Design of a personalized IT system for teachers supporting adaptive, blended, and collaborative learning

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Abstract. The integration of IT into educational processes based on knowledge requires an interdisciplinary pedagogical–informatics approach. However, current technology cannot optimally synchronize pedagogical theories (e.g., learning styles, Bloom's taxonomy, and TPACK framework) with IT tools (e.g., information processing and software for adaptive, blended, and collaborative learning). The key problem is the absence of a universal representation of knowledge that can be understood by both humans and computers. However, both pedagogical research and technological research operate only with the abstract concept of knowledge, so teachers must adapt to the existing technologies. The authors solve this problem in university teaching and research by introducing, as a representation of knowledge, so-called virtual knowledge, which is a specific information structure in the form of a database table. Teachers and students can manually or automatically insert learning content, in the form of unstructured and heterogeneous data, into the tables. Accordingly, it is structured so that it can then be processed by software and the activities of teachers are automated using hypertext links to the hybrid environment. Using examples from university practice, the authors explain the non-relational database paradigm of creating knowledge tables and how such an all-in-one system works as personal IT support for teachers. It consists of the educational software WPad, WPad BVI (which was tested in teaching blind and visually impaired students) and PIKS, and a hybrid IT infrastructure. In the form of screenshots, the authors illustrate how the learning content was inserted into the knowledge WPad tables within adaptive, blended, and collaborative learning. They also present the theoretical idea of a CSU infinite time loop of knowledge processing, which is the basis for future research. The novelty of the presented IT system is supported by registration at the patent office.

Keywords: Integration IT; pedagogical theories; adaptive learning; blended learning; collaborative learning; knowledge representation; non-relational database paradigm; educational software; IT infrastructure

1. Introduction

University teachers perform several types of pedagogical activities. They teach, prepare study materials, evaluate students, publish, conduct research, and perform other activities. For each of these tasks, they need to perform related informatics activities on personal and work computers in a hybrid environment, which poses a challenge for integrating the IT with education. The problem is that there is no universal technology that comprehensively covers these activities. Therefore, teachers must use several different types of software, hardware, and specific IT infrastructure for these activities. However, these are incompatible with each other and have a short technology lifetime.

If we focus only on the computer support for processing and transferring educational content, we have to realize that it should simulate the activities that teachers perform during face-to-face teaching. Teachers use educational content that can be read, spoken, seen, manipulated, and transferred to the students. The equivalent IT support should therefore provide a combination of what in educational theory is called learning styles. Technology should be as fast as paper and pencil or chalk and blackboard, especially when teaching STEM subjects like chemistry, in which it is faster to write out chemical formulas by hand than with technology. Another role of technology is the transfer of educational knowledge to the online learning environment.

Although computers have made tremendous progress, it is common knowledge that teachers must use separate software for writing, reading, processing images, creating sound, or a combination of these. Ordinary teachers therefore have dozens of software programs on their personal and work computers. The combination of these is difficult to manage over time, but they are necessary for the implementation of learning styles. Thus, the questions arise of how this issue can be tackled and whether a universal solution to the interdisciplinary problem of synchronizing pedagogical and IT activities is possible at all.

From a cyber perspective, teaching is a process of transferring the flow of knowledge (curriculum content) between the teacher and the learner with feedback on the basis of which the teacher evaluates, regulates, and manages the teaching [1]. The parameters of process control and regulation are logically (human) knowledge. In terms of digitalization, this means that the problem could be solved if we could isomorphically "switch" knowledge between the mental processes of a human and the physical processes of a machine (computer).

Here, the authors encountered the problem that there is no universal definition of knowledge that even a computer would understand. Moreover, the definition of knowledge differs in the fields of philosophy, education, computer science, and information and communication technologies. Although even a layman can say that knowledge is what is in your head, that is not enough for a computer.

The authors solved this problem with the design of virtual knowledge, which is readable by both computers and humans. Based on this knowledge representation, they have been studying the automation of knowledge-based processes for many years (for newer publishing outputs, see, e.g., [2, 3]). Step by step, they developed a personalized IT system, which allows teachers to simulate all educational activities in a hybrid environment, within various categories of teaching, for example adaptive, mixed, collaborative, distance learning, and e-learning. The personalized teacher IT support system presented in the article can therefore be considered an IT tool for adaptive and other kinds of learning. From the point of view of adaptive learning, there are several added values. The basic benefit of the solution is that the presented IT system is hybrid and personalized to the individual, so he does not need to use any global software. It is also a very cheap solution, because it is enough to have a Windows operating system and a presented desktop and Internet application. In addition, if the university gives the teacher access to the server, the teacher can design any type of teaching, his own e-learning, even his own learning management system.

