SOFIA UNIVERSITY ST. KLIMENT OHRIDSKI
PHYSICS FACULTY
DEPARTMENT OF METHODOLOGY OF PHYSICS EDUCATION

ABSTRACT

of dissertation work

Creating and using information systems for team problem solving in physics education

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for the award of the degree of Doctor of Education and Science
field of higher education: Pedagogical sciences
professional field: teaching methodology of ...
doctoral program: teaching methodology of physics

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SOFIA 2023

The dissertation is structured in an introduction, three chapters, a conclusion, contributions, publications related to the dissertation, a bibliography and five appendices. The dissertation consists of 192 pages, of which 173 pages are the main text. 197 sources are cited, of which 179 in English and 18 in Bulgarian. The dissertation contains 10 tables and 45 figures.

The main results of the thesis have been published in 7 author publications and reported in 18 papers at international and national conferences.

Contents

Introduction

Education is one of the key pillars of any modern and prosperous society. It has the responsible task of preparing students for their fulfilment in the social and economic life of a country and the world at large. Due to their conservative nature, education systems cling to the traditions they have in teaching. We live in a rapidly changing world. Technological progress brings new problems that change social and economic life dramatically. The coronavirus crisis has shown that human civilisation is still very fragile, and dramatic changes are possible that could cause consequences previously unthinkable. People are confronted with new, previously unresolved problems for which the school system must adequately prepare them. This calls for a flexible combination of conservative teaching methods with new ones that meet the contemporary demands and needs of our society.

Since the beginning of the 21st century there have been strong arguments for the need to change education systems. Educational systems need to be more modern and more flexible in order to successfully prepare students for the demands of the 21st century (Kozma, 2009). Due to the growing need for change in education systems, key global organisations such as the United Nations' UNESCO, the European Union, the OECD's PISA programme and others have recommended that the new skills and competencies needed by today's students should be reflected to a much greater extent in relevant national education programmes. The key competences that students need for their successful integration into society and for their successful careers are critical thinking, creativity, collaboration and communication skills. The 21st century skills are critical thinking, communication skills, creativity, problem solving, collaboration, information literacy, technology and digital literacy, media literacy, global awareness, social skills, scientific literacy, civic literacy, social responsibility, and innovation skills (Ananiadoui, Claro, 2009; Larson, Miller, 2011). In addition to the skills and competences mentioned above, the European Union educational frameworks and documents refer to independent learning, effective communication in mother tongue and in a foreign language, initiative and understanding of cultural differences. In addition, European education documents explicitly mention the subjects of mathematics and science (physics, chemistry and biology) as key to the successful personal development of European students.

One of the first global initiatives in this regard was the 21st Century Skills Teaching and Assessment (ATC21S) project (Griffin, McGaw, Care, 2011). Constructed by a coalition of global companies and supported by the active participation of six countries during the exploratory phase, its main goal is to answer the question of what the new requirements for today's students should be in order to successfully meet future demands on their skills and competencies. One of the conclusions drawn is that there is a need for an educational reform in which the implementation of ICT and so-called 21st century skills take centre stage.

There are several frameworks and structures made by different organizations that seek to give the general idea and structure for the transition of today's education systems to modern systems that prepare today's generation for the challenges of the 21st century. Let us just mention some of them. These are ATC21S, LMTF, ERI-NET, NEQMAP, DeSeCo, PISA, etc.

Collaborative problem-solving and problem-solving was selected by the Organisation for Economic Co-operation and Development (OECD) as a new competency that was explored in the 2015 PISA international survey. There are many reasons for collaborative problem solving to be a focus. International research indicates that collaborative problem solving is a key competence for the successful integration of adolescents into society and the workplace. It is also believed that much of the planning, problem solving, and decision making will be done by and through teams and teamwork (National Research Council, 2011). Therefore, a key issue facing the research and education community is the successful integration into today's education systems of group and project-based learning and the teaching and assessment of teamwork and collaborative problem solving as part of an integrated and 21st century skills system.

The implementation and application of the new competences are important for the Bulgarian educational environment. This is evidenced by the relatively low results achieved by Bulgarian students in the PISA tests. For example, in the 2012 PISA survey on the problem solving module out of 43 participating countries Bulgarian students ranked 42nd (PISA 2012 Results), and in the 2015 PISA survey on the collaborative problem solving module out of 51 participating countries Bulgarian students ranked 40th (PISA 2015 Results). These examples show that serious changes are needed in the Bulgarian learning environment to bring about qualitative improvement in 21st century skills and competences.

Research aims and objectives

The aim of the dissertation and the research is to develop a concept, tools and models for the formation of students' teamwork skills in the teaching of physics and astronomy at the junior high and high school levels and for the formation of the key competence of collaborative problem solving in a learning environment. This learning environment can be an in-person or online learning environment.

The research objectives of this dissertation in relation to the set aims are as follows.

1. Describing good international practices in the implementation of the new skills and competences defined in the framework of 21st century skills and competences and in particular the competence of team problem solving.
2. Exploring the best possible practices and methodologies that would yield good results when actually implemented in a Bulgarian school environment.
3. Selecting models and practices that best meet the needs of Bulgarian education.
4. Creation of a theoretical model with appropriate methodology and tools to be applied in physics education.
5. Creation of an information system for training the competence of team solving physical problems based on the established methodology.
6. Practical research and application of the developed theoretical models, methodologies, techniques and information environments, which includes:

6.1. determining the level of collaborative problem-solving competence of a selected sample of junior high and high school students;

6.2. applying the model for developing teamwork skills;

6.3. analysis of the effectiveness of the model in terms of the formation of teamwork skills according to the defined criteria.

7. Analysis and interpretation of results. Revise the theoretical model and information system if necessary.

8. Proposing a workable model for the implementation of collaborative problem solving competences in school physics and astronomy courses in the Bulgarian education system.

Object, subject and scope of the study

The object of the study were students from high school and junior high school who are taught according to the curriculum of physics and astronomy in general education.

The subject of the study is the students' ability to solve physics problems in teams. Team problem-solving, or we will also call it collaborative problem-solving, is a skill that we define as an *individual's ability to participate effectively in a process in which two or more participants attempt to solve a problem by sharing the understanding and effort needed to solve the problem and by pooling their knowledge, skills, and efforts to arrive at the solution* (PISA 2015 collaborative problem-solving framework). Collaborative problem solving and problem solving is viewed as a product of skills – problem solving and teamwork. Problem solving is considered as consisting of four processes. These are exploration and understanding, presentation and formulation, planning and implementation, and monitoring and feedback. Teamwork is divided into three main processes. These are establishing and maintaining a shared understanding, taking appropriate action to solve the problem, and establishing and maintaining team organization. In crossing these processes, we get the corresponding sub-skills that build the competence of collaborative problem solving. These sub-skills will be defined and explored in this dissertation.

Work on the research and writing of the dissertation took place during the academic years 2020 to 2022. Due to the emergence of coronavirus in this period, research in the school setting took place in both face-to-face and online environments, that is, we had a hybrid model of learning during this period. The school in which the study was conducted was 125th School "Boyan Penev" in the city of Sofia.

Hypothesis and methods of the study

The main hypothesis of the study is that with an appropriately chosen methodology to be implemented in physics and astronomy education, a significant improvement in students' team problem solving skills can be achieved. For this purpose, a selected collaborative problem solving concept will be used, which will be described in detail in our work.

The main methods to be used for the pedagogical study are stratified sampling and quasi-experimental design with a control group.

Participants in the study were junior high and high school students in Metropolitan 125th School "Boyan Penev". The school has eight seventh grade classes. Six of the classes are language classes and two of the classes are mathematics classes. Three of the language classes and one of the mathematics classes will be randomly selected to be in the treatment group and the other three language classes and the other mathematics class will be in the control group respectively. In eighth, ninth and tenth grades, two classes per grade are included in the study, for a total of six classes. With one humanities class and one mathematics class for each grade. Each class is divided into two groups. One group is in the control group and the other group is in the treatment group.

A quasi-experimental method with a control group will be implemented to conduct the pedagogical experiment (Haralampiev, 2012) to establish the level of team problem-solving competence and to establish the differences in the initial and final phases of the experiment between the two groups.

The target group, which represents junior high and high school classes, will be divided into a control group and an experimental group. The actual split will be done by stratified sampling.

To accomplish the research task, an information system will be created to support the development and improvement of students' competencies in both problem solving and team problem solving.

Chapter One: Team Problem Solving

Developing the idea of team activity

Teamwork in training has been talked about methodologically since the years of the creation of training methodologies. It also occurs as a group activity and there is research on its effectiveness (Rottier, 1996, Todorina, 1994). Group learning is part of reformist ideas in education and emerged in the early 20th century. Ideas about group learning are dealt with in educational sociology, group dynamics theory and small groups. In Bulgaria, Byzhkov wrote about cooperative work between students within one hour or joint activity in organizing various cognitive activities (Byzhkov, 1994).

The idea of cooperative (group) learning found its most fruitful development in France with the ideas of Roger Cousinet (Cousinet , 1950) as a method of free group work in which children divide their duties, coordinate their actions and finally discuss the results.

Putting the student at the center of learning is the humanistic idea of collaboration and interaction. This is what Jacques Delors "Learning to live and work together" called for in 1996 (Delors, 1996) .

21st century skills

The main goal of education is to prepare the adolescent generations to successfully participate in social and economic life. Therefore, a major driver for the need for change in education will be changes in social and economic life. About 65 percent of children entering first grade are expected to take up entirely new jobs that do not exist at that time (World Economic Forum, 2016).

Most conceptual frameworks agree that 21st century skills include problem solving, critical thinking, teamwork skills, ICT skills and creativity (Griffin, McGaw, Care, 2012; O'Neil et al., 2004; OECD, 2009; Trilling, Fadel, 2009).

In Australia there is a government agency called ACARA (Australian Curriculum, Assessment and Reporting Authority) which is responsible for curriculum, assessment, analysis and feedback in education. In 2013, this agency identified seven key competencies that students should develop throughout their education. These are reading literacy, numeracy (mathematical) literacy, ICT skills, critical and creative thinking, personal and social responsibility, ethical understanding and behaviour and intercultural tolerance(ACARA, 2013).

