Online-Journals.org

iJOE International Journal of Online and Biomedical Engineering

iJOE | eISSN: 2626-8493 | Vol. 19 No. 14 (2023) | OPEN ACCESS

https://doi.org/10.3991/ijoe.v19i14.43163

PAPER

The Remote Experiment in the Light of the Learning Theories

Cornel Samoila[1,2], Doru Ursutiu[1,3](✉), Florin Munteanu[4]

[1]Transylvania University of Brasov, Brașov, Romania

[2]Technical Science Academy of Romania, Bucharest, Romania

[3]Romanian Academy of Scientists, Bucharest, Romania

[4]Complexity Studies – UNESCO Center, Brașov, Romania

ursutiu@unitbv.ro

ABSTRACT

The interference of technology in education requires the development of new theories of learning. The paper analyzes connectivism as the most important representative of the theories related to the "digital age." From the point of view of the environment, called a remote experiment, learning occurs initially at the individual level, encompassing all three classic theories of learning: behaviorism, cognitivism, and constructivism. It shows that the virtual environment has introduced a powerful lever of imbalance for the real environment. This is how we arrived at the explanation of learning theories in real-virtual environments through the theory of chaos or complex environments. Like any knowledge storage network with nodes between which connections can be made, even the remote experiment is subject to random laws. The addition of knowledge is not simply the sum of the effects produced by each individual node (the system is not linear). A distinction is made between information and knowledge. Even if the information in the nodes can be read, this aspect does not represent learning. The remote experiment not only expanded the realm of knowledge but also emphasized the critical role of time. The time remained constant, while the amount of information increased. The teacher, as a knowledge synthesizer, can help orient the student to this vast amount of information, especially when time is limited. Additionally, the student can also play an active role in organizing and systematizing the information. Two examples of experiments are given, which, being inter- and transdisciplinary, can contribute to the introduction of the elements of non-linearity and unpredictability as a method of designing the educational environment, precisely to be able to transform it into a thinking system suitable for the mixture between real and virtual environments in which we live more and more intensely.

KEYWORDS

distance education and online learning, cooperative/collaborative learning, secondary education, pedagogical issues, teaching/learning strategies

Samoila, C., Ursutiu, D., Munteanu, F. (2023). The Remote Experiment in the Light of the Learning Theories. *International Journal of Online and Biomedical Engineering (iJOE)*, 19(14), pp. 26–44. https://doi.org/10.3991/ijoe.v19i14.43163

Article submitted 2023-07-05. Revision uploaded 2023-08-13. Final acceptance 2023-08-14.

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1 INTRODUCTION

The remote experiment has recently established itself as a special educational tool that uses the virtual environment. The current paper proposes an analysis of the remote experiment from the point of view of the theory considered to belong to the "digital age," namely connectivism. The reason for choosing this subject was that the father of connectivism, Siemens (2006) [1], suggests that "the learning is the network." Or, by definition, the remote experiment is part of a network of experiments, either an internal one at the university or an external one that brings together several learning spaces, so it falls within Siemens' definition. In addition, digitization, digitalization, and digital transformation have become objectives to be achieved in all development programs, regardless of the branch to which reference is made [2] [3] [4].

However, there are some aspects of the transfer of knowledge in the virtual environment through the experiential method ("learning by doing"), that somewhat contradict the too-categorical statement of Siemens presented above [5]. Thus, the network of remote experiments can be considered a complex system. Like any complex system, the network is neither completely deterministic nor completely random. More or less independent people work in the network of remote experiments, some who create them and others who use them. The actions of these people are neither imposed nor coordinated by anyone, a fact that determines the manifestation of the two characteristics mentioned above: partial determinism and partial randomness. Consequently, the system of accessible networks, which includes all remote experiments, determines the outputs (knowledge) of products determined not by a single cause but by several. The causes that act in the network, having knowledge as the final output element, interact with each other in a random form and not in an additive (deterministic) form. As a result, the final effect obtained is not the sum of the separate effects produced by each network component (node). This would be the first correction for the too-categorical way in which Siemens says, "the learning is the network" (Figure 1).

The remote experiment itself is perfectly deterministic; it is neither chaotic nor unpredictable. Then what makes the network of which a remote experiment is a part behave as described above? Viewed as an educational tool, networks of remote experiments can be considered chaotic systems because they are not linear and cause irregular reactions (that is, there is no proportionality between cause and effect). Networks are not predictable in terms of the evolution over time of a certain experiment or of the solutions approached, and it is impossible to specify which of the initial conditions determine their temporal evolution [6].

Any educational system is part of a strategic plan. The strategic plans for the new curricula must break the space-time unit (class) and include new study methods imposed by the interference of technology in education. This is how the need to develop new theories of learning adapted to the "digital age" arose. Current theories of learning are models created in an age when information technology does not exist [7] [8]. Behaviorism, cognitivism, and constructivism claim that learning is an internal process of the person (i.e., brain-based). Before delving into the analysis of the relationship between remote experiments as nodes of a network and the current theory of connectivism, it is important to provide a brief overview of the principles of the aforementioned theories.

Behaviorism. Behaviorism was the first theory of learning. She explains learning through the stimulus-response binomial. Learning is the application of an algorithm that leads to correct answers. Completing the algorithm is rewarded with prizes or admonished with punishments [9]. Behaviorism is the creator of "traditional education," or, in other words, the "transmittal model" (King 1993) [10]. He supports the teacher's central role as an instructor, a transmitter of knowledge, and the first source of knowledge. The teacher is in total control regarding the final goal, the methods used, and the content. The student is seen as a subject whose learning performance can be directed from the outside by creating learning situations with dedication.

Cognitivism. The student was considered an organism actively involved in information processing. His learning and problem-solving skills can be developed using new strategies. The one who prepares the development strategy is the teacher, who no longer plays a leading role but a facilitating one. Vygotsky (1978) [11] defined ZPD (zone of proximal development) as "*the distance between the actual level of development, determined by the ability to independently solve problems, and the level of potential development determined through the resolution of a problem under the guidance of an adult or in collaboration with another more capable partners.*"

Constructivism. Piaget (1953) [12], Ausubel (1953) [13], Bruner (1960) [14], and Vygotsky (1978) developed the theory of learning. Constructivism assumes that "*nothing comes from nothing.*" This sentence tries to say, in short, that the new knowledge builds on the previous ones. The student incorporates the new knowledge into his previous experiences and into the mental structures that this old knowledge has created. Thus, learning is neither passive nor objective but is a subjective process in which each person changes, considering the interaction between old and new knowledge. Piaget emphasized the personal nature of learning in constructivism. The accompanying processes of this learning are discovery, the experiment of manipulating concrete reality, critical thinking, dialogue, and continuous questions. For this last situation of dialogue and questioning, Vygotsky developed "social constructivism," which mainly states that "*only in a social context is significant learning is achieved.*"

2 METHODS

The main method of investigation applied in this work is that of critical analysis of the remote experiment, considering classical theories of learning. The experiment at a distance appeared to be a necessity. First time as an industrial necessity, best represented by space research, where without "remote control," everything would have been impossible. Then, based on what was acquired in the development of this field, it appears to be an educational necessity. E-learning in technical specializations must also include the experimental side of didactic training, and without simulation software systems or real-time control of experiments, this inclusion is impossible.