The following sections describe the research approach, methodology, and results as well as the actual instructional software: WPad, PIKS, and WPad BVI (the version tested for blind and visually impaired users). They also formulate the CSU theoretical idea of the "infinite time loop of knowledge processing." The exploration of the current state of the art relies on a literature review of pedagogical theories and technologies with the intention of demonstrating that these only make use of general abstract knowledge.

2. Interdisciplinary pedagogical–informatics state of the art

2.1. Pedagogical theories

It should be noted that learners perceive knowledge through learning styles. The literature [4] states, "lack of empirical evidence, teaching according to the perceived learning style of the learner." However, it is questionable whether it is optimal to evaluate the effectiveness of learning styles-based education by comparing only two isolated styles, as declared there. In principle, technology should support all VARK learning styles (visual, auditory, reading/writing, and kinesthetic) comprehensively [5], especially when working on a computer in a hybrid offline/online environment can be considered a kinesthetic activity. The study by Ali et al. [6] focuses on an adaptive learning strategy based on learner styles applied to the ICDL program, which uses an adaptive model for gathering information from the learner model and the content model. Despite the emphasis on personalization as a current key requirement of e-learning systems for adapting the content to the learner's profile, this does not answer the knowledge question. The literature review by Katsaris and Vidakis [7] concentrates on the use of learning styles in the process of adaptive learning. It emphasizes that more modern adaptation techniques incorporated into electronic education systems enabling personalized solutions must be in accordance with educational theories.

A number of educational theory resources can be found on the Web, usually based on primary education theories such as behaviorism, cognitivism, and constructivism. Federer [8] adds humanism and connectivism, stating that "connectivism focuses on the student's ability to frequently retrieve and update accurate information. Knowing how and where to find the best information is as important as the information itself." The authors' research described in this article is in line with this statement.

Among other pedagogical theories is Bloom's theory, the evolution and extended theory of which are presented by Bloom [9] and Anderson et al. [10], respectively. Bloom's taxonomy is the subject of many scientific articles. It presents taxonomically more than 10 pieces of knowledge, and knowledge of specific facts can be cited as an illustration: knowledge terminology/knowledge of classifications and categories/knowledge of methodology/knowledge of principles and generalizations/knowledge of theories and structures [9]. In Bloom's revised taxonomy, the knowledge dimension consists of substantive, conceptual, procedural, and metacognitive knowledge and related cognitive processes (remember, understand, apply, analyze, evaluate, and create) [10].

From teachers' point of view, general pedagogical knowledge is discussed in a specific literature review [11]. The need for an interdisciplinary approach can be seen in the theoretical approaches describing the so-called TPACK (Technological Pedagogical Content Knowledge) with the intention of connecting the content of pedagogical knowledge with technological knowledge [12, 13]. TPACK has become one of the leading theories regarding educational technologies and their integration. In view of this article's focus on the personalized IT support of teachers who perform both pedagogical and IT activities, the TPACK framework can be considered as an interdisciplinary bridging of pedagogy and technology. For example, Kurt [14] states that "practices are best shaped by content-driven, pedagogically correct and technologically advanced knowledge of thinking" and that there is no "monolithic combination of content, pedagogy and educational technology." Each situation therefore requires a different pedagogical and technological approach. Pedagogical theories can also be attributed to the field of knowledge management, in which tacit knowledge is used within the SECI model [15].

2.2. Technological approaches to integration IT

If we ask ourselves what technology can support, we will encounter the above-mentioned problem that a person or actual technology cannot explain to a computer what human or educational knowledge is. Therefore, teachers use general technologies and test whether they are suitable for their teaching. From this point of view, it can be concluded that teachers must adapt to technology and not the other way around. Conversely, the processing of educational knowledge requires a certain IT infrastructure. In this context, the 7th European Union research framework program introduced the term technology-enhanced learning (TEL) into the challenges.