Many of these activities are also directly related to team problem solving.

Singapore's Ministry of Education has established a curriculum framework for students' 21st century skills and competencies (Singapore Ministry of Education, 2015). The main aim is for students to be confident individuals, have the skills to learn independently, contribute to the common good and be conscious citizens. For students to be successful in a globalising world, they must have the 21st century skills. These skills are global concern, intercultural tolerance, critical and inventive thinking, ICT skills and communication skills.

The Partnership for 21st Century Skills is a program established in 2002 to bring together business with educational institutions and governing bodies to prepare the American education system for the new demands of the 21st century (Trilling, Fadel, 2009). The skills themselves are divided into three broad groups. One group is information, communication, and technology skills. The second group is critical thinking, creativity, communication, and teamwork skills. And the third group of skills are life skills and work skills (career development).

The European Framework for Key Competences and Lifelong Learning of 2006 and subsequent revisions and additions are key documents that define the common principles and values of learning and education in the European Union (European parliament, 2006; European council, 2018). It defines 8 key competences: literacy, multilingual competence, mathematical competence and competence in science, technology and engineering, digital competence, personal competence, social competence and competence in learning skills, citizenship competence, entrepreneurial competence and competence in cultural awareness and expression.

The competence approach is also embedded in Bulgarian education. The competences are set out in the Pre-school and School Education Act (Pre-school and School Education Act) and also in several documents on the implementation of competences in the school environment (MES, Competences and Education, On the Transition from Knowledge to Skills, Competences and Frameworks of Reference, Practical Guide, Key Competences in School Education Subjects). Nine key competences are set out in the law. The first eight competences are directly transposed from the European Framework for Key Competences and Lifelong Learning. The ninth competence is skills to support sustainable development and healthy lifestyles and sport.

Defining teamwork skills

Teamwork in the educational system, especially in schools, can be defined as the collective effort of a group of individuals, such as students or teachers, working together toward a common goal or task (Morgan, Salas, & Glickman, 1993; Wilczenski, Bontrager, Ventrone, & Correia, 2001). This involves sharing ideas, resources, and responsibilities to achieve a desired outcome (Aronson et al., 1978). In schools, teamwork can take place among students in group projects or among teachers in planning and implementing lessons or curricula for better and deeper interdisciplinary connections across subjects (Dillenbourg, 1999). Teamwork requires effective communication, collaboration, and respect for the contributions, skills, and perspectives of each participant. Through teamwork, individual participants can develop important social and emotional skills, such as problem solving, leadership, and empathy, and at the same time achieve better learning outcomes (Thompson, Wang, & Gunia, 2010; Cohen, Lotan, Scarloss, & Arellano, 1999; von Davier & Halpin, 2013; Woolley, Chabris, Pentland, Hashmi, & Malone, 2010).

Defining problem solving skills

Problem solving is an important and sought-after skill in both educational and business environments. And there is perhaps no known and recognized 21st century skills training program and framework that has not included problem solving as a key priority. Problem solving requires thought processes, the application of a plan and a solution strategy that helps students develop their cognitive and metacognitive processes (Garofalo & Lester, 1985). According to research, students who have high proficiency in problem solving skills are able to do qualitative analysis of the problem, have good self-regulatory abilities, understand their strengths and weaknesses, can adapt different methods and strategies to solve the problem, and can make interpretations of the problem and the results (Chi, Glaser, & Farr, 1988; Lester, 1994; Gerace, 2001).

Defining team problem solving competence and comparing existing frameworks

Team problem solving has become an essential part of the research on 21st century skills (Griffin, McGaw & Care, 2012). It enhances student cognitive skill development (Webb, Nemer, Chizhik, & Sugrue, 1998; Zhang, 1998). Team-based problem solving contributes to students' improved responsibility and self-reporting skills, their ability to ask appropriate questions, clarify answers, and their abilities to compromise and make collective decisions (Baghaei, Mitrovic, & Irwin, 2007; Soller 2001; Webb, 1998).

The framework proposed by ATC21s defines team problem solving skill as a skill that consists of a social aspect and a cognitive aspect (Hesse, Care, Buder, Sassenberg, & Griffin, 2015).

Figure 1. presents the competence of collaborative problem solving according to PISA (PISA Framework, 2015). This competence is represented as a matrix that is the product of the two vectors problem-solving competence and teamwork competence. Thus formed, the matrix consists of 12 skills that make up the collaborative problem-solving competency.

The CRESST framework for assessing students' team problem-solving skills brings together, in a common model, the teamwork and problem-solving models (O'Neil, Chuang & Chung, 2004). The teamwork model consists of six skills. These are adaptability, coordination, decision making, leadership, interpersonal and communication skills (O'Neil, Chung & Brown, 1997).

Problem-solving processes	Collaborative problem-solving competencies		
	(1) Establishing and maintaining shared understanding	(2) Taking appropriate action to solve the problem	(3) Establishing and maintaining team organisation
(A) Exploring and understanding	(A1) Discovering perspectives and abilities of team members	(A2) Discovering the type of collaborative interaction to solve the problem, along with goals	(A3) Understanding roles to solve the problem
(B) Representing and formulating	(B1) Building a shared representation and negotiating the meaning of the problem (common ground)	(B2) Identifying and describing tasks to be completed	(B3) Describing roles and team organisation (communication protocol/rules of engagement)
(C) Planning and executing	(C1) Communicating with team members about the actions to be/being performed	(C2) Enacting plans	(C3) Following rules of engagement (e.g. prompting other team members to perform their tasks)
(D) Monitoring and reflecting	(D1) Monitoring and repairing the shared understanding	(D2) Monitoring results of actions and evaluating success in solving the problem	(D3) Monitoring, providing feedback and adapting the team organisation and roles

Fig. 1. Matrix of skills that shape collaborative problem solving.

Problem solving in PISA 2012 and Bulgarian participation

In 2012, the international PISA study was conducted. In this study, problem-solving skills were also included for testing. Of the participating countries, Bulgarian students ranked second to last, which indicates serious problems in our education system related to the mastery of this basic skill for successful implementation (PISA Results, 2012; CPSE, 2013; Svetla Petrova, 2014).

Collaborative problem solving in PISA 2015 and Bulgarian participation

In 2015, PISA included collaborative problem-solving competence in its framework for assessing student achievement. The Bulgarian result is again weak, Bulgarian students rank 40th out of 51 countries that participated in the study of the competence of collaborative problem solving (PISA Results, 2015; CSCE, 2016; Svetla Petrova, 2017).

The information system for team problem solving

The role of information and communication technologies in education

Information and communication technologies (ICTs) have had a profound impact on education over the past few decades. After the coronavirus, it is hard to imagine the educational process without the use of ICT. ICTs have impacted teaching and learning practices by facilitating access to educational resources, supporting collaboration and teamwork, and generally improving the learning process. Let us look at some key aspects of ICT in education.

With the help of ICT, we have improved access to educational resources and services. ICT facilitates access to educational materials by enabling the development and distribution of digital resources such as e-books, online courses, and educational websites (Bingimlas, 2009).

ICT tools such as email, videoconferencing and social media make it easier for students, teachers, and parents to communicate and collaborate on educational projects both inside and outside the classroom (Hew, Brush, 2007).

ICT enables the use of adaptive learning systems and platforms that offer personalized learning methods tailored to individual student needs, making education more effective (Woolf, 2010).

ICT enables the use of online assessment tools and methods that provide real-time feedback to students and teachers, supporting real-world, data-driven decision-making in the classroom (Bennett, Ward, 2015).

ICT provides opportunities for teachers to access professional development resources and to collaborate with teachers from around the world, which contributes to improved teaching and learning practices (Garet, 2001).

ICTs have made it possible for distance education to be effective, allowing students to participate in courses and degree programs at a distance, increasing access to education for learners in remote or more deprived areas (Moore, Kearsley, 2011).

Computer simulations in training

Computer and interactive simulations can play a significant role in learning, enhancing learning experiences, promoting conceptual understanding, and stimulating critical thinking. Various studies highlight the benefits of using simulations in education (Smetana, Bell, 2012; Rutten, van Joolingen, van der Veen, 2012).

Simulations can engage students by providing interactive and dynamic learning experiences. They can help concretize and visualize abstract concepts, which motivates students to explore and learn (Smetana, Bell, 2012).

Simulations can help students visualize complex concepts and processes that are difficult to understand through traditional teaching methods. They can provide dynamic representations of scientific phenomena, making them more accessible and understandable (Rutten, 2012).

Interactive simulations provide opportunities for students to engage in experimentation and inquiry-based learning. They can change variables, test hypotheses, and observe results, which promotes scientific reasoning and problem-solving skills (Smetana, Bell, 2012).

Simulations can offer immediate feedback to students, allowing them to understand the consequences of their actions and adjust strategies and plans to solve the problem. This helps students learn from their mistakes and develop a deeper understanding of the concepts and the nature of the problem (Rutten, 2012).

Computer simulations can facilitate collaboration between students as they can work together to explore, discuss, and solve problems within the simulated environment. This promotes teamwork, communication, and problem-solving skills (Smetana, Bell, 2012).

Interactive simulations can be adapted to meet different learner needs as they can provide different levels of complexity, feedback, and guidance, making them suitable for students with different learning styles and abilities (Rutten, 2012).

Simulation of natural processes and phenomena by numerical methods

In the previous section we saw that ICTs and interactive simulations can contribute to improving the quality of the educational process. We will look at how natural processes and phenomena can be simulated using computer simulations. We will look at how the same system can be simulated using numerical solutions of the differential equations that describe its dynamics, and how the same system can be simulated using cellular automata.

The Lotka-Volterra model is also known as the Predator-Prey Model. As the name suggests, this model describes the interaction of two species, with the predator feeding on the prey. We will simulate this model using the fourth-order Runge-Kutta algorithm. This is one of the most widely used methods for numerically solving ordinary differential equations. This simulation is described in a paper (Kunis, Dimitrov, 2020).