The main tenet supported by behaviorism, cognitivism, and constructivism is that learning occurs internally within the individual. If we think of the student who opens an experiment at a distance and tries to reproduce it, making the necessary measurements and editing his written conclusions, we see that this student acts as a person who learns even in the light of the dogma mentioned above. How does it differ from the classical learning situations based on which learning theories were structured?

Compared to behaviorism, external stimuli accompanied by rewards and punishments depending on the results are converted into individual-internal stimuli. The student opens the experiment out of a desire to fulfill the experimental part of the training. Instead of the teacher's exhortation, an educational necessity appears. Other differences appear here [15] [16]. The student can limit himself to a single experiment on a given topic existing in the internal network of the university, or he can go to the network of remote experiments on the Web and open several applications from different universities located in different geographical places to check how others behave when his topic of interest is approached. This stage contains elements of constructivism. When solving the first chosen experiment, a scheme was formed in the student's mind to include the new knowledge gained through the experiment in his old mental structures. At the opening of the other experiments in the network with the same theme, the process of building new knowledge on the structure of the knowledge already acquired continues. The effects will be acceptance of the new experiments if the effort of fitting them into the existing mental schemes is small, and rejected, if the fitting of the new knowledge brought by the new experiment cannot be based on the previous knowledge and requires a great effort of updating and alignment.

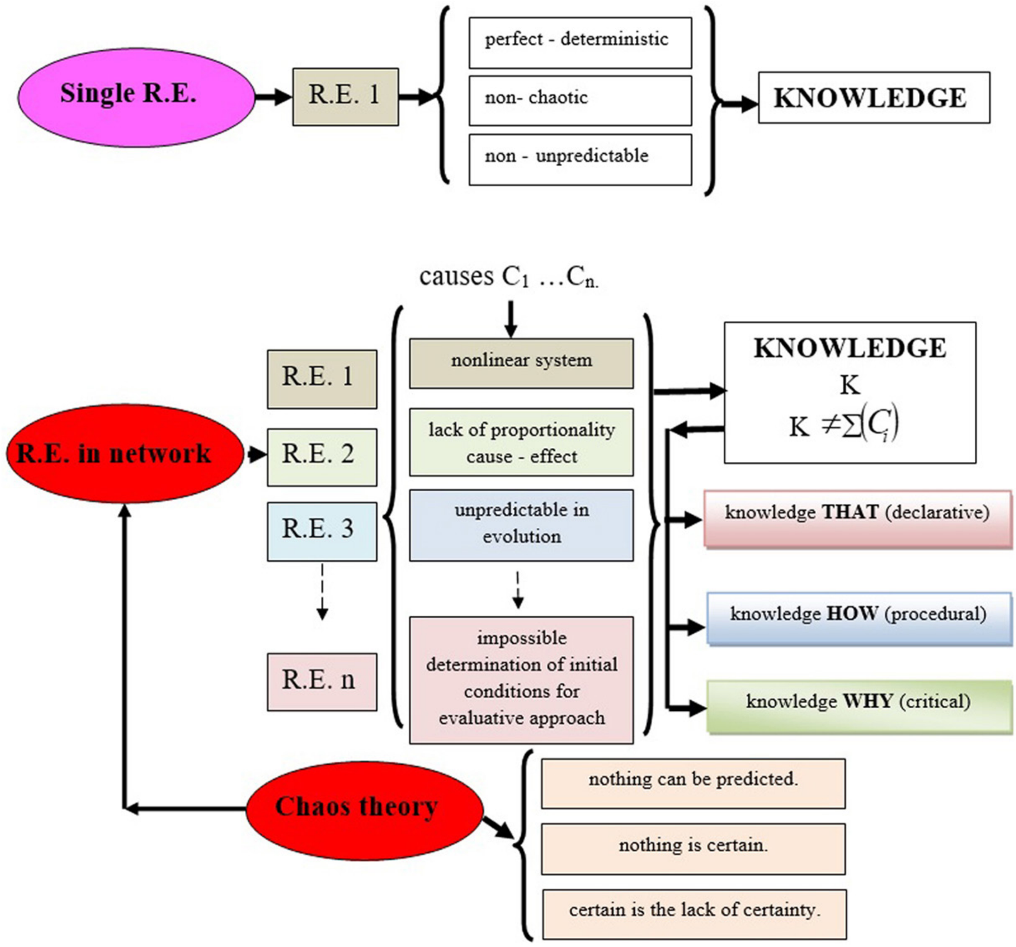


Fig. 1. Effects of the R.E. network on the knowledge

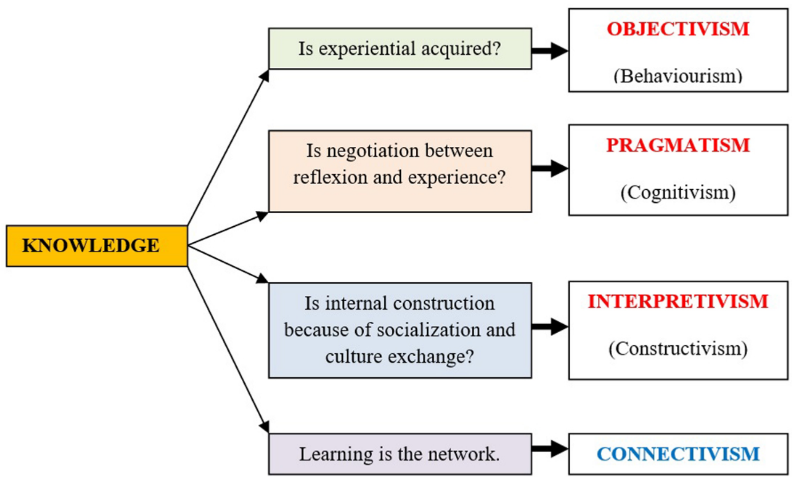


Fig. 2. Relation: knowledge–theories of learning

This is where dialogue and continuous questions can intervene, elements emphasized by Piaget as accompanying learning in constructivism. The Web 2.0 environment offers the student a socialization component that can help to acquire the parts of the knowledge brought by the new experiment that were rejected by the individual mental schemes already formed by fitting them into other individual mental schemes activated by socialization. This is how the limitations that manifest themselves in an individual can be overcome.

The ones described above also fit into the theory of cognitivism, which considers the student, an active information processor, somewhat different from the way behaviorism simplistically considers him a reactive person who only responds to stimuli. The teacher considers that the student learns and thinks to solve the problem, and focuses on organizing experiments that allow information-processing actions. In this vision, each remote experiment is a creation of the teacher meant to support him in his cognitive actions, so it represents, on a small scale, an implementation of a learning strategy. Vygotsky developed the sociocultural paradigm and said: "*although the individual is important, it is not the only variable in learning. His personal history, his social class and, consequently, his social opportunities, his historical time, and the tools he has at his disposal are variables that not only support learning but also are a fundamental part of him*" [11]. Vygotsky's words, in a period when nothing was known about virtual learning environment (VLE), today receive new meanings. All the elements of variability mentioned by Vygotsky remain valid even in the "digital age," but there is one element among them that has become the engine of learning in the virtual environment, I quote: "the tool he has at his disposal" well, these tools, which Vygotsky had no way of seeing in their modern component, became essential and often decisive in the educational picture; it is about ICT tools. In the virtual environment, personal history, social class, historical time and social opportunities, temporal communication methods (synchronous or asynchronous), the lack of geographical boundaries, and, as a limiting variable, the language used for experiments in external networks of the university are added as variables [17].

