promoting student learning and understanding is an *in-depth explanatory questioning* technique. In-depth questions include cause-and-effect questions, 'why or why-not' questions, 'what-if' questions, etc. While using the in-depth questioning technique, a teacher-engineer should encourage students to 'think aloud' by speaking and/or writing their explanations to answer the questions [47–49].

The use of *multiple representations* (including concrete, abstract, graphical, descriptive) is an important strategy in building students' conceptual understanding. Most of low-achieving students may understand a concept with concrete examples using manipulatives. However, using only concrete representation will limit student learning. A teacher-engineer should gradually switch concrete examples into abstract representations (e.g. symbols, formulas, equations) to help students transfer knowledge to new situations. At the same time, a teacher-engineer should connect graphical representations (e.g., graphs, pictures, videos) with descriptive representations of a concept (rather than simply presenting the text alone) to support student learning. Following the recommendation of the contiguity strategy, graphics and accompanying textual description should be presented close in space and time [8; 30].

Research suggests that *involving students in reading and writing* is correlated with the improvement in students' critical thinking, complex reasoning and writing skills. Therefore, while designing a course, a teacher-engineer should include assignments in both intensive reading (more than forty pages per week) and writing (more than twenty pages per course) in the syllabus to increase student performance in critical thinking and writing [50]. Along with reading and writing, it is recommended to use quizzes frequently to re-expose students to key concepts in order to actively recall/generate information. This strategy is based on the generation effect reported by Butler and Roedinger [51] and others. It is also well documented that learning is enhanced, when students construct responses compared to selecting answers among multiple choices. Congruently, *timely feedback* provided after each quiz/test contributes to student learning and understanding of the material covered in the test [51–53]. At the same time, it is recommended that timely feedback with clear learning goals should be provided as a formative assessment with the purpose of improving student learning, as opposed to summative assessment with a focus on evaluation of what students have learned [25]. Timely constructive feedback (compared to delayed summative feedback) is important to student learning and significantly contributes to the improvement of students' performance on exams [25; 54–56].

Strategies to foster students' metacognition and self-monitoring

Below we will consider the research-based strategies that support students' metacognitive and self-monitoring activities:

- debugging misconceptions,
- active information processing,
- constant self-monitoring,
- mixed practice,
- spacing effect,
- goal-directed practice.

The *debugging misconceptions* strategy (briefly discussed earlier) helps a teacher to recognize, address, and correct students' common mistakes. In order to correct students' misconceptions, a teacher should create a bridge between the prior concept and the new one using meaningful examples and model-based reasoning. They could help students to construct new representations different from their initial intuitive conceptions and make them aware of their own misconceptions. Awareness is the first step in helping students to 'fix' their own misconceptions. Next is developing students' epistemological reasoning (beliefs about the nature of knowledge) in order to facilitate conceptual change for revising their own misconceptions. The research also suggests to engage students in Interactive Conceptual Instruction (ICI), which incorporates ongoing teacher-student dialogue and the use of research-based instruments to provide formative feedback, conceptual terrain of student learning including subject matter knowledge and possible misconceptions [57]. Once the students have overcome their misconceptions, the teacher-engineer should engage them in the 'arguing to learn' type of classroom discourses to help strengthen their new concept [57; 58].

An *active information processing* is another research-based recommendation to foster student metacognition and self-monitoring. Learning techniques such as outlining, connecting, and synthesizing information improve student performance (e.g., long-term retention) compared to rereading materials or using more passive techniques. Along with reorganizing and reviewing the material, students may create their own testing situations such as re-stating the information in their own words and synthesizing information from multiple sources (e.g., lecture notes, textbooks, web resources [12]. The research shows that students learn better when they verbally (rather than by typing) explain the material to themselves using self-generated inferences [59–63].

