Virtual Labs and Geometrical Software as a Tool for more Effective Teaching

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Abstract

Significant development of information and communication technologies and Internet boom brings new possibilities in teaching STEM subjects at all levels of the educational process. In first part we want to present some results of international ICILS study 2013 related to the digital competences of pupils related to the computer aided education, which use virtual reality and computer simulations. The virtual reality is distinguished by unique sorts of interaction, that responds to users' behaviours and actions. It is considered to be a new model of computer-based learning that provides the individual learner with a wider range of scientific vision. In mathematics education it is important to represent and visualize various mathematical concepts, relationships and practices including algorithms. Visualization is usually implemented through different models. It is possible to present these models using virtual and remote laboratories. These models may have the form of real mathematical devices, but may also be implemented in a suitable virtual software environment. Virtual modelling has particular importance in the stages of cognitive processes in STEM education.

Keywords: Virtual Laboratories, motivation, simulations, e-learning, ICILS.

1 INTRODUCTION

Information and communication technologies bring to the educational process the possibility of using virtual laboratories especially in teaching STEM (Science, Technology, Engineering, Mathematics) subjects. For their effective use by pupils and students they need to have a certain level of computer and information literacy (Computer and Information Literacy - CIL). This problem has already been dealt with many countries around the world on different continents within the international comparative research ICILS - International Computer and Information Literacy Study.

The study compares the level of computer and information literacy of different countries. According to [9] Computer and Information Literacy (CIL) is the ability to use a computer to explore, create and communicate in order to participate effectively at school, at home, at work and in society. CIL combines technical competences and intellectual abilities to achieve communicative intent. CIL construct consists of two components - the collection and work with information and the creation and exchange of information. Each of them has some aspects:

1. Gather information and work with them:
• ability to use a computer and general knowledge about it,
• gathering information and evaluation,
• work with information.
2. The creation and exchange of information:
• transformation of information
• creation of information
• sharing information.

According to [10] in international study ICILS 2013 18 countries were involved - (Australia, Chile, Croatia, Czech Republic, Denmark, Germany, Hong Kong (China), South Korea, Lithuania, Netherlands, Norway, Poland, Russian Federation, Slovak Republic, Slovenia, Switzerland, Thailand and Turkey. The research was carried out in the eighth year of primary school. This comparison showed that Slovakia has significantly greater point gains 517 points as an average 500 points across studies ICILS. A similar level as Slovakia has the countries - Germany, Russian Federation, Croatia and Slovenia. A significantly higher level than Slovakia has - the Czech Republic, Australia, Poland, Norway, South Korea. A study provided interesting results for Slovakia on the question: On which school subjects usually or almost every hour do they use a computer. 82 percent of the students answered: informatics, that was more than the average of study ICILS. In mathematics, it was 11 percent and students in science subjects (Physics, Chemistry, and Biology), it was 17 percent. These subjects belong to STEM and it is significant that these results are worse for these items than the average of study ICILS. It is therefore important to conduct research and support activities to increase the use of computers in STEM subjects. For this aim we think that virtual laboratories and educational software are appropriate.

2 ACTIVITIES THAT SLOVAK PUPILS USE COMPUTERS AND INTERNET FOR, AT HOME AND AT SCHOOL

According 70 % of pupils of Slovakia involved in ICILS study claim that they use computer for at least 5 years, only 3 % of our pupils use computer less than a year. Approximately 95% use computers at home at least once a week, at school 77 % and at other places (e.g. library, internet bar) 12 % of Slovak pupils.

Usage of computers and internet at school and for school purposes

Tab 1. Slovak pupils use computers out-of-school at least once a month for following scholar reasons.

52 %	To prepare papers and essays	+
51 %	To preparing presentations	+
41 %	To cooperate with other students of the same school	*
35 %	To elaborate worksheets or exercises	-
30 %	To elaborate tests	*
27 %	To organize time and work	-
14 %	To cooperate with other students from other schools	*

Tab 2. Slovak pupils use computer on most or every class on subjects.

82 %	Informatics	+
18 %	Humanities (history, geography, civics, etc.)	*
17 %	Natural science subjects (physics, chemistry, biology)	-
16 %	Foreign language	*
11 %	Other subjects (practical and technical subjects, ethic/religious/physical education)	*
11 %	Mathematics	-
10 %	Art subjects (art / music / dance / drama education)	*

10 %	Language (Slovak or Hungarian)	-

Tab 3. Slovak pupils learned following tasks at school.