So, in the concrete case of the remote experiment, the classical theories of learning cannot be neglected: behaviorism, cognitivism, and constructivism. The remote experiment, although it belongs to the tools of the "digital age," retains important characteristics regarding external stimuli (behaviorism), learning based on previous mental structures (constructivism), and information processing (cognitivism). In our analysis, the educational qualities of the remote experiment cannot be explained only through the principles of connectivism, a theory of learning presented as appropriate for the "digital age."

3 DISCUSSIONS

3.1 Remote experiment and the principles of connectivism

Before dealing with the relationship between the remote experiment and the theory of connectivism, its principles will be reviewed.

1. Learning is the process of connecting with the nodes of a network where the sources of information are located.
2. Learning consists of a diversity of opinions.
3. Knowledge is stored in non-human environments.

4. Maintaining the connections between the nodes of the network and constantly supplying them with knowledge facilitates continuous learning (Figure 3).
5. The main benefit of online learning is the ability to make connections between fields, ideas, and concepts.
6. Everything that is learned must be viewed from the point of view of reality, which is continuously changing. Information alters its validity over time, thus influencing decisions regarding what is useful to learn.

In connectivism, the world, systems, and groups are connected and form an integrated entity called a network. The knowledge in this network, seen as "knowledge in action," is located outside the person, within databases and organizations, and learning consists of connections made on sets of specialized information. Synthetically, it can be said that the approach of connectivism takes place through interactions within networks inside and outside of the mind, in entities called nodes. Connectivism does not tell individual memory what to do (behaviorism); it does not tell the person how to process (cognitivism); or how to combine old meanings with new ones (constructivism).

Returning to the principles of connectivism and trying to position the remote experiment within them, the following considerations can be made:

1. In the case of a remote experiment, learning is done in the first stage only on the network node that contains the application. If the student has all the necessary knowledge to understand and handle the experiment, the connection processes mentioned above in Principle 1 of connectivism remain to be done only inside the student's mind (cognitivism).
2. If the student does not have all the necessary knowledge to understand and operate the experiment remotely, he will start using connections from other networks. The process is focuses on the concrete problems of the experiment. If the networks do not quickly provide this information, "search fatigue" intervenes with negative effects such as an incomplete solution of the experiment, postponing the solution, searching for a similar experiment already solved, and the exchange of information with other colleagues, which impacts the final results.
3. If the students manages to gather, from the networks with various information and from the discussions with colleagues, all the necessary knowledge for running the experiment, after solving it, they may become interested in finding similar experiments, being curious to validate their obtained results. This is the closest case to learning through connection because the requirements of the second principle of connectivism, that of the diversity of opinions, are met.
4. It is true that the principle of storing knowledge in non-human environments works in connectivism, but it must be specified that learning consists in the transfer of this knowledge to the human mind and that the dialogue between the storer called the mind and the non-human storers is the engine of learning. So here we conclude that the basic principle of constructivism makes sense.
5. In the same sense, maintaining the connections between the nodes and feeding them permanently with new knowledge are activities that the human mind also does through the permanent correlation between new and old. So we can talk about a new form of "teaching" that keeps connections active and enriches the content of non-human memories. The principle of "teaching" knowledge in this way is the main characteristic of the remote experiment, which the teachers (actually a team led by one among them) think about, perfect, and modify if it is exceeded.

6. Remote experiments, by nature, make connections between fields, ideas, and concepts because they are primarily interdisciplinary. The notions that the experiment wants to convey to the user are supported by software, assemblies, and equipment (hardware), by principles of simulation or real-time control, which are complementary to the basic notions and support them.

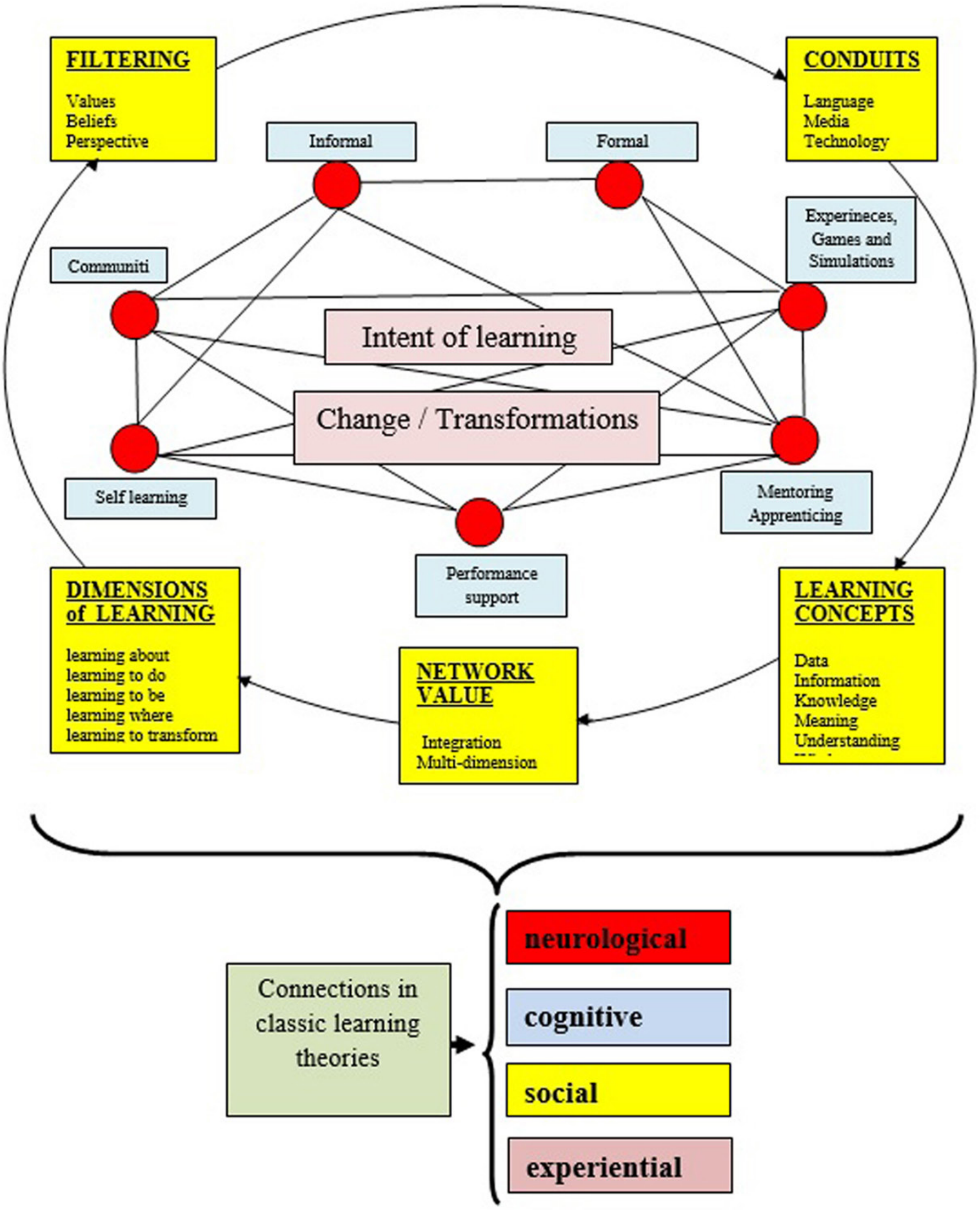


Fig. 3. Comparison between types of connections in real and virtual environments

3.2 Remote experiment and the limits of connectivism

It is totally contraindicated for a new theory of learning, such as connectivism, to be regarded by some as the supreme explanation for the "digital age" era. The "merits" of the other three classical theories, behaviorism, cognitivism, and constructivism, in deciphering the learning processes cannot be neglected, only on the argument that they no longer reflect the educational system modified by information and communication technology (ICT) interference in education. There are several arguments for this, and we will present them in direct connection with the concrete case of the remote experiment.