A teacher should constantly engage students in a variety of metacognitive activities to *monitor and control their own learning*, including but not limited to assessing the difficulty of the assigned task, evaluating their own strengths and weaknesses, planning their actions, self-monitoring their performance, and assessing the degree to which the task is complete. In order to be more effective, the results of self-monitoring should be shared with the teacher and the peers [25; 64–67].

The study by Smith and Vela [68] claims that when the material is studied in one environment, associations are established between what is studied and contextual factors, preventing the transfer of learning. Contrary, when the same material is studied in multiple environments, its associations with one or a few particular locations dissipates. This, in turn, facilitates students' flexible recall of the material in the new and different environments (Ibid). The strategy called '*mixed practice*', when the student solves problems related to different topics within the same study session, improves student learning compared to the 'blocked practice' where all problems are taken from the same topic (Rohrer) [69].

The research conducted by Capeda et al. [70], Kornell [71], and Rohrer [69] indicates that students learn better when they spread their study over several shorter practice sessions, rather than concentrate it into one longer session. The practice distributed over time results in better retention of material than cramming (Ibid). The *spacing effect* increases, if a student is engaged in the distributed practice that focuses on a specific goal. The *goal-directed practice* supported by the timely targeted feedback, promotes greater learning gains [25; 72; 73]. Finally, while designing a course, a teacher-engineer should make a schedule of course quizzes, tests and exams, because students benefit more from repeated testing when they expect exams rather than when exams are unexpected [74].

The above research-based strategies play an important role in the engineering of learning through designing engaged learning experiences and effective learning environments.

Conclusion

The market of online educational services has been steadily growing. With the purpose of expanding online services, the leading universities create the MOOC consortia (e.g., Coursera, Udacity, edX) to initiate special programs for supporting the design and delivery of online courses as well as the development of new tools for online learning systems. However, some skeptics claim that massive open online courses are not a panacea. The Gallup/ Inside Higher Ed conducted a survey of the presidents of several US universities involved in offering the MOOC. The major finding of this survey is that 54% of the participants somewhat disagree or are not sure whether MOOC foster creative pedagogical strategies. Moreover, 83% of the participants disagree or are not sure that the MOOC improve the learning of all students. Some colleges such as the Duke University and the Amherst College rejected proposals to join the MOOC consortia because the faculty does not see the benefits of the MOOC in improving student learning, in particular at the undergraduate level. The question is how to make sense of this skepticism? A possible answer may be that the speed at which colleges have embraced MOOCs has little to do with the readiness of the "MOOC industry" to offer high quality products. To do so a paradigm shift should occur: the shift from teaching to engineering of learning, which will foster creative pedagogical strategies to design and implement online courses (Tchoshanov) [75]. And, consequently, this shift develops an urgent need for developing theoretical underpinnings for the distance learning phenomenon which, in its turn, will help in conceptualizing the training of "online" educators who are able to design and deliver effective distance education. Instead of the traditional teacher training, the focus should shift toward a new type of training for teachers who can work in the digital age, with high demands on teachers' knowledge and ability to engineer an effective online learning.

The 'engineering of learning' paradigm places a critical emphasis on the development of teachers' engineering design thinking. The development of teacher-engineer's design thinking is a complex process based on the advancements of the Learning Sciences. It involves the design of learning objectives: to create outcome-based, technology-enhanced learning environments that enable students to set their own learning objectives, monitor and assess their learning progress. It includes the engineering of content: to develop interactive content and relevant learning experiences through the selection and design of tasks, problems, projects, and activities that incorporate digital tools and ICT resources to promote student learning and creativity. It also aims at the design of assessment: to select and develop authentic assessments aligned with the learning objectives and content, and to use assessment data to improve teaching and promote student learning.

In order to respond to the challenges of the digital age, the theoretical underpinnings of distance learning itself needs to be re-conceptualized. This re-conceptualization has a clearly defined vector – the Learning Sciences with its emphasis on understanding learning from a multidisciplinary perspective and design of effective online learning environments.

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