As highlighted above, human knowledge is the primary parameter for automating learning processes. Of course, some IT infrastructure is also needed. However, the concept of general abstract knowledge is sufficient to build the infrastructure. In contrast to educational knowledge, a computer does not need to understand it.

Regarding the IT infrastructure for education, huge progress has been made in areas such as e-learning, learning management systems, content management systems, cloud repositories and services, and translators up to the current penetration of artificial intelligence, which is already being implemented in search engines. For example, Windows 11 already provides teachers with wonderful possibilities in the design of teaching and learning materials (BING+AI search, speech recognition, and text-to-speech). This progress is also reflected in the fact that methodological procedures for blended, adaptive, computer-supported, computer-assisted, hybrid, and distance learning are autonomously declared under the integration of IT infrastructure into education.

This situation creates some terminological chaos. Surprisingly, scholarly journals focusing on educational technology do not deal with the design of educational technology but usually only publish simple case studies using existing generic technologies with the argument that these are educational technologies (even Facebook). The authors use the term TEL, which covers all this, not the term educational technology. Although there are many publications on TEL, the authors consider the TEL monograph [16]. In this context, there is still an absence of suitable software for TEL [17], which is very important for adaptive learning or its synonym personalized learning. It is also possible to mention the absence of theoretical approaches [18]. A very useful detailed description of the factors of TEL application in higher education can be obtained from Timotheou et al. [19] or a survey on TEL conducted among Swedish teachers [20]. In the context of the previous analysis of learning theories, there is an interesting article that connects them with TEL [21].

However, if we compare the above learning theories and technological approaches in integration IT, the state of the art does not provide a definition of knowledge, and it does not present educational processes as knowledge based. It should also be emphasized that the solution to the concentration of educational content and educational knowledge over time, which the authors deal with (see the next section), is absent from the scientific literature. For the sake of completeness, it should be added that the term adaptive learning is currently being promoted within the framework of personalized learning. This is discussed as a new approach by Adams Becker et al. [22], which states that "adaptive learning refers to technologies that monitor student progress and use data to modify instruction at any time" and "A variety of adaptive learning technologies support student learning by testing their understanding as they go." It also asserts that "adaptive learning software impacts student learning" by arguing that "this student-centered teaching method can lead to significant educational gains." The presented in-house educational software WPad was developed for such purposes around 10 years ago. A thousand undergraduates assisted in the development of the first version, so the authors, in the spirit of the new terminology, can claim that they have been using IT adaptive learning tools for years.

3. Research approach, methodology, and results

3.1. Basic Participatory action research - Technology-enhanced learning

The authors' research began around 2007, when they declared that knowledge workers should be technologically armed in such a way that they can process a huge amount of information on their computers. Research focusing on the automation of knowledge processes began to be carried out [23] under the heading of technology-enhanced learning, which was then a topic among the challenges of the 7th Framework Research Program of the European Union. At that time, the focus of empirical research was on the mass creation of e-learning material that needed to be implemented in the teaching of undergraduates. Operatively, its own database application (currently named WPad) was gradually developed, using a specific paradigm of batch processing of information and knowledge—specific because it did not use the classical relational database paradigm of E. F. Cod but the principle of free tables. This meant practically that the teacher and students produced database tables with educational content in the application environment, and these were transformed into html tables (the program also functions as a simple html editor). Since the html format is the language of the Internet, it was possible to construct and place the educational and e-learning material on the faculty server immediately. In a short time, an extensive library of study materials from several STEM study subjects was created and a virtual learning environment began to be built. Gradually, however, the need arose to tackle the use of accumulated educational content in the classroom, for self-study or to transfer the flow of educational knowledge between online and offline environments. In this phase, different variants of active learning were addressed and presented at world conferences as educationally driven TEL. After building a personalized virtual learning space with rich learning material, the focus of the research changed to a parallel pedagogical and informatics-oriented research approach.

Based on the literature survey, the authors established that their research has the character of so-called participatory action research (PAR), referring to the TEL monograph by Goodman. In this publication, PAR is referred to as research when a teacher selects and evaluates technology for teaching. In this context, own technology (WPad software) was developed, including a virtual learning environment built for undergraduates on the faculty server to connect the classroom with the learning space. For this purpose, a simple, functional information and communication channel, which allows chatting, was programmed. Its function is illustrated by a screenshot below with examples from practice.