84 %	Gain the access to the information using computer	*
76 %	Present information using computer to given audience or given purpose	*
71 %	Decide where to seek for information about given topic	*
71 %	Decide which information is important to be included into the project or task	-
68 %	Search for different types of information about the given topic	*
67 %	Mention links to the internet sources	-
63 %	Sort the information gained from the internet	-
59 %	Check the credibility of information from the internet	-

Tab 4. Slovak pupils use computers in out-of-school time at least once a week for following activities:

25 %	To create and edit documents	-
22 %	To create simple presentations	+
18 %	To create multimedia presentations	+
18 %	Use graphic and drawing software	*
14 %	Use spreadsheets for calculations, saving data and creating graphs	+
14 %	Use educational software, designed to help with learning process	-
11 %	To create computer programs, macros and scripts	*

Tab 5. Slovak pupils use internet in out-of-school time at least once a week for following activities:

87 %	To type messages using communication software or social network	+
60 %	Voice communication, on-line chatting with friends and family	+
53 %	To poste comments to on-line profiles or blogs	+
47 %	To poste pictures, photos or videos to profile on social network	+
42 %	To search information for study or school project	-
39 %	Use WIKI or on-line encyclopedia for study purpose or school project	-
29 %	To respond to the questions from other people on forums or web pages	+
24 %	To write posts on their own blog	+
21 %	To ask questions on forums or web pages	*
14 %	To create or edit web pages	+

Tab 6. Slovak pupils use computers for out-of-school activities at least once a week for:

88 %	Listening to music	+
74 %	Watching downloaded videos or streamed videos	+
69 %	Using the Internet to obtain news about things they're interested in	+
61 %	Playing games	+
38 %	Reading reviews, comments about things they would like to buy	+
35 %	Searching information about places they want to visit or activities they want to do	+

+ the percentage of students is significantly bigger in SR compared with the average of ICILS

- the percentage of students is significantly smaller in SR compared with the average of ICILS

* the percentage of students representation is comparable in Slovakia and the average of ICILS

3   SIMULATIONS IN MATHEMATICS

ICT can support creation and processing of teaching materials during the teaching process by ICT users' tools, creation of educational simulations and tests along with an assessment of knowledge by testing programs and evaluation of educational outcome.

visualization is an important aspect of ICT aided education. Within the framework of mathematics education, it can bring forward the following points:

- Effective approach while looking for the results, solving the problems and discovering the very structure of the model.

- Visualisation of relations in the model allows to infer new results in other areas and fields of mathematics and other subjects related to the mathematics.

- Support of mathematical competences and basic competences in science and technology; digital competences.

GeoGebra software supports the realization of these aspects aspects. This software connects features of a computer algebra system, a dynamic geometric software and spreadsheet. Its big advantage is a user friendly interface and possibility to create dynamic HTML websites with interactive pictures (see [7]). Materials developed by GeoGebra can be found on GeoGebra Tube website. Here we can find teaching materials for Mathematics at school (http://www.geogebra.org/en/wiki/

index.php/Slovak). These materials, simulations and applets use the interactivity and dynamical character of software. Moreover, topics of materials follow the Slovak curriculum from calculus and geometry (e.g. topics of an exponential and logarithmic function, cube or hexagonal prism, constructions of triangles, parallelograms). The website contains also materials for teaching physics and computer science. Here are some examples of them.
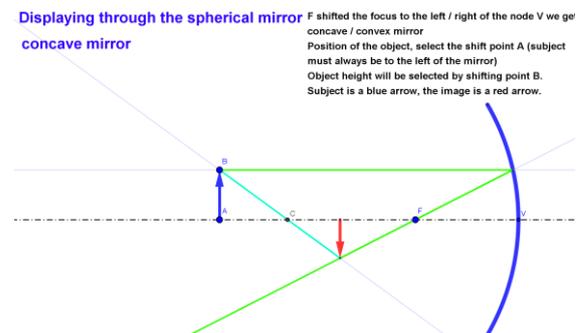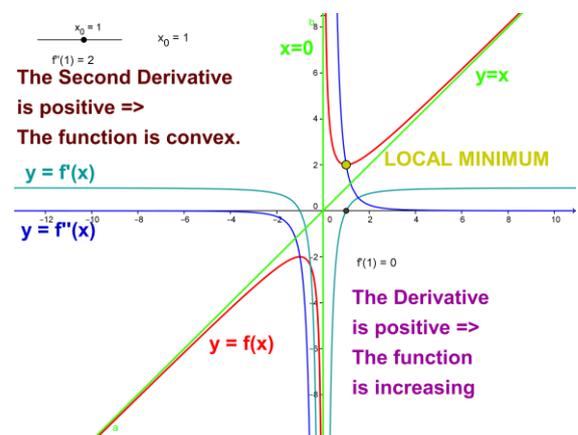