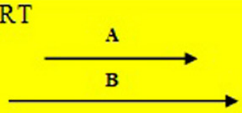
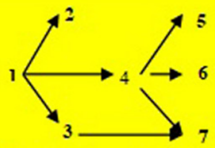
1. The experiment has always been part of the engineering education system. The theories of "learning by doing" and "experiential learning" are also widely accepted, despite originating in an era dominated by classic "face-to-face" education. Neither the new tools nor the new information media have lost their importance. As well as the remote experiment. It represents an extension, in the virtual environment, of the need for the practical acquisition of phenomena. Of course, its appearance has considerably widened the experimental area available to students, facilitated the application of e-learning to technical subjects as well, and given lifelong learning content. The remote experiment does not cancel the "hands-on" laboratory experiments. On a small scale, just as connectivism cannot cancel the internal learning processes that classical learning theories explained, neither can remote experiments deny the usefulness of "hands-on" laboratories. We must be aware that when we talk about the interference of ICT technologies in education, we are talking about two learning environments. Classical theories of learning were built around the real learning environment, while connectivism mainly refers to the virtual environment. Since these two environments coexist, the learning theories that explain them must also coexist.
2. There are also differences in meaning. Connectivism refers to networks whose nodes contain information. Information has always been external to the human being before learning, and there is no reason for this to change just because the virtual learning environment has been added to the real learning environment. Thus, the connections between nodes that connectivism defines as a learning process are connections to obtain information. Reading the information, even if it is done in a critical system with multiple connections, is only the first stage of learning.

   Comparing a remote experiment with other experiments in the network only brings the student a picture of the solutions used in various places to demonstrate the same principle or phenomenon, so it only brings him the completion of the information. The fact that the student can describe what solutions he found online for Ohm's law, for example, does not mean that he knows Ohm's law without repeating at least one of the experiments that he added to his information baggage. Therefore, from the information, all the stages of Bloom's taxonomy must be completed, that is, knowledge, comprehension, application, analysis, synthesis, and evaluation, to be able to say that learning has taken place. The information provided by the nodes primarily covers the first two stages of this taxonomy. To learn, you must go through all these stages focused on handling a single remote experiment. So, the nodes and the connections between them do not ensure the enrichment of "explicit" knowledge and its transformation into "tacit."
3. There are also differences in balance. The old system of "face-to-face" experiments was in balance with the theory and the teacher's requirements. Under the sign of this balance, the classic theories of learning were born: behaviorism,

cognitivism, and constructivism. The virtual environment attached to the real environment has introduced a strong imbalance component, and the students are subject to the action of this component. In the "face-to-face" case, it was enough to carry out the "hands-on" experiment. In the case of virtual networks, there are so many experiments on similar subjects that the student feels that he will be in balance only when he knows everything that the network contains. But he still feels that such a thing is not possible. For this reason, recently, for learning in real and virtual environments, the theory of chaos and complex systems has become more credible. Reigeluth (2004) said that when we are able to understand the dynamics of these new learning processes, we will be able to find a new balance in education.

What are the remote elements of the experiment that lead to the conclusion that experiential learning has weaknesses, makes the teaching of theory often ineffective, and creates feelings of imbalance determined by powerlessness in the face of the avalanche of sensational information that often leads to giving up effort? Chaos theorists argue that these situations are based on the non-linear characteristics of the human mind and the uncontrollable nature of social interaction. The main factor in chaos is, therefore, the virtual environment.

Table 1. Factors of differences between real–virtual environments

FACTORS of DIFFERENCES	ENVIRONMENT	
	REAL	VIRTUAL
Coordination with practice	After learning	Embedded in learning
Learning path	START  FINISH Fixed by teacher: LINEAR, PARALLEL	 With bifurcation (adaptive)
Level of access to knowledge	Limited	Practically unlimited
Feedback	After learning	During learning

3.3 Remote experiment and virtual real binomial

It is obvious that the appearance of the tool called a remote experiment in education did nothing but help the real learning environment. This finding is so evident through the measurable positive effects produced that a new discipline, "Captology," appeared (Fogg, 2003) [18], which "*focuses on the design, research, and analysis of interactive computing products created for the purpose of changing people's attitudes or behaviors.*"

Also, from the point of view of the remote experiment used in the transfer of knowledge, it can be stated that the learning environment is in a state of transition. The use of the virtual learning environment is done in a confusing way because the traditional teaching and learning methods have not been changed. To trigger the change, the remote experiment must not only be added to the system as a useful option but also be viewed from three angles: as a tool, as an environment, and as a social actor. The remote experiment ensures, simultaneously with the experiment, the sorting and processing of the data, which makes it a tool. The remote experiment as an environment should be seen as a generator of symbols (text, graphics) or as a sensor, able to educate the user on the environment-measurement-conclusion relationship. The remote experiment as a social actor allows, within the experiment it presents, problems of language used, communication, and defining the space in which it operates (very important for the industry), helping the student understand the necessary balance between private life, career, and education. The remote experiment as a social actor reduces the dependence on space-time and offers both the chance of individual learning and that of working in a team.

The appearance of the remote experiment in learning shows that it is not necessary to draw a border between real and virtual environments. The key to success is being able to integrate these environments. The lack of integration determined the separation between the classical theories of learning and those of the "digital age." From the above, it was highlighted that the remote experiment—a typical element of the virtual environment—integrated many elements that belong to classical theories of learning. This supports the previous mention regarding the need to integrate environments.

An important aspect of the relationship between the remote experiment and the two environments, real and virtual, is that the virtual environment has extraordinarily widened the space of knowledge but has highlighted the critical nature of time. Time has not expanded; it has remained the same, so access to information is a restriction that can only be overcome by systematizing information. This role belongs, as in all eras, to the teacher. The student whom the virtual environment has made more active can transform, under the influence of the same environment, from a receiver into an actor, having, along with the teacher, a role in the systematization of information.

A critical analysis of the remote experiment network highlights characteristics valid for information from the entire virtual environment:

- The remote quality of the experiments included in the network is uneven.
- Many times, remote experiments contain information that is not validated.

Hence the need to accompany any search in the network of remote experiments with search rules.