At this time, the faculty cloud began to be modeled, which the main author used himself for several years (later its use as a shared remote computer for a group of teachers in an international project was tested). More attentive readers will surely have noticed that, in this case, unlike the standard PAR methodology, the teacher is not looking for some external technology but designing his own technology, that is, educational software and a hybrid infrastructure (one can talk about "technological" PAR).

The interdisciplinary need for IT integration is very difficult to explain to researchers from social sciences (who are only used to asking research questions and testing hypotheses) or computer science (who usually consider e-learning as pedagogy). It is better to understand it through a practical application from teaching undergraduates, for example following the Basics of Environmental Protection study course. From a pedagogical point of view, the teacher discovered that the undergraduates who came to the university have different and mostly weak knowledge of chemistry. Therefore, he incorporated into STEM teaching an explanation in the form of schemas, which he drew on a blackboard or by hand on paper, took a photo of, and posted in the learning space of the faculty. A unique feature of tables in WPad applications operating under Windows is the possibility of using hypertext, so students could switch from WPad or HTML tables to e-learning scripts with schemas and online functions through a personalized information communication chat channel that the teacher programmed for them. This is an example of technology being designed according to a specific pedagogical need and defined educational algorithm (pedagogy must be first).

In the given case, from a pedagogical point of view, the teacher's aim was to find out whether the students understood the scheme of photosynthesis (so he did not have to describe all the chemical reactions in detail). The teacher also chose to apply educational schemes because computers in this case are not faster than pencil and paper or chalk and a school blackboard. If the teacher were to use Powerpoint, it would take him hours. From this example alone, it should be clear to a third person that pedagogy and informatics go hand in hand. When teaching undergraduates, it must be respected that the lesson (lectures or exercises) is usually only about 50 minutes long and that the teacher must cover several different thematic units during it. Applying schemes therefore made it possible to squeeze the curriculum into a limited time span.

Mastering the design of the WPad educational software made it possible to resolve other pedagogical situations by allowing the teacher to program the mentioned information and communication channel as an online application. It was then used for the exchange of information, to provide instructions for students, or as additional study material. As part of distance learning, the teacher tested the students' exam through this channel. Figure 1 illustrates the course of the 2011 exam, for which students sitting in a classroom with computers were given an assignment from the faculty website via a communication channel. They had to explain schemas that were hand made or scanned by the teacher. Today, there are several technologies that can be used to support this, but such testing was carried out 10 years before the COVID-19 pandemic. In addition, the teachers and students only needed Windows, an Internet connection, and the mentioned database applications. It is therefore a very cheap, fast, and effective solution for integrating IT into education.

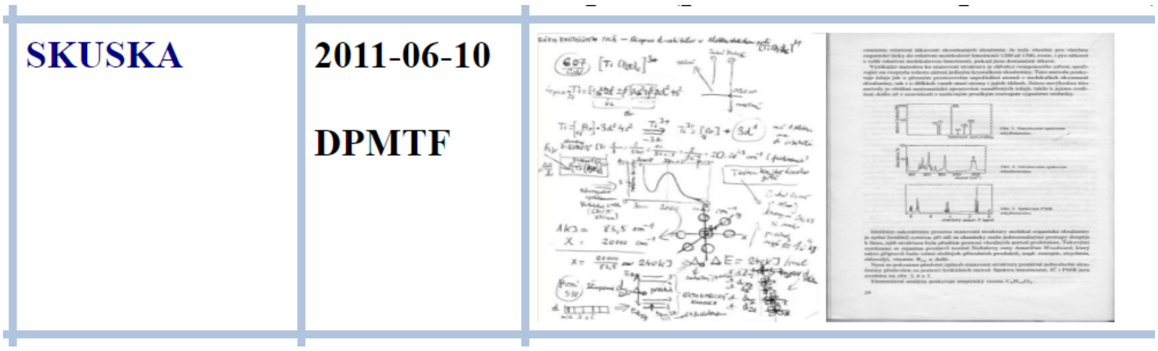

Figure 1. Communication channel, the predecessor of today's online PIKS application.