Figure 1: Concave mirror

Figure 2: Derivative of the function

3 GEOMETRY SIMULATIONS IN STEM EDUCATION

Historical mathematical textbooks is a good source for motivation in mathematics education. We present some examples from the Franz Močnik textbook *Visual Geometry* (see [18]).

Example 1. Construct three circles with the radii *m, n, p* where each circle touches the other from the outside.

Solution: We construct the triangle *ABC* with sides $|AB| = m + n$, $|AC| = m + p$ and $|BC| = n + p$. Now we construct the circle with center *A* and radius *m*, the circle with center *B* and radius *n* and the circle with center *C* and radius *p*. The circles fulfill the objective of the task.
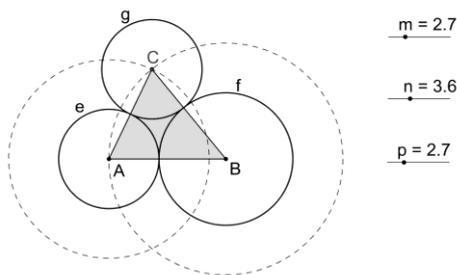

Figure 3: The solution of the example 1 in GeoGebra

Example 2. We have made three circles of the same size, e, f, g, which touch each other outside. We must now circumscribe a fourth circle k, which the previous three circles are inside of.

Solution: Example 2 is a continuation of example 1 and has a logical connection to it. First we construct three circles of the same size, *e, f, g* in a similar way, to example 1. The circle *k* has its center in the orthocenter of the triangle *ABC*.
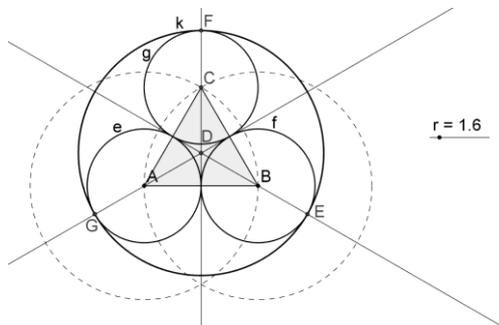

Figure 4: The solution of the example 2 in GeoGebra

This kind of simulations are used already used in some other student's project. One

example is GeoGebra project in secondary school Liceo Scinetifico Isaac Newton (see [17]). Generally, we can according to [16] present following classification of didactic material resources:

I.   *Teaching aids*
1.   Original objects and real things:
     a)   Natural:
          -   In their original state
          -   Processed
     b)   Artefacts and manufactured products – in their original state
     c)   Phenomena and processes – physical, chemical, etc.
2.   Images and representation of objects and reality:
     a)   Models – static, functional, construction
     b)   Images:
          -   Presented directly
          -   Presented with the help of didactic equipment
     c)   Sound recordings
3.   Written tools:
     a)   Textbooks – classical, programmed
     b)   Workbooks – worksheet, collection of tasks, atlases
     c)   Supplementary and auxiliary literature – magazines, encyclopedias
4.   Briefings and programs presented using didactic equipment:
     a)   Briefings – television, radio
     b)   Programs – for teaching machines, systems and computers
5.   Special equipment:
     a)   Experiment equipment
     b)   Equipment for physical education

II.   *Technical learning resources*
1.   Sound equipment

2. Visual equipment:
   - Slide projector
   - Overhead projector
   - Dynamic projection
3. Audio-visual equipment:
   - Film projectors
   - Video recorders
   - Video equipment
   - Computer multimedia systems
4. Technical control and evaluation:
   - Computer systems
   - Personal computers
   - Simulators

III. *Organizational and reproduction equipment*
   - Dark room
   - Photocopiers
   - Radio and video studios
   - Computer networks
   - Database systems

IV. *Classroom and their equipment*
   - Specialized classrooms, labs
   - Laboratories
   - Workshops, school grounds
   - Gyms, theatres

V. *Equipment for teachers and students*
   - Stationery
   - Drawing and designing tools
   - Calculators and notebooks
   - Gym clothes, work clothes

4 VIRTUAL LABORATORIES AND SIMULATIONS IN STEM SUBJECTS

Practical experience is an important part of the educational process. However, there are time and economic issues at many schools. The solution to this problem can be found in the use of virtual reality technology that could allow the creation of a virtual laboratory (VL) that will simulate the processes and activities similar to those in real labs.