3.4 Science of complexity and remote experiment

In order to be able to argue the need for a paradigm shift in the educational system, a series of interviews and discussions were organized, and questionnaires were completed that referred to the training of young people and mature people for exact sciences. An alarming statistic resulted:

- ✓ 54% of young people between the ages of 12 and 16 declare that they do not intend to pursue a scientific career.
- ✓ Of the 54% declared above, 14% is the percentage of those who presented skills that would allow them to approach a scientific career.
- ✓ 63% of the people tested are interested in science and its achievements, but from the position of spectators and not from that of active participants.
- ✓ 18% of the young people tested frequently watch TV programs with scientific content or look for web pages with scientific content on the Internet.
- ✓ 82% of the young people surveyed do not have basic scientific knowledge, nor do they possess concepts that would allow them to adapt to STEM-type school programs.
- ✓ 93% of the young people questioned know how to use the PC for e-mails, music, movies, games, Facebook, and Twitter, but, apart from being users, they did not ask themselves any problems that would allow them to understand more deeply the virtual environment and the significance of its relationship with the real one.
- ✓ 98% of the young people tested do not know how a PC can be used for a physical measurement or as part of a scientific experiment.
- ✓ 84% of the surveyed teachers were not trained in experiments organized in the virtual environment, so they do not have the basic knowledge for "learning by doing" or "experiential learning" in this environment.

What are the conclusions we can draw from the global analysis of the contribution to the knowledge of each theory of learning, in relation to the statistics above, that can also define a way forward and explain the situation described statistically? We will present some ideas:

- ✓ We live in a dynamic conglomerate of natural, artificial (man-made), and virtual systems. This dynamic is called co-evolution.
- ✓ This new dynamic is partially controllable, partially unpredictable, and can only be approached at a multidisciplinary and transdisciplinary level.
- ✓ The only methodology capable of integratively approaching the conglomerate of natural, artificial, and virtual systems is offered by the science of complexity. Here is the definition given by Wolfram for a complex system [19], "*it can be said that the component elements are simple, and their law of interaction is also simple. Complexity appears in the organization of the whole under the pressure of the infinite combinations in which they can interact*."

The operating laws of the whole are built based on the dynamics of the parts, and the parts follow these laws as long as the whole is not fragmented. The above conclusion immediately highlights the fact that the current educational system aims to study parts and not the whole. This explains why there are so many learning theories. This explains why, with the advent of the virtual environment, capable of encompassing all parts of the "whole" we are talking about, the educational system began to show imbalances and a lack of prediction. They tried to blame the exponential growth of knowledge on the emergence of the Internet and the facilities it offers for information. None of the explanations that have gained some notoriety for explaining the unpredictability of educational development, including the one given by us above, has not been attempted. One of the reasons is that current education has generally included the new disciplines generated by the non-linear treatment of natural phenomena, such as complexity physics, catastrophe theory, and synergetics. This lacunar approach removed from the general knowledge the appropriate mathematical models for these new disciplines, such as the Theory of Dissipative Systems, Fractal Geometry, Genetic Algorithms, Cellular Automata, Chaos Theory, Intelligent Agents, Artificial Intelligence, etc. What is lost after this lacunar approach to the integrated natural-artificial-virtual system? It blocked the understanding of the local, global, and part-whole reports that we needed to explain the system and not the parts.

What measures should be taken to overcome these limitations? We consider that the crucial problem is the redesign of the educational system so that it can respond to the changes generated by the new paradigm of complexity. Why would this new paradigm change the educational system? Because, by accepting complexity as a theory of the global system, the approach to the surrounding reality also changes drastically. Complexity science introduces a holistic, non-linear approach that can be modeled using cellular automata, neural networks, or intelligent agents. Ilya Prigogine mentions it while proposing "The Theory of Dissipative Systems" in 1976. In this theory, he specified that order appears spontaneously in systems that are far from thermodynamic equilibrium. The order appears because of self-organization processes, which, in turn, are strongly dependent on the energy flow present in the system. In 1988, Per Bak, Chao Tang, and Kurt Wiesenfeld [19] discovered and formulated the "Principle of Critical Self-Organization," through which they highlighted an essential property of complex systems, namely their extreme sensitivity to small changes in the initial conditions. In 1978, Feigenbaum [20] consolidated the Science of Complexity with the scenario of the transition to chaos through successive bifurcations. According to the "Chaos Theory," a chaotic system shows sensitivity to the initial conditions. The principles of this theory applied in the field of electronic circuits led to the realization of chaotic oscillators (Chua's circuit) and contributed to the formulation of the concept of chaotic resonance, besides providing the method of synchronization using chaotic oscillators. Eve Mittlelon-Kelly from the London School of Economics states that "*the science of complexity provides a conceptual framework, a way of thinking, a way of seeing the world*" [17].

This very succinct presentation of the science of complexity, we believe, has succeeded in convincing me that the new educational technologies must be closer to "learning by discovering" and "learning by direct implications in experimental projects," actions that are strongly interdisciplinary and transdisciplinary, a fact that makes them a gateway to understanding the science of complexity [21]. These new educational approaches support self-education in the virtual environment through e-learning processes using real artifacts (hardware), which we will call "personal laboratory" in the following.

The first experiment is called Nexus. This program wanted to initiate a specific cognitive process by encouraging the participants to launch pertinent questions in the field of complexity science and try to give their own answers based on a broad base of self-instruction, through their own experimental research, and through communication with people involved in research in the same field of interest. For this purpose, a multi-component assembly was created consisting of:

– The NEXUS room is a space supported by mentors, dedicated, and equipped for multidisciplinary experiments. The activities in this space take place in groups according to affinity for a given theme, without differences based on age. The list of topics studied was proposed by the Scientific Council of the NEXUS program.

- A complex teaching object (CTO) is a hardware and software synthesis that allows multidisciplinary experimental explorations. Its stated purpose is to simulate attention, the ability to correlate concepts, assimilate principles and results, encourage personal initiative, and the ability to communicate within interdisciplinary teams. The syntheses were created by ASRech (www.astech.ro), a private Romanian company, under the guidance of the scientific council of the NEXUS program. The hardware and software syntheses allow the complete cycle of needs: idea, solution, and product, which also ensures a solid preparation for real life.
- CONNECTUS is a hardware and software set intended for the development of personal experiences. It is designed as an interface that allows a combination of playing, teaching, and learning, all based on "self-discovery." It is a kit that invites interactivity within the teams formed "ad hoc" to tackle topics of maximum difficulty. The standard version includes a vibration sensor, a plethysmograph intended for the study of peripheral blood circulation, a signal generator, a software package for data acquisition and processing, and a course for numerical data processing. Operating as a personal laboratory (PL) CONNECTUS is oriented toward topics such as "The heart is a chaotic oscillator," "Plants as biological sensors," "Technical diagnostics and the noise," "Can stress be diagnosed by monitoring the neuro-muscular electric activity?" Semnificative details in the topic "Plants as biological sensors" are oriented towards understanding and deepening knowledge in botanic, physics phenomena (diffusion), periodic and non-periodic oscillations, concentration piles, thermoelectricity, noise, mathematics (numerical methods and their application in signal analysis, functions, graphic representations, basic elements in fractal geometry, fundaments of biomathematics), electronics (preamplifiers, operational and instrumentation amplifiers), informatics, and software programming (MatLab, LabVIEW, Excel, Word, and C++).