3.2. Design of virtual knowledge and creation of knowledge tables

In the framework of the publication, the authors declared the focus of the research on the automation of educational processes as processes that are based on knowledge. In general, knowledge is stored in computer files, but only part of the content is useful. From this point of view, the use of free database tables was beneficial or added value. Specifically, it should be emphasized that only reduced content is inserted into WPad tables, so only "useful" knowledge is transferred through them (a table can be in tens of kilobytes, while a pdf, doc, or text file can generally be in tens of megabytes). However, it is especially important that, thanks to the framework structure of the table, it is then possible to program a user menu that can process the knowledge in the rows of the table in software en masse.

Further progress was helped by the consideration that, if people attend a high school reunion years later, they first remember the year, city, class, classmates, and teachers as meta-information. Then they remember various events and situations that they experienced, which actually represent some "content" that is identified by meta-information. This is how one understands human knowledge, that is, as meta-information plus content. If we transfer this consideration to the tables of the WPad database application, then meta-information can be inserted into its columns, and one column can function as the content that identifies them. Such a table can be called virtual knowledge, and one row of the table thus represents its basic unit. Although the computer does not know what knowledge is, it knows that information is 0 or 1. However, it can process a database table extremely quickly because it is an information structure composed of zeros and ones. Such virtual knowledge is therefore a framework representation of knowledge from an informatics point of view (framework representations of knowledge are similarly used in the field of AI). Coincidentally, at that time, the authors discovered that they could rely on older cybernetic literature, which understands the educational process as the transfer of knowledge between a teacher and a student with feedback, based on which the teacher evaluates and controls the process. In cybernetics, a connection is also sought between the living mental processes of a person and the physical processes of a machine, which can be connected isomorphically. It follows from the formulation of virtual knowledge that it can actually function as an isomorphic switch between a person and a computer because, for a person, it is an ordinary table in which text is written.

However, this means that the automation of knowledge-based mental processes can be addressed as a simulation of any teacher's activities. The only requirement is that the teachers themselves design and schedule how they will describe the educational content or educational activity in text and hypertext. However, in practice, a big problem arises here, connected with the fact that filling in the columns of the table requires their structuring, that is, how the teacher, or the user in general, chooses meta-information. It turns out that teachers are not used to working with computers in this way. Figuratively speaking, teachers do not know how to think in a structured way. This is the only way to explain the fact that, over the years, the success rate of manually filling in tables for students even with poor IT skills has been 100%, while for teachers it has been only around 5%!

What is the difference between students and teachers? Specifically, a student comes to class and is told: "Open your WPad and write Semester work in the first column, Chemistry, semester in the next column and write the name of the semester work and the name of the pair who will undertake it in the text field." Since students do not have to deal with structuring (i.e., choosing the meta-information), they have no problem because they are able to use the computer keyboard. Teachers, unlike students who have received instruction, cannot fill in such a simple text table intuitively or without instruction. Hence, they do not realize the advantage that, through hypertext table fields, they can be connected online (Internet links) and offline (paths in the notebook's folders and files) or that they can automate their computer activities (using the WPad software with a rich user menu).

The insertion of content into the rows of the virtual knowledge table, which is identified by meta-information, is illustrated in Figure 2. Teachers can create the tables manually or the raw tables can be generated from the WPad menu. Subsequently, these can be modified pedagogically. In this way, teachers can establish their own information system for adaptive learning.

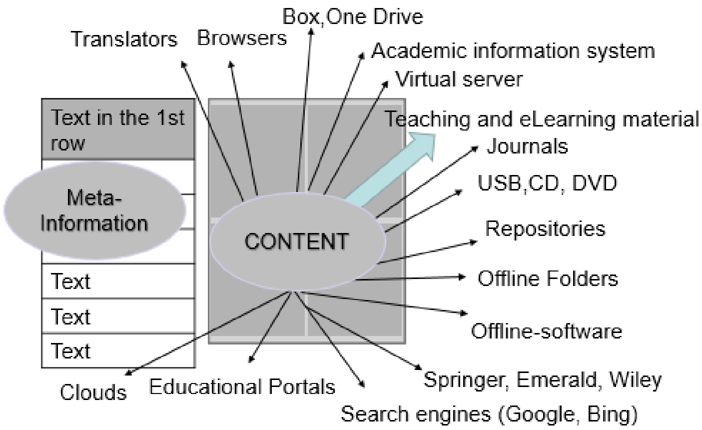

Figure 2. Scheme for inserting educational content from various sources into a virtual knowledge table

As an example of manual creation, we can mention the WPad (CHINA) table created for supporting the writing of this paper, as illustrated in Figure 3.