The Lotka-Volterra model (Lotka, 1910, Volterra, 1926) is based on two species that interact with each other. We will call one species the predator and the other species the prey. Let us introduce the following notations:

$$P(t) = population\ of\ predators; p(t) = population\ of\ preys \qquad (1)$$

Our goal is to describe this interaction. Therefore, we will introduce a coefficient a as the rate of change of the number of preys in the absence of predators. In the absence of predators we will have an exponential increase in the number of preys:

$$\frac{dp}{dt} = ap, \quad \Rightarrow \quad p(t) = p(0)e^{at}. \qquad (2)$$

In the presence of predators, exponential growth does not occur because predators will attack more prey the larger their population. Therefore, to account for this interaction, both species must be present. We will assume the simplest case of straight proportionality from the product of their numbers. The interaction is proportional to:

$$bpP \qquad (3)$$

The factor b is interpreted as a parameter describing predator-prey interactions in which prey are reduced. Thus, we arrive at a model of prey variation that takes into account both the fecundity of prey and their interaction with predators:

$$\frac{dp}{dt} = a\,p - b\,p\,P \qquad (4)$$

If we continue with the same logic, predators should also breed and therefore increase their population. But predators need the preys in order to exist. If there are no preys, they will start to attack each other, which in turn will lead to an increase in mortality, which we will denote by m:

$$\frac{dP}{dt} = -mP, \quad \Rightarrow \quad P(t) = P(0)e^{-mt} \qquad (5)$$

If there are preys to serve as food for the predators then predators will interact with preys by bpP factor, which will lead to an increase in the predators' population:

$$\frac{dP}{dt} = \epsilon\, b\, p\, P - m\, P \tag{6}$$

Here ε is a constant that measures the efficiency with which prey favours the predator population. Thus, we arrive at the following two equations of our model:

$$\frac{dp}{dt} = a\, p - b\, p\, P$$

$$\frac{dP}{dt} = \epsilon\, b\, p\, P - m\, P \tag{7}$$

We will solve these equations using the Runge-Kutta method, writing them in standard form:

$$\frac{dy}{dt} = f(y,t)$$

$y_0 = p$ $\quad$ $f_0 = ay_0 - by_0y_1$ $\quad$ (8)

$y_1 = P$ $\quad$ $f_1 = by_0y_1 - my_1$

The Runge-Kutta method is based on the formal integral of the differential equation (Runge, 1895) (Kutta, 1901):

$$\frac{dy(t)}{dt} = f(t,y) \Rightarrow y(t) = \int f(t,y)dt \Rightarrow y[n+1] = y[n] + \int_{t[n]}^{t[n+1]} f(t,y)dt \tag{9}$$

The approximation of the method consists developing the Taylor series of the subintegral function around the midpoint of the integration interval i.e. around the point:

$$t[n+1/2] = (t[n] + t[n+1])/2 \tag{10}$$

$$f(t,y) \cong f(t[n+\tfrac{1}{2}], y[n+\tfrac{1}{2}]) + (t - t[n+\tfrac{1}{2}])\frac{df}{dt}|t = t[n+\tfrac{1}{2}] + O(h^2) \tag{11}$$

If we integrate the above equation over the interval (t[n],t[n+1]), the second term in the right-hand side is reset to zero and we obtain a higher-order algorithm than Euler's algorith, even though we use the same number of terms:

$$\int_{t[n]}^{t[n+1]} f(t,y)dt \cong \int_{t[n]}^{t[n+1]} f(t[n+\frac{1}{2}], y[n+\frac{1}{2}])dt \cong f(t[n+\frac{1}{2}], y[n+\frac{1}{2}])h \tag{12}$$

$$y[n+1] \cong y[n] + hf(t[n+\tfrac{1}{2}], y[n+\tfrac{1}{2}]) \tag{13}$$

The resulting algorithm cannot be used immediately because it requires knowing the values of y[n+1/2], *which cannot be* determined from the initial condition. We can, however, use Euler's algorithm to determine y[n+1/2] from the initial conditions:

$$y[n+\tfrac{1}{2}] \cong y[n] + \frac{dy}{dt}\frac{h}{2} = y[n] + \frac{h}{2} f(t[n], y[n]) \quad (14)$$

We can now summarize the second-order Runge-Kutta algorithm as follows:

$$y[n+1] \cong y[n] + k_2 \quad (15)$$

$$k_2 = hf(t[n] + \frac{h}{2}, y[n] + \frac{k_1}{2}) \quad (16)$$

$$k_1 = hf(t[n], y[n]) \quad (17)$$

We now give the algorithm of the fourth-order Runge-Kutta method. The function *f(t,y)* is approximated by 4 gradient (k) terms near the midpoint which are determined by only 4 operations (Press, 1992):

$$y[n+1] = y[n] + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \quad (18)$$

$$k_1 = hf(t[n], y[n]), \quad (19)$$

$$k_2 = hf\left(t[n] + \frac{h}{2}, y[n] + \frac{k_1}{2}\right), \quad (20)$$

$$k_3 = hf\left(t[n] + \frac{h}{2}, y[n] + \frac{k_2}{2}\right), \quad (21)$$

$$k_4 = hf(t[n] + h, y[n] + k_3) \quad (22)$$

We will simulate the Lotka-Volterra model using the fourth-order Runge-Kutta method. The running program, written in the Java programming language, is presented in Figure 2. In Figure 3 the two populations are presented together for comparison. A plot of the phase portrait of the predator population against the prey population is presented in Figure 4. Let us now analyze the results. In the beginning, the prey population will grow very fast (almost exponentially), while the number of predators is relatively small. Once the number of predators increases a sharp decrease in the number of preys starts. The behaviour is similar for predators. In the presence of a large number of prey, they begin to increase sharply. But in the absence of preys their population will melt down due to starvation or as a result of their self-destruction. The probability of interaction, i.e. a predator encountering a prey, is proportional to the product of their populations, i.e. the greater the number of a species, the greater the probability that an encounter and then interaction between them will take place. Any variation in the number of preys affects the number of predators and vice versa. The two populations oscillate and evolve cyclically. If the prey population increases, then the probability of encountering a predator increases. And this leads to an increase in the predator population. But an increased predator population leads to a decreased prey population. This, in turn, leads to a decrease in the number of predators, which in turn increases the number of preys, and so on.

```java
/*
   Programa za reshavane na modela na Lotka-Volterra
    s izpolzvane na metoda na Runge-Kuta ot 4-ti red.
   Koeficientite sa :
   a=0.523598776, b=0.016362462, m=0.523598776, epsilon=0.711111
   Nachalnite uslovia sa:
   p=30, P=5.
   */

import java.io.*;

public class PredatorPrey {

  public static void main(String[] argv) throws IOException, FileNotFoundException {
    // zapisvane na informaciqta v otdelni fajlove
    PrintWriter w = new PrintWriter(new FileOutputStream("Pp30.dat"), true);
    PrintWriter q = new PrintWriter(new FileOutputStream("Pp31.dat"), true);
    PrintWriter l = new PrintWriter(new FileOutputStream("Pp32.dat"), true);

    // deklarirane i inicializirane na parametrite za reshavaneto na RK4
    double h, t, Tmin = 0.0, Tmax = 500.0;
    double y[] = new double[2];
    int Ntimes=1000;

    // Inicializirane na nachalnite uslovija
    y[0]=30.0;  y[1] = 5.0;

    // Inicializirane na stapkata i vremeto
    h = (Tmax-Tmin)/Ntimes;
    t = Tmin;

    //Zapisvane na informacijata
    for (t = Tmin;  t <= Tmax; t += h) {
      System.out.println(" t=" +t+" , x= "+y[0]+", v= "+y[1]);//printout
      w.println(""+t +" " +y[0]+" ");//output to files
      q.println(""+t +" " +y[1]+" ");
      l.println(""+y[0] +" " +y[1]+" ");
      rk4(t, y, h, 2);
    }
    System.out.println("Done.");
  }

  // metod na RK4
  public static void rk4(double t, double y[], double h, int Neqs) {
    int i;
    double F[]  = new double[Neqs]; double ydumb[] = new double[Neqs];
    double k1[] = new double[Neqs]; double k2[] = new double[Neqs];
    double k3[] = new double[Neqs]; double k4[] = new double[Neqs];
    f(t, y, F);
    for (i=0; i<Neqs; i++){ k1[i] = h*F[i]; ydumb[i] = y[i] + k1[i]/2;}
    f(t + h/2, ydumb, F);
    for (i=0; i<Neqs; i++) { k2[i] = h*F[i];  ydumb[i] = y[i] + k2[i]/2;}
    f(t + h/2, ydumb, F);
    for (i=0; i<Neqs; i++) { k3[i]=  h*F[i]; ydumb[i] = y[i] + k3[i];}
    f(t + h, ydumb, F);
    for (i=0; i<Neqs; i++) {
    k4[i] = h*F[i];  y[i] = y[i] + (k1[i] + 2*(k2[i]+k3[i]) + k4[i])/6;}
  }

  // Model na Lotka-Volterra
  public static void f(double t, double y[], double F[]) {

     F[0] = 0.523598776*y[0]-0.016362462*y[0]*y[1];                    // uravnenie za gertvite
     F[1] =-0.523598776*y[1]+0.011635528*y[0]*y[1];                    // uravnenie za hishtnicite

}

}
```

Figure 2. A program for solving the Lotka-Volterra model written in Java.