The NEXUS program (www.terranexus.ro) appeared as an initiative of the Center for Complex Studies (CSC), a UNESCO center; it was implemented in a pilot experiment at the Tudor Valdimirescu Theoretical High School in Bucharest and was later extended to high schools in Suceava, Buzau, and Otopeni on three levels of complexity: university, high school, and gymnasium. It seeks to structure and maintain an environment of interference between disciplines with a scientific and educational component, with a multivalent highlighting of the role that science and technology have in development.

Hardware reconfigurable software is another example of an attempt to concretize the principles defining the science of complexity. It is an idea promoted by the Center for Valorization and Transfer of Competence (CVTC) at Transilvania University in Brasov. It is a way by which the hardware is thought of from the beginning as a PL, which has the quality of being configured through software in experimental forms suitable for the intended purpose. For this, Student Educational Device for Electronic Applications (StudentEDEA) was built (Figure 4).

The basis of the system was PSoC 1 (CYPRESS), the first system that had a programmable CIP. It includes in a single CIP: configurable analog-digital peripheral functions, analog and digital buses, memory, and a microcontroller. The student EDEA card has the possibility to program the CYPRESS PSoC1 cip CY8SC29465-PXI to work like a development board. The system was thinking of a low-cost, multifunction device that can extend students' understanding of the phenomena that occur in electronics and embedded systems. Combining Student EDEA and NI, my DAQ/my

RIO will be converted into one of the most high-tech educational devices available on the market to sustain practically the idea of PL with huge variants due to the hardware being reconfigurable software concept mentioned above. Figure 4 shows the general structure of the EDEA system.

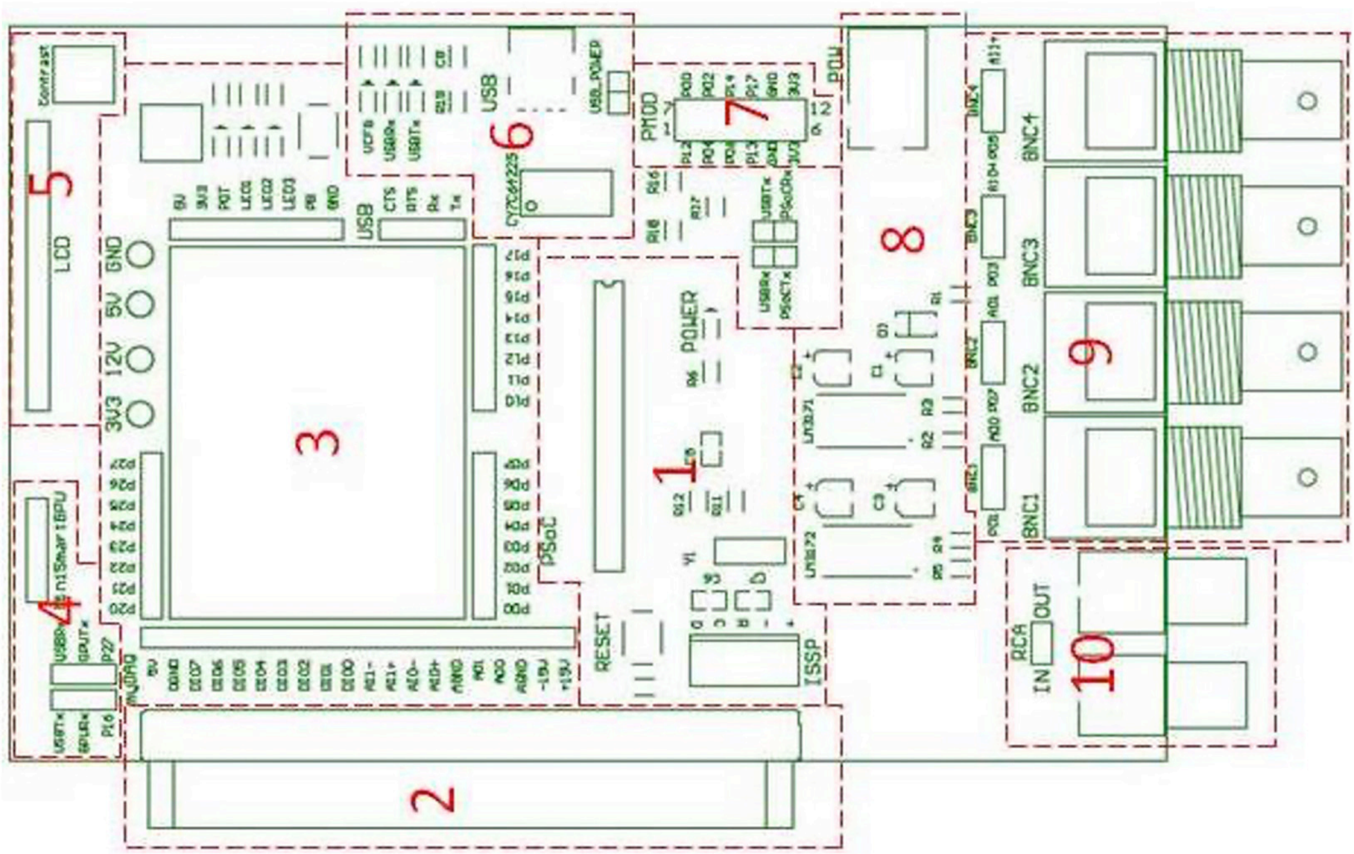


Fig. 4. General structure of the StudentEDEA

1. Cypress PSoC1–CY8SC29466-PXI-the core of device.
2. MyDAQ/myRIO PCB connector–the standard 20 pins connector.
3. Prototyping area–a resource available for other applications and complex experiments.
4. MiniSmart GPU intelligent embedded graphics processor.
5. A character LCD interface with a 2 × 16 alphanumeric LCD module.
6. USN connection–that uses the CYPRESS CY7C64225–USB–UART interface.
7. PMOD connector–for connection to DIGILENT’s PMOD peripheral modules.
8. The power supply system–converts the 9.12 V to 5 V and 3.3 V.
9. BNCs with jumpers that switch between PSoC1 and the NI my DAQ.

One example regarding the student EDEA board is shown in Figure 5 where, using PSoC Designer 5.4 for programming, CY8SC29466-PXI developed a thermometer that had in the back the temperature sensor of the Analog Device AD22100. The application was developed in LabVIEW. Also, using the breadboard, the PSoC extensions (Po, P1, and P2), and the Student EDEA DAQ connector (Figure 5), the system becomes capable of complex applications, especially for electronic component testing.

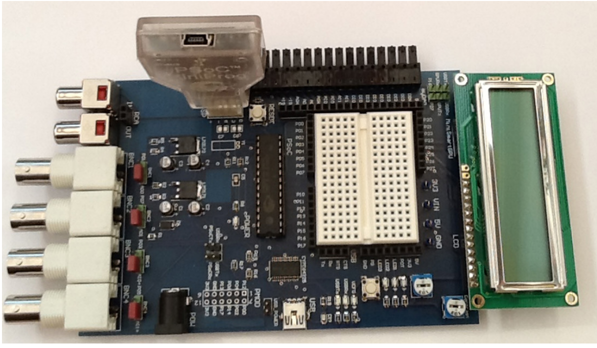


Fig. 5. Student EDEA with the programmer

The versatility of the Student EDEA concept was proven when the Smart GPU2 LCD 320 × 240 touchscreen was added, replacing the Micro Smart GPU (Figure 6). The solution allowed the development of general applications with more touchscreen-selectable functions: oscilloscopes (with touch-selectable time bases), voltmeters (with display waves from chart recorders), and images (to browse the images recorded with the oscilloscope or voltmeter applications and stored on a Smart GPU 2 Micro SD card).