One of the unique capabilities of the technology of VL is successful translation of abstract concepts into visualized events with possibility of user interaction [7].

One of the trends evolving in this direction is an experimental learning, where users are not just passive receivers of information. Experimental learning requires a high degree of interactivity

1. sharing resources is becoming a reality, improving the utilization of expensive equipment,

2. access to educational and research material is easier for students and teachers,

3. standards of scientific research are established in areas where practical experimentation is mandatory part of the research,

4. reducing travel costs and increasing productivity.

VL have as main objective the creation of virtual learning environments in order to provide further practical teaching material and teaching experience in disciplines such as computer science. VL further provide communication and collaboration tools such as chat, application sharing, etc. to simulate the interaction of participants. Users access the system using a web browser.

Well designed laboratory activities can provide learning opportunities that help students to develop concepts. They also provide important opportunities to help

students learn how to examine construct scientific arguments and justify these arguments in the community. In order to achieve important but challenging goals, the education system must provide time and opportunity for teachers to communicate with their students, as well as sufficient time for students to perform complex investigative tasks.

It is clear that there are serious discrepancies between what was recommended for teaching at lab classrooms and what actually occurs in many classes.

Explanation may lie in the differences in the perception of teachers and researchers. For example, teachers can be seen that they do not have the time or skills necessary to implement such methodology. Educational research should produce information to inform the development of strategies, protocols and resources for teaching and professional development for teachers.

At a time of rapid changes in science and technology, teachers need to be informed on current professional issues. The development is very important and requires attention not only teachers and their professional associations, as well as educational policy-makers at all levels of schools, municipalities and governments.

5 BASIC FUNCTIONS

The main objective of the educational VL is to provide all the simulation tools, applications and conditions that will be an effective space where experimentation, communication and collaboration can be used for maintenance and exchange of knowledge. This means that the virtual environment used for laboratory, tries to simulate the learning process from the very beginning to its end. Users should simulate the real process as realistically as possible.

Traditional laboratory was a part of an integrated training comprises using a laboratory considerably predefined experiments that simulate the essential phenomena taken from the real situation. Unfortunately, this system has its flaws and demanding requirements.

VL appear to be more advantageous than the actual laboratories particularly for specific experiments. There are tests that can be simulated on computers only.

Virtual reality offers a pleasant representation of information, interaction with a system that does not require advanced knowledge of computer technology and lower costs compared to other technology.

6 USAGE OF THE VIRTUAL LABORATORIES

1. Support of teaching theory
- illustration and demonstration of events
- application of theory to real situations
- demonstration of the theory of constraints
- Interaction with phenomena in authentic life situations
2. Create a set of knowledge
- on materials, equipment and technology
- the safety rules and practices
- of special equipment and technology
3. Create a set of skills including
- manual skills
- critical observation, interpretation and evaluation
- diagnostic skills
- planning and organization
- solve practical problems
4. Develop attitudes that

- stimulate interest in science
- create confidence in all areas

We assume that the VL can contribute to the development of these skills as realistic images of laboratory situations provide opportunities for learning.

We define VL as a software simulation experiments which data output is indistinguishable from data of real experiments.
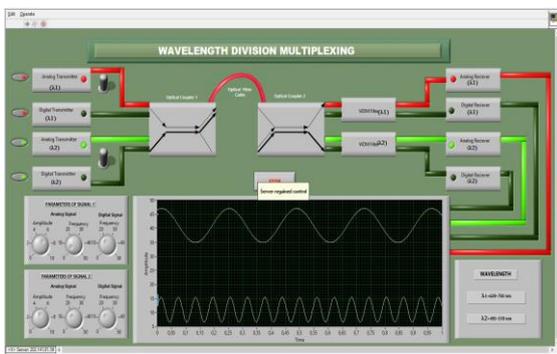

Figure 5: Virtual Labs in Fiber optics subjects [15]

VL opens up new challenges, such as separation of imperfections in learning technologies and methodologies and developing strategies for the assessment, providing reliable feedback on the students' abilities. VL can also be enriched with video guidelines for adjusting. The video should include instructions on how to connect the optical circuit devices used in laboratories, and instructions for measurement.