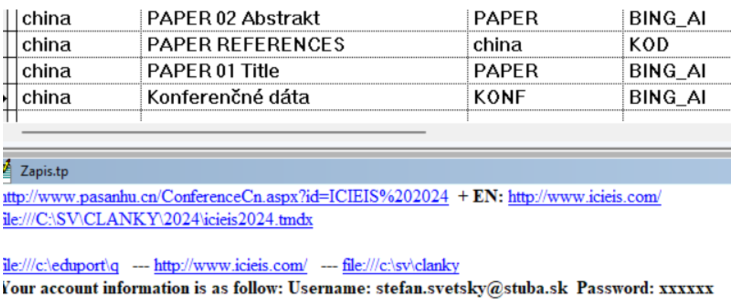

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Figure 3. WPad table illustrating the use of online/offline hypertext links

At the top of the WPad table is the meta-information Konferenčné dáta [conference data] identifying the content in the text field. This contains hypertext links from which one can link to the conference pages (icieis.com), file directories, and the manuscript of this article (link to icieis2024.tmdx).

3.3. Collaborative design of educational packages on a remote desktop computer

The creation of knowledge tables, the design of the WPad desktop application, and its modifications to the PIKS internet application, together with the use of the faculty cloud and a virtual learning environment for undergraduates, enabled the authors to build a personal IT system supporting various types of learning (blended, adaptive, distance, collaborative, and e- learning). As part of the international cooperation of teachers from the countries of the Visegrad Four (European Union) and Ukraine, the creation of so-called educational packages was collaboratively modeled from knowledge tables on a remote computer. In practice, this means that navigation tables and multi-search tables were automatically compiled from dozens of files of various computer formats that the researchers delivered to the cloud server. From them, teachers view the learning outputs via the default browser (EDGE) or the WPad environment. Figure 4 shows what the educational package can look like for teaching the Management study course.

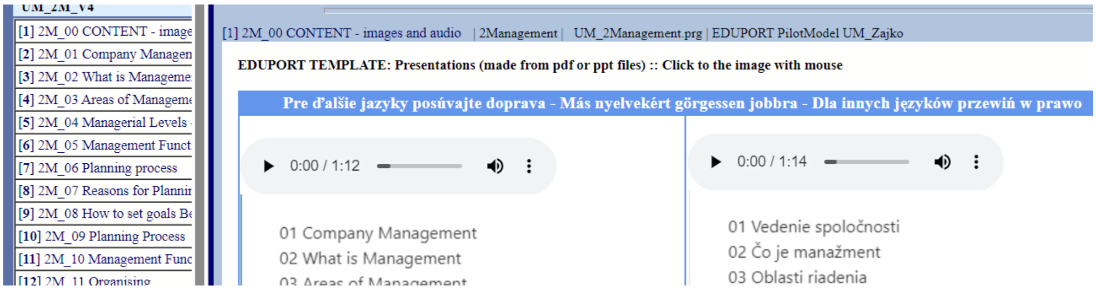

Figure 4. Educational package example: Multilingual audio-textual output

The desktop application WPad is installed on a virtual machine with a Windows 2022 server, and the teachers have it on their computers at the same time, so it enables table transfers between their computer and a remote computer on a client–server basis. As part of the solution, a beta version of WPad BVI was simultaneously developed, which the Polish partner of the project tested in teaching as a modification for blind and visually impaired students. Currently, the possibility of using the internet modification of PIKS for distance learning is also being verified. The teacher enters an online instruction, the students upload the files, and a WPad table with the students' answers is automatically created on the teacher's offline laptop.

Any technological support must simulate face-to-face teaching, that is, the knowledge flow from the teacher to the students. As explained above, it enables the use of virtual knowledge tables, the developed educational software, and the relevant IT infrastructure. Figure 5 shows such infrastructure, which was built as part of an international project for collaborative modeling of adaptive learning. The virtual knowledge flow within this IT infrastructure is linked to the utility model UV 8787 registered at the National Patent Office [24].