The transfer of the idea of "hardware reconfigurable software" into a device with multiple functions, which can be a portable experimental platform, a true PL, is the way in which the two environments are integrated: real and virtual, practically, not only conceptually. That is exactly the message of the present work.

The two examples given, NEXUS and Student EDEA, do not exhaust the possible practical achievements, do not deny other similar achievements in operation, nor do they consider the action finished. The road from the current deterministic and very conservative concept of the educational system to the one that will reflect all the principles of complexity science is long and difficult. It is important to take the first step because it is known "no matter how short or long a road is, it always begins with the first step."

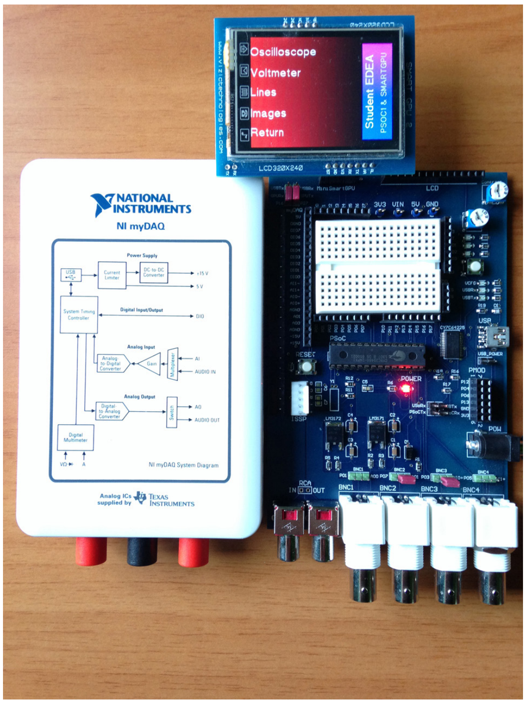


Fig. 6. Student EDEA with the SmartGPU2 LCD 320 × 240 touchscreen

If we try to classify the current experiments at a distance in relation to the concepts of complexity science, two main classes are obtained:

Type A: Experiments that impose an increase in complexity and facilitate interactions with complex systems within formal education (complexity is beyond the learner, who thus has access to complex, natural didactic objects).

Type B: Experiments that stimulate emerging processes (the remote laboratory structure is the one that determines emerging processes). Networks of remote experiments are becoming more and more complex, and thus they too will produce emergent effects.

Based on these two large classes of experiments, a proposal can be made for the classification of remote experiments capable of being developed immediately (Table 2).

Table 2. Types of remote experiments (proposal)

Type of R.E.	Pursued Objective	Characterization	Observation
"Showcase type" **Tip A**	The provision of real data within the bachelor's and master's projects.	It represents a "*linear*" extension of the "*classic*" project concept	Follows the accommodation of young people with real data that includes "*error*" as a learning method, and stimulates critical/creative thinking.
Unique labs with Multiple users **Tip A**	The experimental exploitation of some spots on a global level, with certain unique features (eg: the Californian fault, the geodynamical active area of Vrancea, a metropolis with excessive human activity, an area of a reservation, the orbital station… etc.)	Multi- and interdisciplinary, delocalized laboratories, presenting complex, natural processes and phenomena, monitored remotely by multiple users. It expands the subject matter through access to real processes and phenomena that cannot be brought into a laboratory (the laboratory is Nature itself and the location is where the studied phenomenon manifests itself most meaningfully)	Multiple and interdisciplinary laboratories, delocalized, presenting complex, natural processes and phenomena It ensures the formation of skills to approach real, global processes, It stimulates working in mixed teams, the real organization of the remote experiment, the power to interpret the results and extend the experience gained to other socially useful applications
Remote laboratory for creative projects **Tip B**	It provides the context of the high-level experiment for homologate processes, proposed by society, intended for progress	Society stimulates scientific and technical development in an organized way. The principle of operation is of the creative contest type. The finalist is the one who configures the final form of the laboratory that will provide the necessary data at the company level. The company can find different applications to the problem proposed by the winner.	Stimulates interest in science and technology (science with and for society) The level of content of the scientific production circulated through the Internet is raised It is an educational process by encouraging the performance of absolutely new experiments (preliminary phase, useful in motivating youth)
Network of personal laboratories **Tip B**	Ensures the management (orientation, capitalization) of individual activities by creating artifacts with access to both the real and the virtual environment (Hobby type)	It directs the creative effort of society that manifests itself informally	Involvement of society in observing, formalizing, and solving real problems by encouraging individual Hobby type efforts or collective creative circles-type efforts.

4 CONCLUSIONS

The problem of the remote framing of the experiment in learning theories raises many aspects that support the idea of integrating the classic ones with the newly created ones so that the explanation of the transformations produced in learning by the "digital age" has consistency. From the analysis of the above, the following conclusions can be drawn:

1. Any knowledge storage network of nodes, between which connections can be made, is subject to random laws. The addition of knowledge is not the sum of the effects produced by each individual node (the system is not linear).
2. The interference of technology in education requires the development of new theories of learning. In the paper, connectivism is analyzed as the most important representative of the theories related to the "digital age."
3. From the point of view of the environment, called a remote experiment, learning takes place, in the first stage, at the individual level, thus fitting into all three classic theories of learning: behaviorism, cognitivism, and constructivism.
4. Learning in the remote experiment environment assumes that the student is an information processor, if we consider the interdisciplinary nature of this environment. From this point of view, the remote experiment obeys the principles declared by cognitivism.
5. After the student has mastered a remote experiment and wants to compare it with other existing experiments in the network built for the same purpose, he will have to understand the new experiments by fitting them into the knowledge already acquired. The process is characteristic of constructivist theory, where the assimilation of new knowledge is done based on what has already been assimilated.
6. According to Vygotsky's social-constructivist theory, the remote experiment introduces, in addition to personal and social history, opportunities, and historical time, two elements uniquely enabled by the virtual environment:temporal communication methods (synchronous and/or asynchronous) and the ellimination of geographical borders.
7. In relation to the connectivism theory, although remote experiments are nodes in a network, they first assume an individual learning stage of the content of a single node and only then allow the transition to the connections between nodes. In the individual learning stage, connections can also take place with the nodes of other networks that contain the fundamental elements of the experiment that the student does not possess and must look for.
8. The critical analysis of similar remote experiments found in the network can only be done after the complete acquisition of an experiment. Many times, this process no longer happens if "search fatigue" appears during learning. This negative aspect, related to cognitive theory, can contribute to the incomplete resolution of the experiment.
9. While classical theories of learning were built around the real environment, connectivism is based on the virtual environment. The argumentation related to the remote experiment leads to the idea of the necessity of coexistence between theories and the acceptance of those parts of them that are obviously valid.
10. A distinction is made between information and knowledge. Even if the information in the nodes can be read, this aspect does not represent learning.
11. It is shown that the virtual environment has introduced a powerful imbalance lever for the real environment. This is how the explanation of learning theories in real-virtual environments is justified through the theory of chaos or complex environments.
12. The remote experiment introduced, together with other properties of the virtual environment, a state of transition in the learning process. Efforts are being made

to restore balance in the learning environment by simultaneously highlighting the computer as a tool, environment, and social actor.