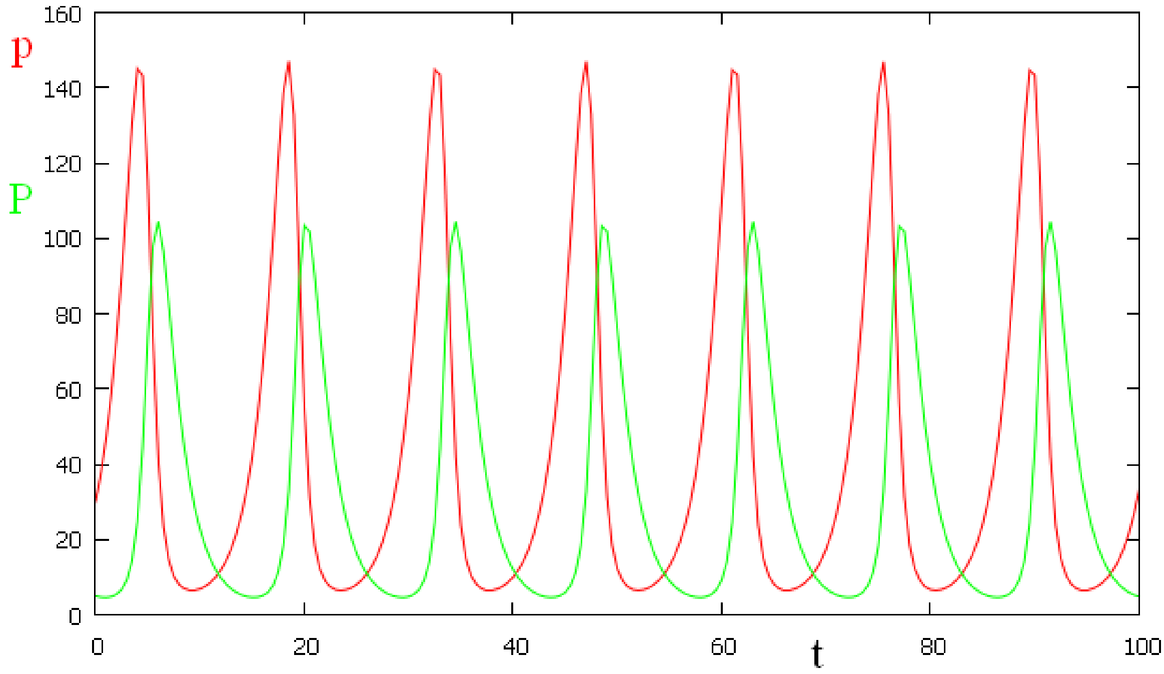

Figure 3. Number of preys (in red) and predators (in green) as a function of time from the Lotka-Volterra model.

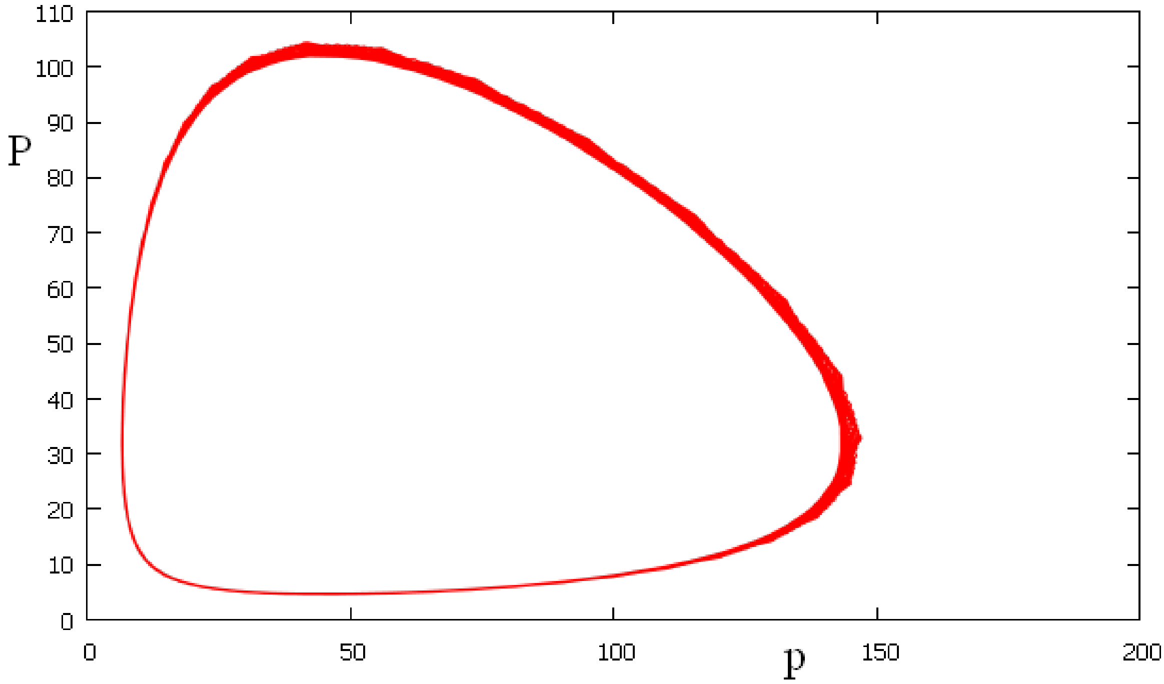

Figure 4. Phase portrait of the number of predators versus the number of preys from the Lotka-Volterra model.

Simulating natural processes and phenomena using cellular automata

A cellular automaton is a model consisting of a rectangular lattice (grid) of cells, where each cell can have a finite number of states, for example alive or dead (Shiffman, 2012). For each cell a neighborhood is defined. The neighborhood determines how many other cells a given cell will interact with. Neighborhood can be done in many ways, but usually the neighbors of a cell are its neighboring cells.

An initial state is assigned to each cell at the start time, and this can be done randomly. All cells and their states at a given time t are called generation at time t. The next generation is created by executing a specific set of rules. These rules determine the new state of each cell depending on its current state and the states of its neighboring cells. By executing these rules repeatedly, at each iteration we obtain the evolution of the system. This way we can track how a system will evolve.

Let us start by constructing a cellular automaton that will simulate the Lotka-Volterra model. We will have a square lattice that will consist of 100 by 100 cells. This choice of size is reasonable because it contains 10000 cells, which gives us on the one hand a sufficient number of cells from a statistical point of view, and on the other hand a sufficiently large choice of different configurations. The set of cell states will have three states. These will be environment or we will also call these cells empty (in our simulation we will color them black), preys (we will color them blue) and predators (we will color them yellow). Now we have to choose the neighborhood. The Moore-type neighborhood gives us more options and more flexibility, so we'll go with it.

Let us now define the rules that we think will accurately simulate the system. Since the number of states is three, we will consider the three cases. When the active cell is empty, when it is a prey and when it is a predator.

When the active cell is a predator:

- The predator lives (the cell remains yellow) if there is a prey around it.
- The predator dies (the cell turns black) if there are no preys around it.

When the active cell is the prey:

- The prey lives (the cell remains blue) if there are no predators around it.
- The prey dies (the cell turns black) if there are a sufficient number of predators around it.
- If there are too many predators around the prey, then the prey dies, and a predator is born in its place (the cell turns yellow).
- If the number of predators is greater than zero and less than 5, then the prey remains alive.
- If the number of predators is equal to or greater than five, then the prey dies, and a predator is born in its place.
- If the number of adjacent preys is greater than 7, the prey dies (the cell turns black).

The latter is done to limit the possible prey population. Because it is not realistic for a population to expand indefinitely.

When the active cell is empty (environment):

- An empty cell becomes a prey (the cell turns blue) if the number of adjacent preys is greater than the number of adjacent predators.

- An empty cell becomes a predator (the cell turns yellow) if the number of adjacent predators is greater than the number of adjacent preys.
- If the number of adjacent predators is equal to the number of adjacent preys, the cell remains empty (black).

Figure 5. shows the encoding of the environmental, predator-prey evolution rules. Consider the results of the program implementation. Figure 6. shows the simulation at different time points from 0 to 220 over 20-time steps. Figure 7 shows the prey and predator populations as a function of time.

```
// Start simulation
for (int gen = 1; gen <= genCount; gen++) {
    int [][] nextGrid = new int[n][n];

    // Calculate next generation
    for (int i = 0; i < n; i++) {
        for (int j = 0; j < n; j++) {

            int preyNeighbours = countPreyNeighbours(i,j);
            int predatorNeighbours = countPredatorNeighbours(i,j);

            // Rules for empty cell
            if (grid[i][j] == 0) {

                if (preyNeighbours > 0) {
                    if (predatorNeighbours > preyNeighbours) {
                        nextGrid[i][j] = 2;
                        predatorStats[gen]++;
                    }
                    else if (preyNeighbours > predatorNeighbours) {
                        nextGrid[i][j] = 1;
                        preyStats[gen]++;
                    }
                }
                else {
                    nextGrid[i][j] = 0;
                }
            }
// Rules for prey
else if (grid[i][j] == 1) {
    int Rand = rand.nextInt(100);

    if(preyNeighbours > 3){
        nextGrid[i][j] = 0;
    }
    else{
        if(predatorNeighbours > 0 && Rand < 100){
            nextGrid[i][j] = 2;
            predatorStats[gen]++;
        }
        else{
            nextGrid[i][j] = 1;
            preyStats[gen]++;
        }
    }


// Rules for predator
else if (grid[i][j] == 2) {

    if(preyNeighbours < predatorNeighbours + 1){
        nextGrid[i][j] = 0;
    }
    else{
        nextGrid[i][j] = 2;
        predatorStats[gen]++;
    }

}
```

Figure 5. Coding rules for empty cells, predators and prey.