Tab 7. Questionnaire 1

AD – Absolutely Disagree, D- Disagree, A-Agree, AA-Absolutely Agree

QUESTION	AD	D	A	AA
VL increased my understanding of the LASER	15	8	77	0

Setting up wavelengths was simple	9	33	59	0
My understanding of fiber loss is now better	0	0	66	34
Measuring the strength of optical signal in the fiber was simple	0	2	72	26
Control of VL was simple and intuitive	0	19	71	10
Functions of measuring equipment were clear	5	12	68	15
VL gave me the similar experience as a real laboratory	4	16	60	20
Instructions to measurements were easy to understand	0	9	81	10

Tab 8. Questionnaire 2

QUESTION	Yes	No
Were you able to identify the used various connectors?	98	2
Were you able to perform the experiment?	100	0
I was able to measure the output peak power for different lengths of fibers.	95	5
Laboratory helped me to better understand the concepts.	100	0
I was able to set a different wavelength ranges in Optical Spectrum Analyzer.	100	0
I was able to set the correct OSA and gain characteristics of the spectrum.	95	5

Tab 9. Questionnaire 3

QUESTION	Yes	No
Control speed of laboratory was sufficient.	100	0
Remote control software is simple to use.	100	0
Visualization tool was clear.	90	10
It was easy to read data from the devices.	100	0
The web interface was easy to follow and understand.	85	15

7 VIRTUAL LABORATORIES IN THE WORLD

Open University, since 1969, offers distance studies and has more than 240,000 students worldwide. Until the late 90's, the science courses provide students with kits that include microscopes, printed circuit boards, chemistry sets, containers or even lasers. Students experimented at home and then sent the unit back. But it was expensive and not very practical.

Currently, almost all laboratory work is available online via the university Open Science Laboratory. Like many working scientists, students can collect real data from remote controlled devices. Students can also explore realistic simulated data from tools like a virtual microscope with which we look at the high resolution images instead of real samples.

Transformative Technology Lab at Stanford University in California, goes on with a new generation of digital laboratory courses. One example of using remotely controlled centralized tools for biological laboratory - a project developed with

Ingmar Riedel-Kruse is bioengineering at Stanford.

One of the key elements in effective mentoring is a conversation, says Graesser. When people only read books or listen to a lecture receive a smattering, Graesser and his colleagues, for example, developed a system based on trilogies in which the student interacts with two computer animated agents - teachers or students. Real students can interact with the teacher directly, or they can deepen their knowledge by learning with peers.

One of the biggest barriers to wide adoption of systems for the teaching of practical skills is that many single experiments are not associated with MOOCs or anything else. Once the project is completed, you can put your application on any website where they can be almost none found, said Daphne Koller, co-founder of the largest MOOC company courser in Mountain View, California.

Courser is trying to change, says Koller - not only by encouraging experimentation, but also rewriting their own software in order to offer practical applications next lecture courses. It is hoped that creating a single market for these applications, and gives them a much wider exposure.

Computer science has invaded the educational process and is providing us with many opportunities to exploit. An additional challenge faced by STEM educators has been the integration of Inquiry Based Science Learning (IBSL) in teaching. While the use ICT has already penetrated in Inquiry Based Teaching, we have yet to create and implement STEM lesson plans that promote the development of methodological skills and competencies, investigation through experimentation,

teamwork and communication among students through collaborative activities.

In recent years, Inquiry-Based Science Education (IBSE) has proved its efficacy in education by expanding on "traditional" lessons and motivating students to actively participate in science [11]. Virtual laboratories are an essential digital tool. In fact, many European schools are equipped with computer classes, tablets and high-speed internet connection while using a huge variety of web-based learning applications, simulations and visualizations. [3]

8 DESCRIPTION OF VL ENVIRONMENTS

We can divide VL environments into following categories [16]:

Simulations

Simulations are imitations of operating systems through time, via computers. These represent a process on the basis of a model that is cheaper, faster, less risky and more affordable than the real process.

Network applets

The applets are experimental devices in small virtual laboratories and are quite popular in science subjects. They are small in size and easily transported and they can be used regardless of the operating system type.