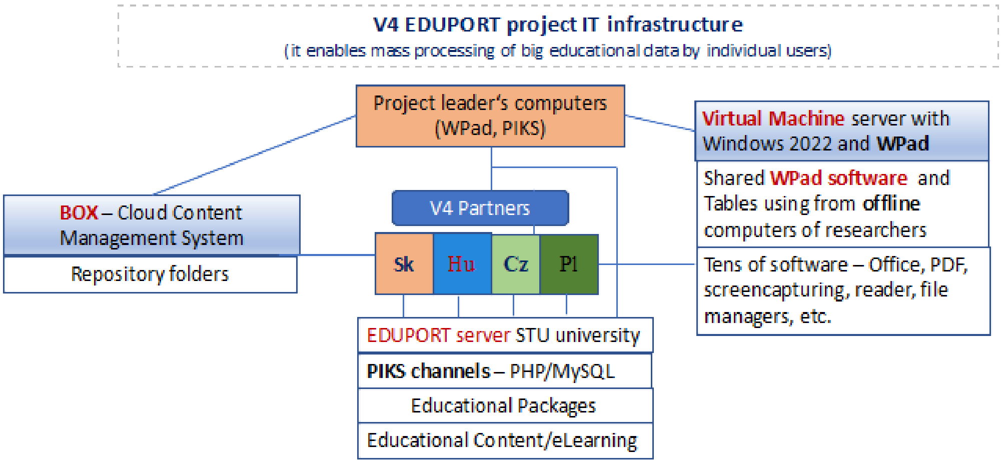

Figure 5. Personalized IT infrastructure for IT integration in education

3.4 CSU model of CSU infinite knowledge-processing time loop

Although there is a large number of articles in the scientific literature dealing with the digitization and integration of IT in education, or in monothematic journals in the field of social science and computer science, these do not deal with the fact that the flow of knowledge happens over time. In practice, however, this must primarily fit into a lesson, lecture, or exercise, and it needs to be adjusted over time. Technology should be able to solve these problems.

As mentioned, the authors conducted empirical PAR research (creating their own technology for the pedagogical algorithms that they designed). Although they are no theorists, based on more than 15 years of research, they have found a certain theoretical generalization that must guide any IT integration. This is an "Infinite Time Knowledge Processing Loop," as illustrated in Figure 6.

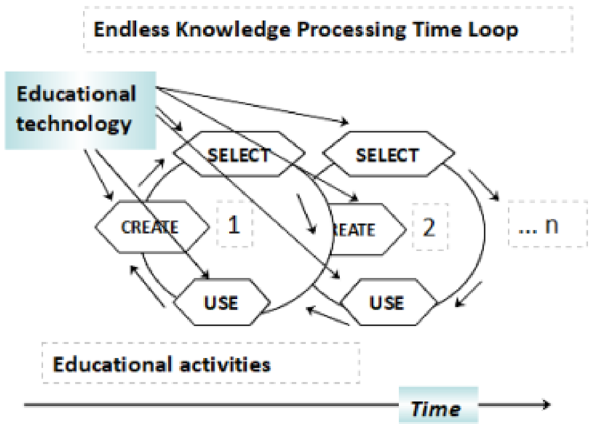

Figure 6. Create–Select–Use (CSU) infinite time loop model for knowledge processing

4 Conclusion

The current state of technological support for education cannot deal with the comprehensive integration of IT into teaching because technology cannot operate with the concept of knowledge. Despite the existing state of the art supporting infrastructure, the technology uses only abstract knowledge that the computer cannot understand. In the article, the authors presented a model of virtual knowledge, which a person can understand and calculate. Its software management in the form of WPad tables made it possible to automate educational processes in university education and research. The article brought closer a personal IT support system for teachers, suitable for all types of teaching, for example adaptive, blended, and collaborative teaching, including self-study. This system works under the Windows operating system. It is made up of WPad tables, managed by the educational software WPad, PIKS, and WPad BVI (for blind and partially sighted users), personal computers, a remote computer on a virtual machine with Windows 2022, and the university's web space. It is used by teachers from four Central European countries and Ukraine for the collaborative design of educational packages. From the IT point of view, it was explained that the system uses a paradigm of mass processing of information and knowledge based on database technology and the principle of a free table. From the standpoint of adaptive learning as part of learning technologies, the presented system can be considered an effective adaptive learning tool. The authors also outlined a theoretical CSA model of an infinite time loop of knowledge processing, which should guide the integration of IT into education. Since the presented automation of educational processes simulates mental processes, which are endless, it is also a given that future research is a never-ending story.

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