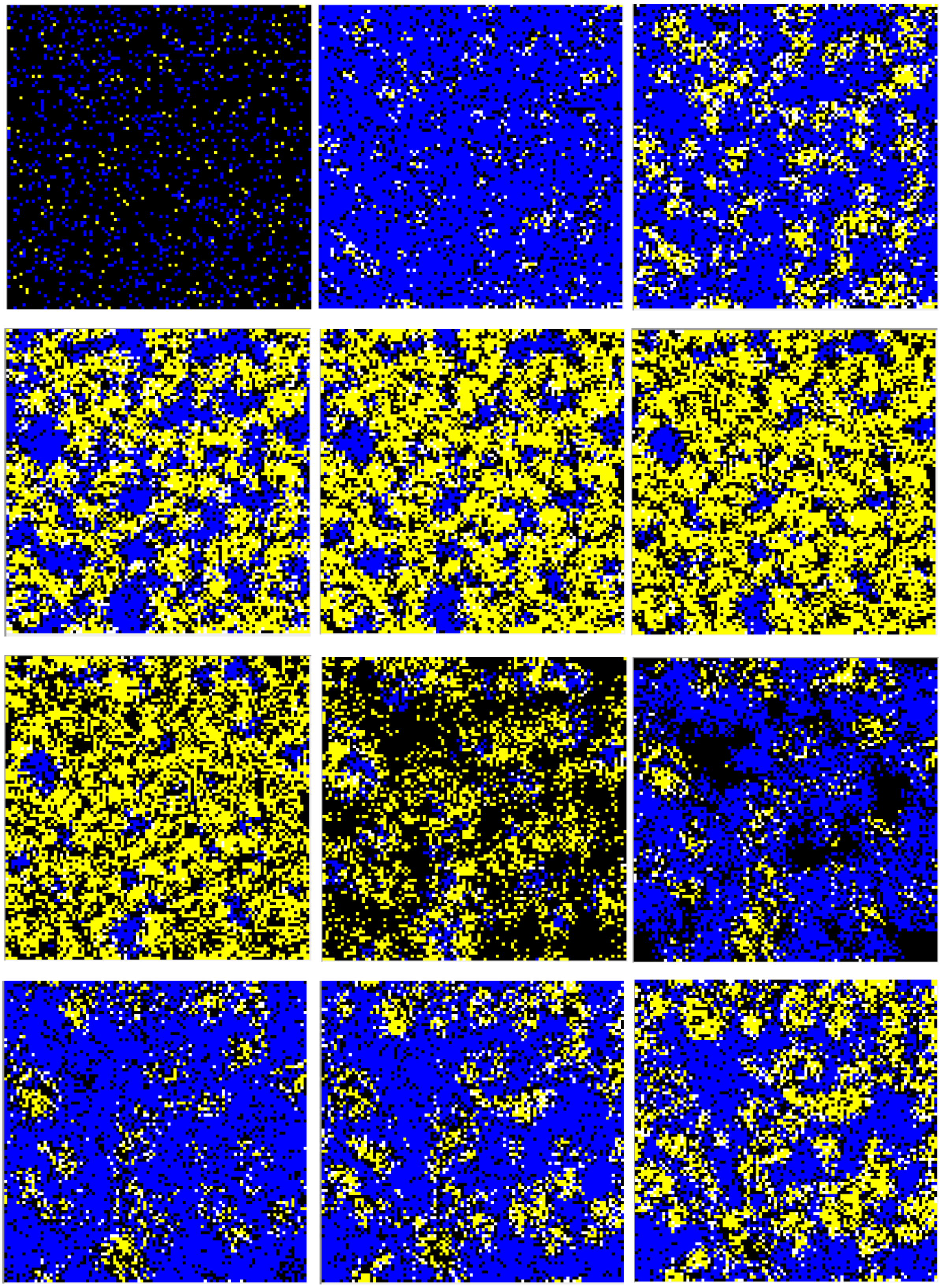

Figure 6. Simulation of the Lotka-Volterra model with a cellular automaton at the corresponding time instants t = 0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220.

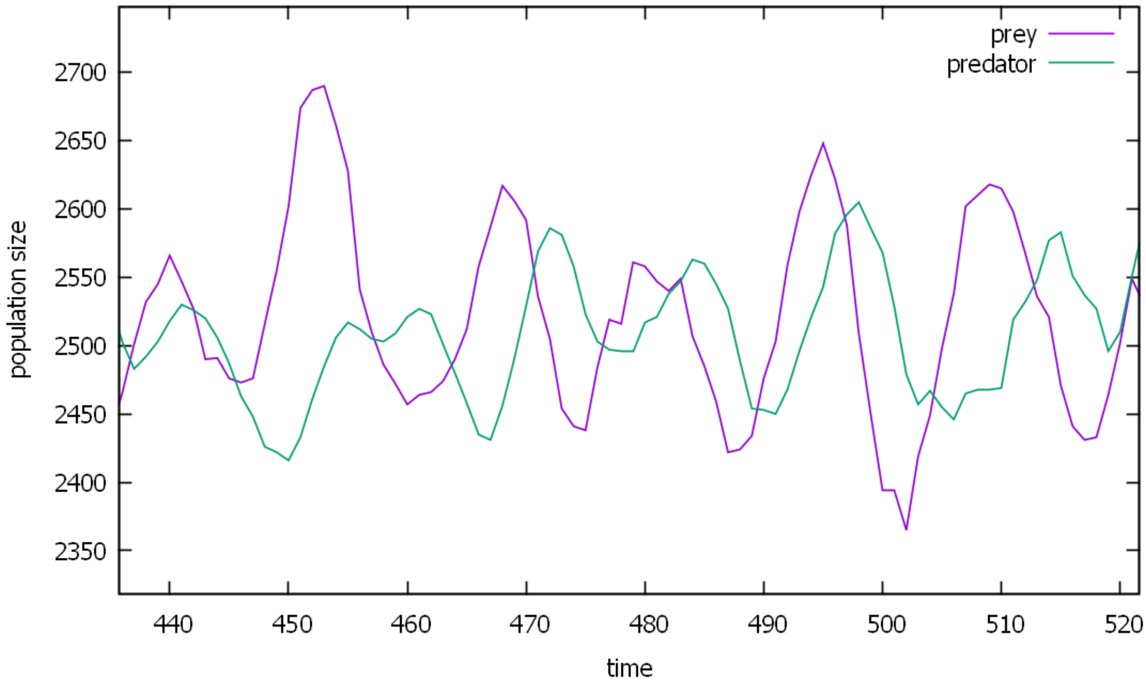

Figure 7. Number of preys (in purple) and predators (in green) as a function of time from the Lotka-Volterra model simulation with a cellular automaton.

Design of the information system

In this section we will look at the information system we have made. Our information system is designed to be able to work in different modes. These modes are improving and evaluating problem solving competence, improving and evaluating collaborative problem solving competence. We consider these competencies by placing them in a physical context. But the system itself allows to be implemented in any context, e.g. natural sciences, mathematics, humanities, social sciences, etc. Our system can also work in test mode. Our system allows to test problem solving and collaborative problem solving competencies, but in addition, competencies in science, mathematics, humanities, social sciences, etc. can also be tested. One of the advantages of our system is its ability to adapt and customize as the student completes the tasks.

Our system is a web application that can work online and offline. No permanent internet access is needed for the student to work with the system. The front-end interface is written in HTML, CSS and JavaScript. Figure 8 shows the system in test mode.

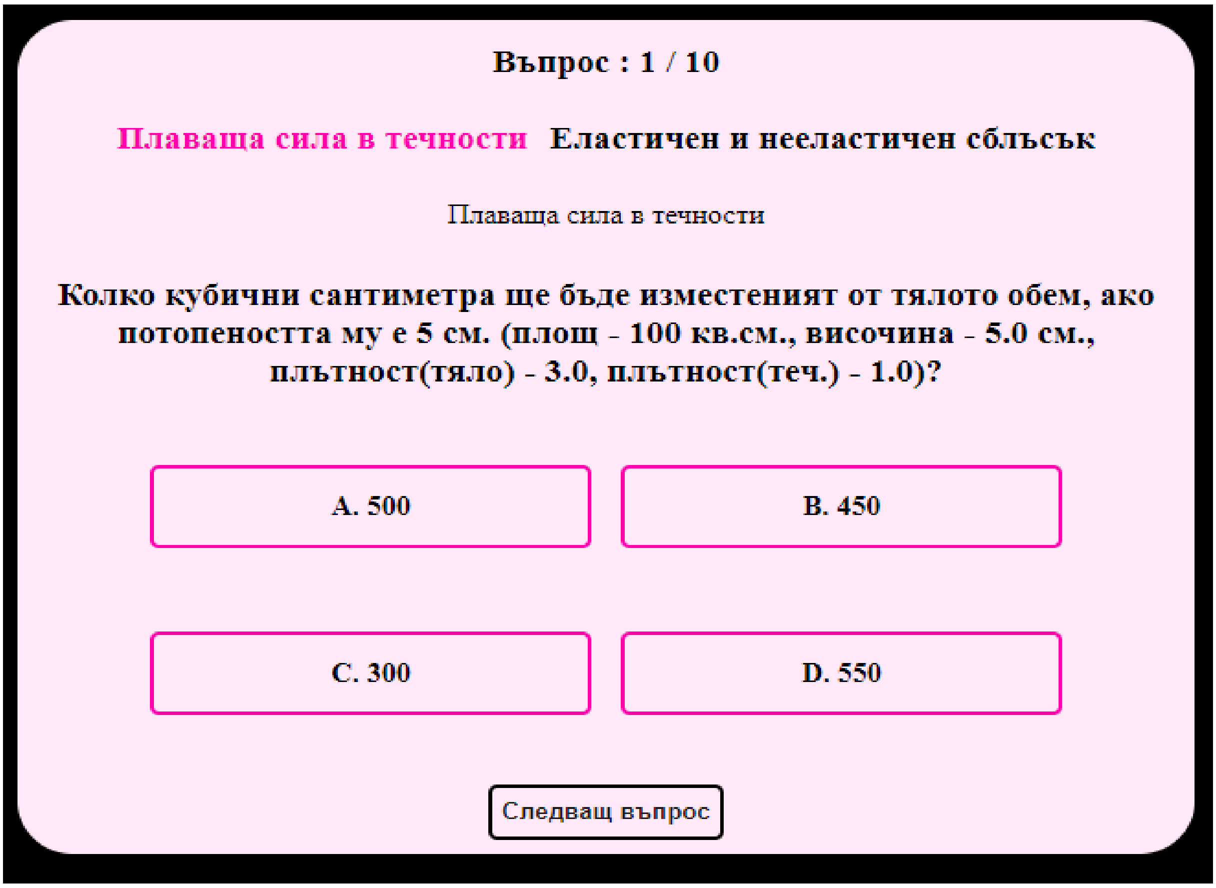

Figure 8. Screenshot of the information system in test mode.

We aimed for our electronic system in evaluation mode to meet the following requirements (Buzzetto-More, 2009):

- reliability: the system should ensure fair, accurate and correct assessment, with the resulting score reflecting as closely as possible the student's actual knowledge and competencies.
- validity: the system and the tests must be sufficiently precise and measure what is asked of them, i.e., they must assess the knowledge, skills and abilities that the test is designed and claims to assess.
- usefulness: the system provides feedback that helps to improve the learning and training process. This can include instant feedback for students and detailed analytics for teachers.
- safety: the system must protect student confidentiality and prevent fraud attempts.