Virtual labs

Virtual labs (virtual laboratories) simulate a virtual operating system, the computer screen, Science laboratories, exploiting the potential offered by modern media technology key feature technical

interaction and direct and plausible manipulation of objects and parameters.

Virtual Reality Laboratories (VRL)

VRL workshops are computer based and highly interactive. The user becomes a participant in a "virtually real" world, in an artificial three-dimensional optical environment. These workshops are essentially an interface high level including real time three-dimensional simulations through different sensory channels.

Laboratories Controlled by Distance (Remote Labs)

Workshops controlled remotely (remote labs, otherwise known as online labs or workbenches) include real experiments conducted from a distance with the use of telecommunications, while the user uses this technology from another location.

Most of the virtual laboratory software consists on computing applications running on the local user's computer, for speed and security reasons. They can be operated remotely. An example are those based on applets or robotic workshops (remote labs) that can accept commands via the Internet [12]

9 BENEFITS OF USING VL IN TEACHING AND LEARNING SCIENCE

Virtual labs can be very useful, especially in cases where:

The experimental activities need to be done quickly and observation and safe measurement are not easy,

- experimental process is very slow and complex and there is not enough teaching time available,

- experiments involve health risks

- learning activities require modeling.

VL encourages collaboration and communication between teachers and students. STEM teachers participate actively in the learning process: asking questions, trying to find answers, organizing procedures and commenting on them, helping in formulating conclusions, understanding their mistakes and highlighting any misconceptions.

But what are the differences between real life experiences and those formed by representations in a computer screen?

With VL, students acquire a tool with which they can experiment without limitations of time or space. They are available all year round, as opposed to school laboratories, limited to a specific place and for a limited time. [4].

The use of virtual environments makes students acquire better computer skills, which can be considered skills for lifelong learning. The use of these technologies also bring together different STEM subjects and provides with great resources for more inclusive workshops [8].

10 ROLES AND POSSIBILITIES OF THE ICT IN COGNITIVE LEARNING THEORIES

Accoding to Malach, Malčík, Mechlová in [19] the place of the ICT in cognitive learning theory can be derived from the reasoning of the Instructional Design (ID) model. The ID should be based on 5 easy principles: 1) individualization of teaching, 2) establishing short-term and long-term aims, 3) need for planning and organization, 4) use of the system theory, and 5) respect to learning conditions. Fulfilling the mentioned principles when creating teaching programs can be well linked with the ICT applications. This option is evident mainly when individualizing the teaching process (ad1) or when using a systemic approach (ad 4), which provides an organizational frame for ID and at the same time does not neglect any of the inputs, process files and results of the teaching process.

The potential applications of the ICT in this learning concept can be also deduced from the teaching process sequence of events, which result from systemic and systematic organization of the teaching process. The organization is as follows: 1. Attract student's attention; 2. Inform student about aims and set the level of the expected results; 3. Remind the already learnt contents; 4. Introduce a new subject matter clearly; 5. Control learning, require proofs; 6. Ensure feedback; 7. Evaluate a student's performance and support the transmission of knowledge and its application in other areas.

This enumeration of the obligatory and logic steps in the teaching process justifies the use of the ICT in the presentational, feedback, regulative, evaluative (both from the viewpoints of hetero-didacticism and auto-didacticism) functions.

11 CONCLUSIONS

The virtual Lab Concept was defined as laboratory experiment without real laboratory with its walls and doors. It enables the learner to link between the theoretical aspect and the practical one, without papers and pens. It is electronically

programmed in computer in order to simulate the real experiments inside the real laboratories.

There exists many simulations in the mathematics education developed by GeoGebra. The GeoGebra research community has already international character which brings the opportunity to exchange the experiences in the field of motivation of pupils and students in mathematics and STEM education.

Visualisation through simulation in STEM education helps students to understand new notions, relationships between them and incorporate this new knowledge in existing structure. It is important for development of different levels of thinking in science education. Simulation is possible to use in many e-learning courses for STEM education and other fields such aviatics (see [2])

Real experiment is impossible to change through virtual experiment in educational process. The role of the virtual experiment is such supporting tool for better understanding of principles of demonstrated phenomena. If teacher has possibility to realize virtual experiment using computer simulation, he can develop important students´ skills needed for their professional life not only in STEM field, but also in other fields (see also [15]).

Acknowledgment

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