13. The remote experiment obviously widened the space of knowledge but also highlighted the critical nature of time. The time remained the same, while the information increased quantitatively. In the face of this abundance of information and limited time, both the teacher, in their role as a knowledge synthesizer, and the student, who can also take on an active role in systematizing knowledge, play crucial roles in guiding the student's orientation.
14. Is a new approach to the educational system required? A principled answer was attempted to this question by presenting very succinctly the requirements of the Science of Complexity and the way in which these requirements contribute to the design of another educational paradigm.
15. Two examples of experiments are given, which, being inter- and transdisciplinary, can contribute to the introduction of elements of non-linearity and unpredictability as a method of designing the educational environment, precisely to be able to transform it into a thinking system suitable for the mixture between the real and virtual in which we live more and more intensively.

5 ACKNOWLEDGEMENT

The paper was written under the aegis of CVTC (Centre of Valorization and Transfer of Competence) from the Transylvania University of Brasov, Romania.

6 REFERENCES

[1] G. Siemens, "Connectivism: Learning and knowledge today," *The International Review of Research in Open and Distance Learning*, vol. 9, pp. 1–13, 2006. http://admin.edna.edu.au/dspace/bitstream/2150/34771/1/gs2006_siemens.pdf

[2] C. P. Dai, F. F. Ke, and Y. N. Liu, "Exploring students? Learning support use in digital game-based math learning: A mixed-methods approach using machine learning and multi-cases study," *Computer and Education*, vol. 194, p. 104698, 2023. https://doi.org/10.1016/j.compedu.2022.104698

[3] M. L. Wilson, A. D. Ritzhaupt, and L. Cheng, "The impact of teacher education courses for technology integration on pre-service teacher knowledge: A meta-analysis study," *Computers & Education,* vol. 156, p. 103941, 2020. https://doi.org/10.1016/j.compedu.2020.103941

[4] E. Brieger, V. Arghode, and G. McLean, "Connecting theory and practice: Reviewing six learning theories to inform online instruction," *European Journal of Training and Development*, vol. 44, no. 4–5, pp. 321–339, 2020. https://doi.org/10.1108/EJTD-07-2019-0116

[5] M. J. Zhang, E. Croiset, and M. Ioannidis, "Constructivist-based experiential learning: A case study of student-centered and design-centric unit operation distillation laboratory," *Education for Chemical Engineers*, vol. 41, pp. 22–31, 2022. https://doi.org/10.1016/j.ece.2022.09.002

[6] T. Hug, "Radical constructivism mainstreaming: A desirable endeavor? Critical considerations using examples from educational studies and learning theory," *Constructivist Foundations*, vol. 6, no. 1, pp. 58–64, 2011.

[7] I. S. Jung, "Connectivism and networked learning," in *Open and Distance Education Theory Revisited: Implications for the Digital Era*, Book Series Springer Briefs in Education, 2019, pp. 47–55. https://doi.org/10.1007/978-981-13-7740-2_6

[8] B. Wu and C. C. Wu, "Research on the mechanism of knowledge diffusion in the MOOC learning forum using ERGMs," *Computer and Education*, vol. 173, p. 104295, 2021. https://doi.org/10.1016/j.compedu.2021.104295
[9] C. R. Aylward and C. J. Cronjé, "Paradigms extended: How to integrate behaviorism, constructivism, knowledge domain, and learner mastery in instructional design," *Educational Technology Research and Development*, vol. 70, no. 2, pp. 503–529, 2022. https://doi.org/10.1007/s11423-022-10089-w
[10] R. A. King, K. F. Cochran, and J. A. De Ruiter, "Pedagogical content knowing: An integrative model for teacher preparation," *Journal of Teacher Education*, vol. 44, no. 4, pp. 263–272, 1993. https://doi.org/10.1177/0022487193044004004
[11] L. S. Vygotsky, *Mind and Society: The Development of Higher Mental Processes.* Cambridge, MA: Harvard University, 1978.
[12] J. Piaget, *The Origin of Intelligence in the Child.* Routledge and Kegan Paul, Open Library OL17501355M, pages 425, 1953.
[13] D. P. Ausubel, "The nature of educational research," *Educational Theory*, vol. 3, no. 4, pp. 314–320, 1953. https://doi.org/10.1111/j.1741-5446.1953.tb01065.x
[14] J. Bruner, *The Process of Education.* Cambridge, MA: Harvard University Press, 1960.
[15] A. P. Gilakjani, H. Lai, and H. N. Ismail, "Teachers' use of technology and constructivism," *International Journal of Modern Education and Computer Science*, vol. 5, no. 4, pp. 49–63, 2013. https://doi.org/10.5815/ijmecs.2013.04.07
[16] E. A. Al Dahdouh, "Understanding knowledge network, learning and connectivism," *International Journal of Instructional Technology and Distance Learning*, vol. 12, no. 10, 2015. Available at SSRN: https://ssrn.com/abstract=3063495
[17] E. Mittlelon-Kelly, "Complex systems and evolutionary perspectives on organizations: The application of complexity theory to organizations," *Advanced Series in Management Pergamon*, Amsterdam, pp. 240, 2003.
[18] B. J. Fogg, *Persuasive Technology: Using Computers to Change What We Think and Do.* Amsterdam: Morgan Kaufmann, 2003. https://doi.org/10.1145/764008.763957
[19] P. Bak, C. Tang, and K. Wiesenfeld, "Scale invariant spatial and temporal fluctuations in complex systems," in *Random Fluctuations and Pattern Growth: Experiments and Models. Stanley,* H.E., Ostrowsky, N. Eds., vol. 157. NATO ASI Series, Springer, Dordrecht, 1988, pp. 329–330. https://doi.org/10.1007/978-94-009-2653-0_47
[20] E. A. Feigenbaum, "The art of artificial intelligence: I. themes and case studies of knowledge engineering," in *Proceedings of the International Joint Conference on Artificial Intelligence*, 1978. https://apps.dtic.mil/sti/pdfs/ADA046289.pdf
[21] B. Atay and E. Sumuer, "College students' readiness for connectivism learning: The development and validation of a scale," *International Journal of Information and Learning Technology*, vol. 38, no. 2, pp. 230–242, 2021. https://doi.org/10.1108/IJILT-12-2019-0124

7 AUTHORS

Cornel Samoila, Transylvania University of Brasov, Brașov, Romania; Technical Science Academy of Romania, Bucharest, Romania (E-mail: csam@unitbv.ro).

Doru Ursutiu, Transylvania University of Brasov, Brașov, Romania; Romanian Academy of Scientists, Bucharest, Romania (E-mail: ursutiu@unitbv.ro).

Florin Munteanu, Complexity Studies – UNESCO Center, Brașov, Romania (E-mail: florin@florinmunteanu.ro).