Our system most commonly uses the following question types: multiple choice, short answer, and extended response questions.

Coding problem solving skills.

Figures 9 and 10 show screenshots of the interactive simulations we have implemented that can be used to develop and assess students' problem-solving skills. Figure 9 shows the interactive problem where an apple falls on different planets of the solar system. The problem is complex and requires students to show creative thinking and creativity. In order to solve the problem, students must come to the conclusion that the information system itself does not give them the tools they need to reach a complete solution. In this case, they should use an external mobile device to perform some of the measurements. Once the measurements have been taken, students will find that certain values are too small to be analysed without additional software. Without the use of this additional software, some of the experiments are virtually impossible to analyze. After using the additional software, students have the ability to successfully apply the physics formulas to find the individual physical quantities being looked for.

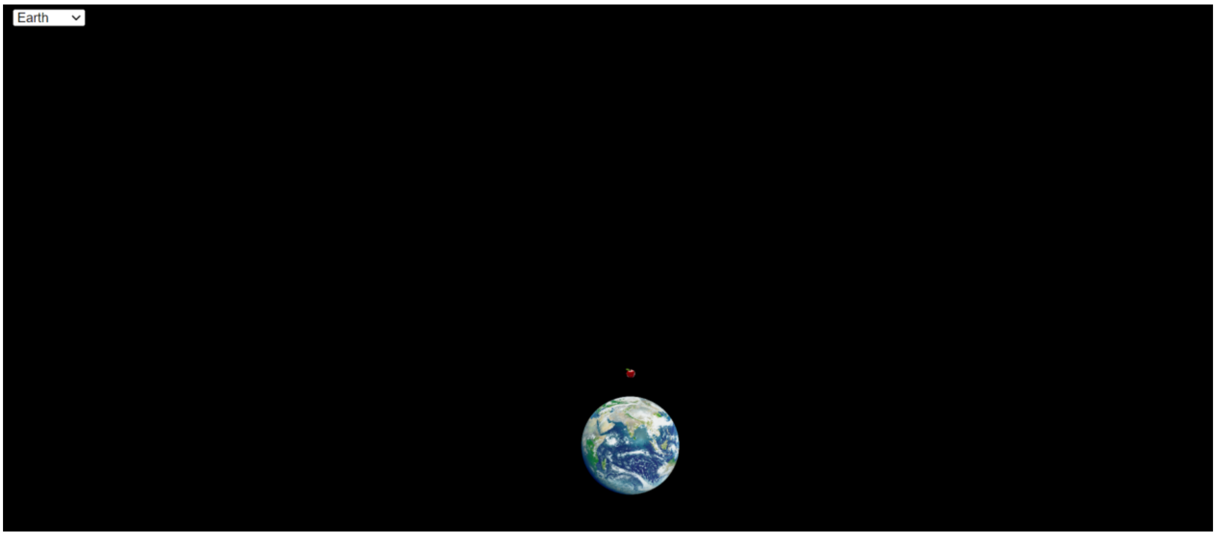

Figure 9. Screenshot of the Falling Apple problem.

Coding team problem solving skills

Our system allows team problem solving exercises to be given. Students can be divided into small teams and given a specific physical task. They will then have to work together to define the problem, determine the strategy, complete the individual sub-tasks, and provide supervision and feedback. This reflects team practices in the industry and requires participants to communicate effectively, manage their time and tasks, and collaborate to solve emerging problems. Teamwork has been shown to improve the quality of the solution and the skills of the individuals involved (Salleh, 2011).

Figure 10 shows a screenshot of the home screen. In this part, the student should familiarize himself with the system and get oriented. In the right panel there is a brief explanation of the tasks. In the left panel, the student is introduced to the team and tested on their ability to initiate successful communication.

In Figure 11 the student gets the first question about what the period of the mathematical pendulum depends on. In the right panel, the student sees an interactive simulation of a mathematical pendulum. The student has to familiarize and navigate the simulation on their own. At the same time, in the left panel, the computer agents start a dialogue, and the student has to take a stance by proposing the discussion of an initial strategy with the team.

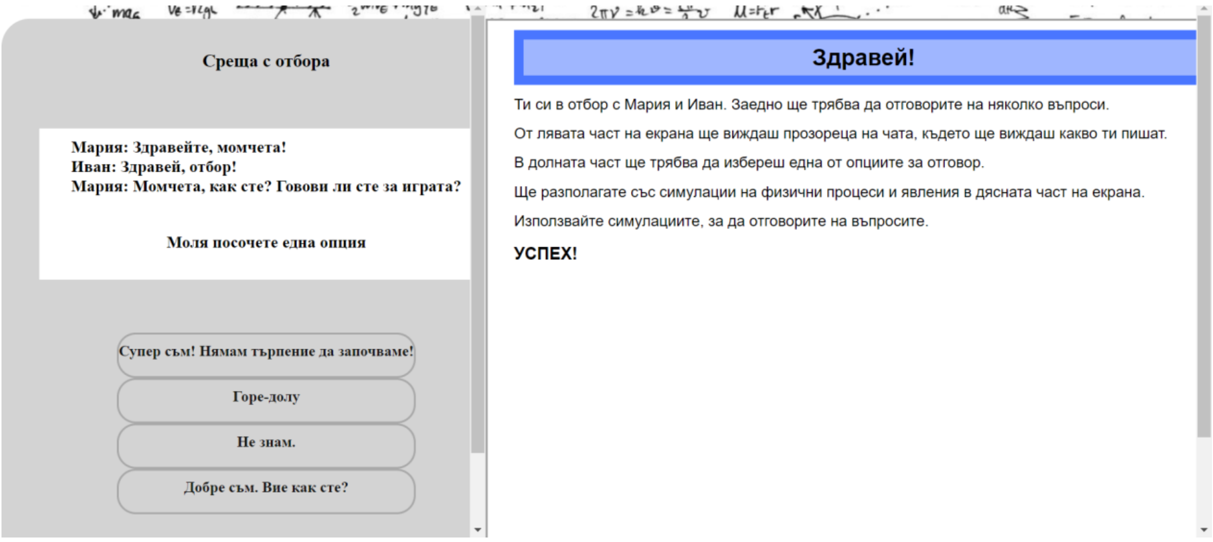

Figure 10. Screenshot of the team problem solving part 1.

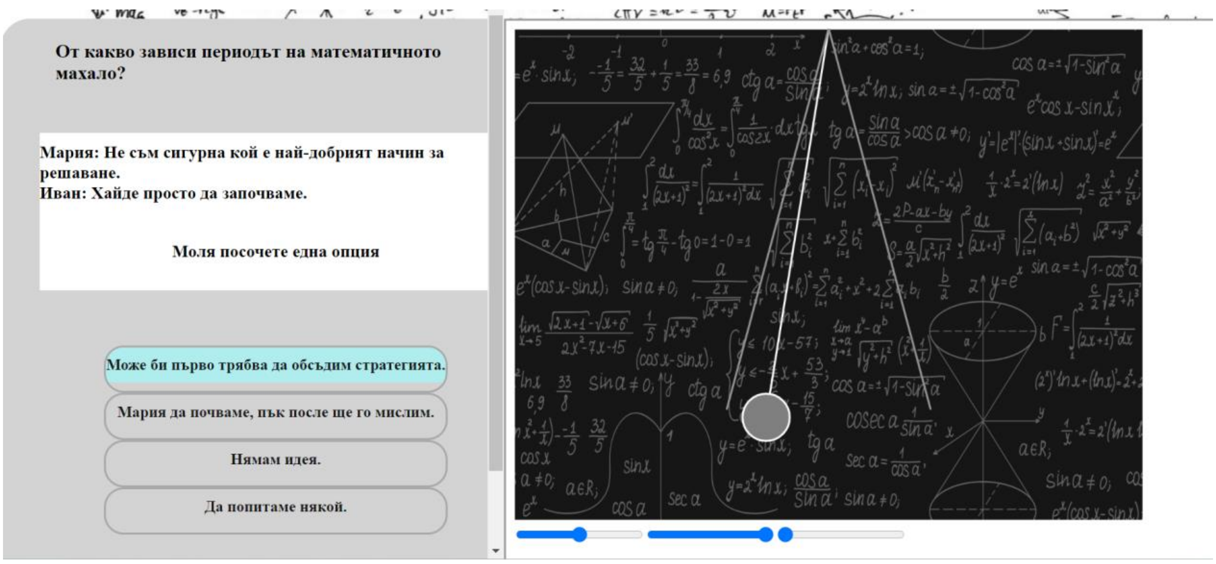

Figure 11. Screenshot of the team problem solving part 2.

In Figure 12 the computer agents Ivan and Maria discuss developing a plan that will lead to the solution of the problem. The student must choose one of the four options where he or she thinks it will be most useful in eventually arriving at a correct plan to solve the problem.

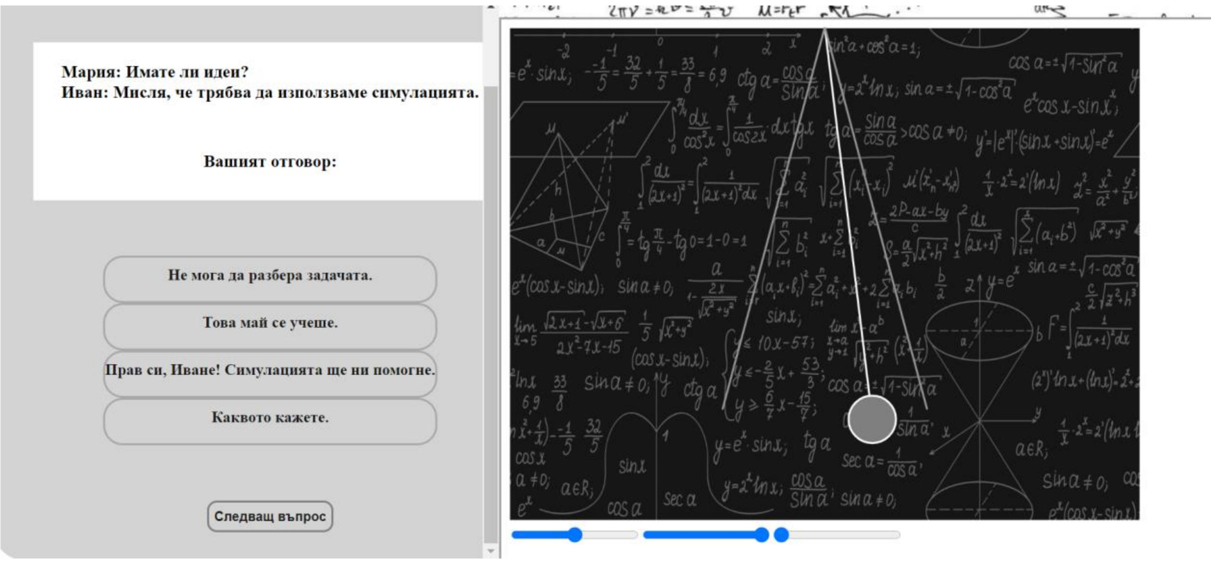

Figure 12. Screenshot of the team problem solving part 3.

In Figure 13 a specific task is given to the student to test their problem-solving skills. The student is asked to answer the question as the mass of the ball increases whether and how the period of the mathematical pendulum changes. In order to solve the problem correctly, the student must first orient themselves to which button is used for what. Once he or she has determined this, only the mass of the mathematical pendulum should change, and the other parameters should not change. In this way, the student can come to the correct conclusion that mass does not affect the period of the math pendulum.

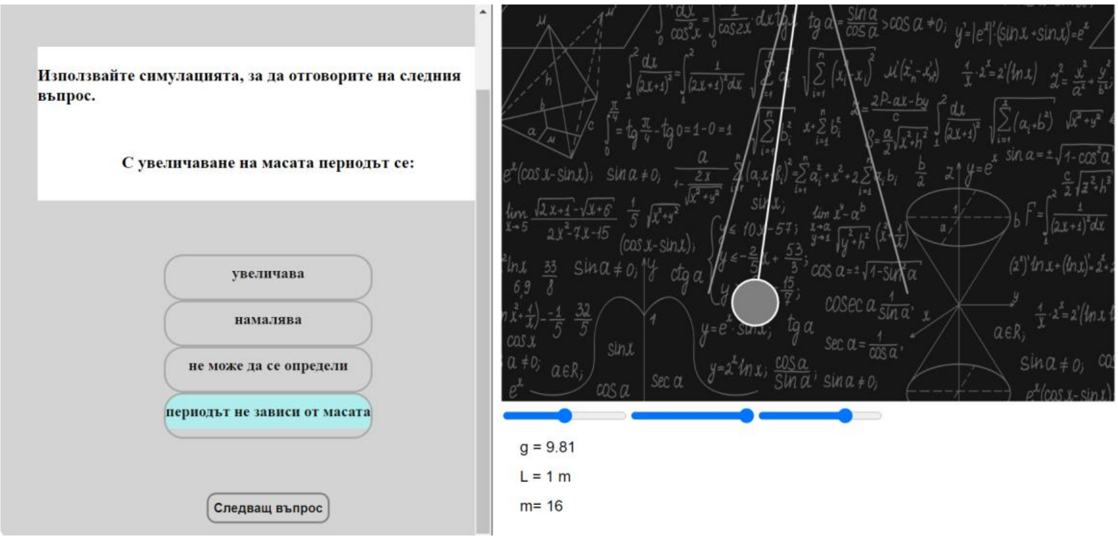

Figure 13. Screenshot of the team problem solving part 4.

In Figure 14 another problem is given to the student, again to test his problem-solving skills. The student must answer the question as the length of the pendulum increases whether and how the period of the mathematical pendulum changes. To solve the problem correctly, the student must first orient himself to which button is used for what. The student is assumed to already know this if they worked correctly in the previous problem. Once he or she has determined this, only the length of the math pendulum needs to be changed, and the other parameters should not change. In this way, the student can come to the correct conclusion that as the length of the mathematical pendulum increases, the period increases. Here the student does not need to know the formula for the period and length of a mathematical pendulum. For students with a heightened interest in mathematics and science, the question may be to try to derive this formula or, if they know it, to correlate it with experimental data from the simulation.

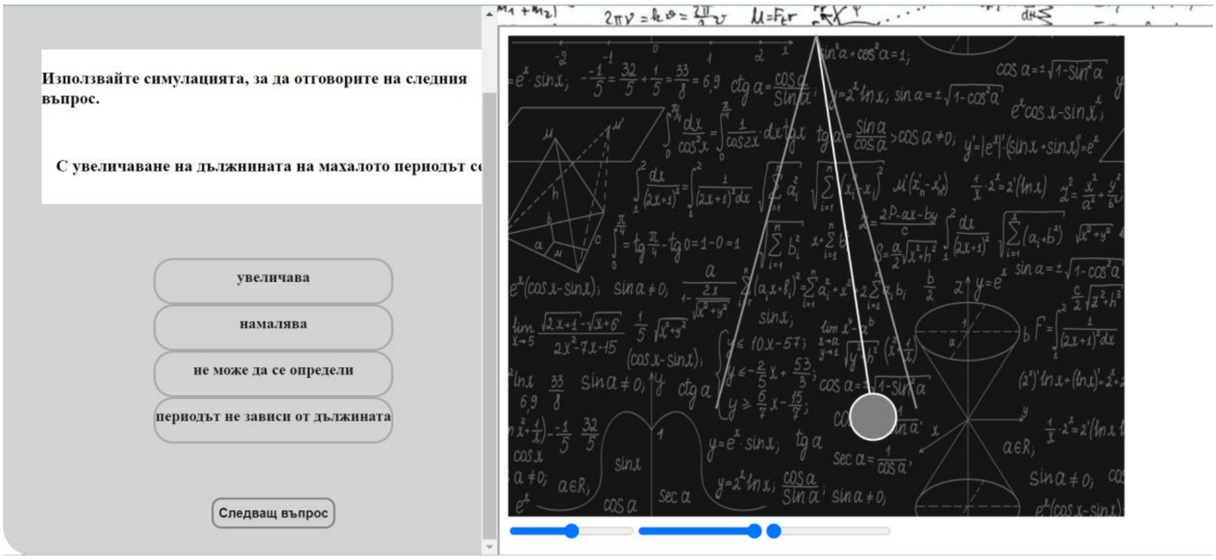

Figure 14. Screenshot of the team problem solving part 5.

In Figure 15, another problem is given to the student, again testing their problem-solving skills. The student must answer the question as the gravitational acceleration decreases whether and how the period of the mathematical pendulum changes. To solve the problem correctly, the student must first orient themselves to which button is used for what. The student is assumed to already know this if they worked correctly in the previous two problems. Once he or she has determined this, he or she only needs to change the magnitude of the gravitational acceleration and the other parameters should not change. In this way, the student can reach the correct conclusion that as the magnitude of the gravitational acceleration increases, the period decreases. Here the student does not need to know the formula for period, length of a mathematical pendulum and gravitational acceleration. For students with a heightened interest in mathematics and science, the question might be to try to derive this formula or, if they know it, to relate it to experimental data from the simulation.

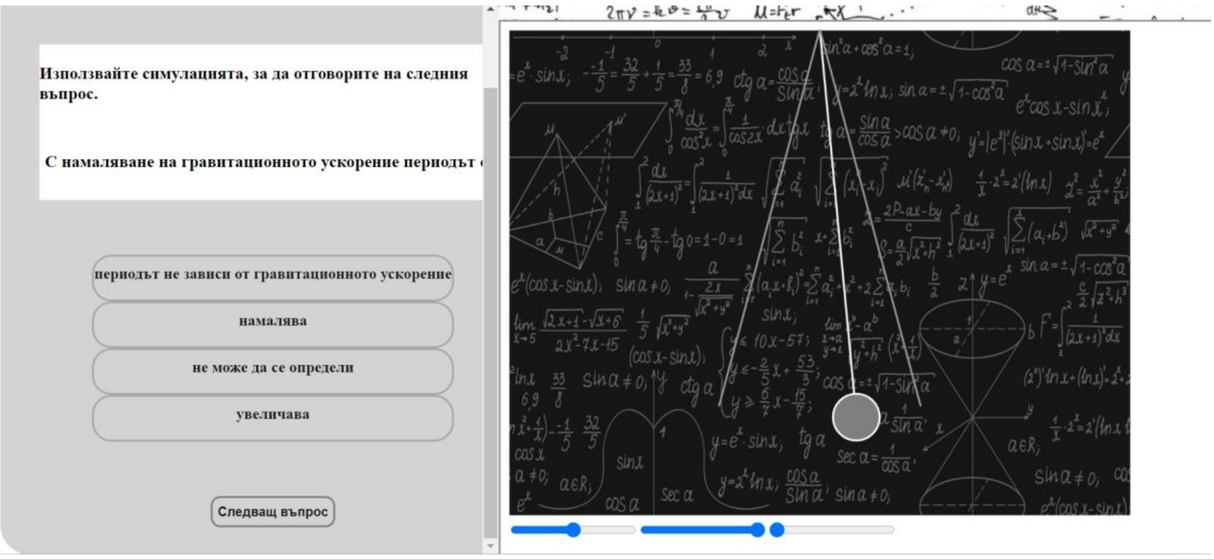

Figure 15. Screenshot of the team problem solving part 6.

Chapter Three: Research Part

Research aims and objectives of the study.

The aim of this dissertation is to develop a concept, tools and models for the formation of students' teamwork skills in the teaching of physics and astronomy at the junior high and high school levels. This concept to be implemented in real school practice. An experiment should be carried out to allow the collection of data from which appropriate conclusions can be drawn.

The tasks to be completed in order to successfully complete the dissertation are.

1. Choosing a methodology for testing and identifying the level of acquired knowledge and skills in the field of collaborative problem solving.
2. Selecting a methodology to be applied to the group of students to improve their collaborative problem solving skills.
3. Selecting the methodology of the study to obtain representative results
4. Testing the students of the control and experimental groups on the level of their knowledge and skills in collaborative problem solving with the methodology from point 1.
5. Training the students of the experimental group with the methodology of point 2.
6. Upon completion of the training, test the students of the control and treatment groups on the level of their knowledge and skills in collaborative problem solving with the methodology of point 1.
7. Analysis of data and results.

Description of study conditions - participants, location, time, period, approach to grouping, validity

Having researched the world's experience in the areas of 21st century skills, problem solving and team problem solving, we needed to decide on a methodology on which to build the information system for team problem solving. Three platforms were subjected to in-depth analysis. These are CRESST, PISA, ATC21S. We chose the PISA methodology because of the ease of assessment, the ability to automate the process and the greater objectivity of the assessment.

Once we selected the methodology, we began to develop the information system for team problem solving. The information system itself is described in detail in chapter two. The system consists of two main modules. These are a problem-solving module for interactive simulation of a physical process or phenomenon and a teamwork module, which is a virtual chat with computer agents. Through our information system, we test twelve components that build team problem solving competence. These components are:

- (A1) discovering perspectives and abilities of team members,
- (A2) discovering the type of collaborative interaction to solve the problem, along with goals,
- (A3) understanding roles to solve the problem,
- (B1) building a shared representation and negotiating the meaning of the problem (common ground),
- (B2) identifying and describing tasks to be completed,
- (B3) describing roles and team organization (communication protocol/rules of engagement),
- (C1) communicating with team members about the actions to be/being performed,
- (C2) enacting plans,
- (C3) following rules of engagement (e.g. prompting other team members to perform their tasks),
- (D1) monitoring and repairing the shared understanding,
- (D2) monitoring results of actions and evaluating success in solving the problem,
- (D3) monitoring, providing feedback and adapting the team organization and roles.

The second stage was to implement the methodology and information system for team problem solving in a school environment. We implemented our system in seventh, eighth, ninth and tenth grade physics and astronomy education classes. The school we selected was 125th School "Boyan Penev" in Sofia. The students from whom we formed the stratified sample were from seventh to tenth grade. The main method in our study was a didactic experiment with a control and experimental group.

The number of students in the experimental group was 132, of which 63 were girls and 69 were boys. The number of students in the control group was 154, including 71 girls and 83 boys.

Before the experimental group started training with the information system, both groups (control and experimental) were tested with a test to establish the entry level of team problem solving competence. The test was conducted using the information system we developed with the methodology we described.

The experimental group was trained with our information system in physics and astronomy classes, information technology classes and extracurricular activities between November 2021 and April 2022. Five in-person and three online training sessions were conducted in grades seventh and eighth. In grades nineth and tenth, four in-person and four online training sessions were conducted. After the training was completed, the control and experimental groups were tested again to establish the final level of team problem solving competence using our information system.

Analysis of the data and results

We will introduce the following notations to make the tables easier to read:

A1: discovering perspectives and abilities of team members,

A2: discovering the type of collaborative interaction to solve the problem, along with goals,

A3: understanding roles to solve the problem,

B1: building a shared representation and negotiating the meaning of the problem (common ground),

B2: identifying and describing tasks to be completed,

B3: describing roles and team organization (communication protocol/rules of engagement),

C1: communicating with team members about the actions to be/being performed,

C2: enacting plans,

C3: following rules of engagement (e.g., prompting other team members to perform their tasks),

D1: monitoring and repairing the shared understanding,

D2: monitoring results of actions and evaluating success in solving the problem,

D3: monitoring, providing feedback and adapting the team organization and roles,

CPS: Team (collaborative) problem solving competency rating from 0 to 100.

Figure 16 shows the descriptive statistics from the initial test to investigate the team problem solving competence of the control group.

The average of the scores is around 50, indicating that students vary widely in skill, with some doing very well (scores closer to 100) and others not so well (scores closer to 0). The scores for each skill are scattered, as indicated by the standard deviations and coefficients of variation, suggesting a diverse group of students in terms of scores on these skills. Skills B1, B2 and B3 are those where students have more difficulty, as their means are the lowest. These are forming a shared understanding and discussing the nature of the problem, defining and presenting the tasks to be completed and defining the role of each member of the team and team organisation. The highest averages are A1, A2 and C1, indicating that students are generally better at these skills. These skills are understanding the perceptions and abilities of team members, understanding the nature of collaboration and goal formulation, and discussing with team members what actions should be taken to solve the problem. The standard deviations show that there is considerable variability in student scores for all skills. The variation is particularly high for skills A1, A2, C1 and D1. The ranges show that for all skills some students scored very low while others scored very high. This is particularly noticeable for skills A1, A2 and D1.

	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	CPS
Valid	154	154	154	154	154	154	154	154	154	154	154	154	154
Mode [a]	51.374	56.554	55.659	26.519	26.328	40.731	66.114	45.365	38.091	44.862	33.742	52.479	14.342
Median	54.030	53.225	46.898	30.938	34.603	42.582	56.319	47.654	44.945	47.855	45.681	44.732	47.725
Mean	54.071	53.757	47.624	30.340	34.680	43.071	56.043	47.057	45.467	46.099	44.512	43.168	45.491
Std. Error of Mean	1.385	1.423	1.378	0.905	0.961	1.151	1.482	1.259	1.213	1.484	1.291	1.239	1.151
95% CI Mean Upper	56.785	56.546	50.325	32.112	36.562	45.328	58.947	49.523	47.845	49.006	47.043	45.596	47.748
95% CI Mean Lower	51.356	50.968	44.923	28.567	32.797	40.815	53.139	44.590	43.089	43.191	41.981	40.741	43.234
Std. Deviation	17.189	17.658	17.101	11.225	11.920	14.288	18.388	15.618	15.056	18.410	16.024	15.370	14.290
95% CI Std. Dev. Upper	19.423	20.105	19.277	12.635	13.415	16.309	20.587	17.635	17.086	21.033	18.047	17.369	15.880
95% CI Std. Dev. Lower	14.802	15.111	14.765	9.655	10.391	12.250	15.759	13.320	12.730	15.598	13.671	13.202	12.573
Coefficient of variation	0.318	0.328	0.359	0.370	0.344	0.332	0.328	0.332	0.331	0.399	0.360	0.356	0.314
95% CI Variance Upper	377.250	404.222	371.601	159.652	179.952	265.978	423.834	311.004	291.923	442.371	325.699	301.666	252.181
95% CI Variance Lower	219.100	228.333	218.016	93.212	107.980	150.056	248.337	177.412	162.041	243.283	186.907	174.284	158.076
Range	97.665	100.000	94.826	61.197	72.967	86.090	92.654	89.289	88.880	98.987	93.169	83.578	69.736
Minimum	2.335	0.000	3.092	2.720	0.000	3.703	7.346	6.186	2.930	1.013	0.913	0.000	14.342
Maximum	100.000	100.000	97.919	63.917	72.967	89.792	100.000	95.475	91.810	100.000	94.082	83.578	84.078

Figure 16 Descriptive statistics from the initial test of the team problem solving competence of the control group

	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	CPS
Valid	154	154	154	154	154	154	154	154	154	154	154	154	154
Mode [a]	100.000	100.000	39.332	35.984	26.998	34.297	100.000	33.653	34.810	45.964	22.826	37.668	15.215
Median	56.359	57.371	50.459	31.639	36.709	46.378	58.290	50.602	47.650	49.940	47.934	45.735	49.952
Mean	56.305	56.400	50.395	31.931	36.389	45.850	57.947	49.505	47.590	48.216	46.392	45.154	47.673
Std. Error of Mean	1.435	1.472	1.472	0.991	1.017	1.257	1.541	1.335	1.296	1.540	1.342	1.318	1.200
95% CI Mean Upper	59.118	59.285	53.280	33.873	38.382	48.314	60.968	52.121	50.130	51.234	49.023	47.737	50.025
95% CI Mean Lower	53.492	53.515	47.509	29.988	34.396	43.387	54.925	46.888	45.050	45.197	43.761	42.572	45.321
Std. Deviation	17.811	18.266	18.270	12.298	12.618	15.596	19.129	16.568	16.080	19.112	16.659	16.350	14.893
95% CI Std. Dev. Upper	20.045	20.660	20.633	13.817	14.164	17.846	21.438	18.460	18.253	21.625	18.892	18.263	16.466
95% CI Std. Dev. Lower	15.384	15.614	15.842	10.795	11.111	13.333	16.662	14.241	13.750	16.228	14.319	14.201	13.055
Coefficient of variation	0.316	0.324	0.363	0.385	0.347	0.340	0.330	0.335	0.338	0.396	0.359	0.362	0.312
95% CI Variance Upper	401.792	426.821	425.718	190.913	200.609	318.494	459.605	340.784	333.155	467.656	356.911	333.541	271.115
95% CI Variance Lower	236.660	243.783	250.956	116.528	123.451	177.763	277.626	202.817	189.052	263.340	205.032	201.666	170.444
Range	97.501	97.500	92.930	69.436	73.016	86.127	92.513	88.361	89.710	98.929	99.057	88.945	72.506
Minimum	2.499	2.500	3.030	2.789	3.600	3.666	7.487	7.114	3.018	1.071	0.943	1.963	15.215
Maximum	100.000	100.000	95.960	72.226	76.616	89.792	100.000	95.475	92.728	100.000	100.000	90.908	87.722

Figure 17 Descriptive statistics from the final test of the control group's team problem solving competence.

In Figure 17 we see the summary results of the team problem solving competence of the final test of the control group students, which was conducted 6 months later. Each skill is again rated on a scale from 0 to 100. The mean scores (average) continue to be close to the median for all skills, again indicating a fairly even distribution of scores across all subcompetencies. The mean scores in the second exam are comparable to those in the first exam. The mode, or most common value, varied between skills, but for some a maximum value of 100 was reached. Standard deviations continue to be high for most skills, again indicating a wide variation in student performance. The minimum and maximum scores for all skills were comparable to those of the first exam, with the maximum score for some skills reaching the maximum score of 100. The coefficient of variation (the ratio between the standard deviation and the mean) is relatively stable for all skills, similar to the first exam. This indicates that the variation in scores continues to be similar across skills. Statistically, the data from the second exam is similar to the first exam.

Figure 18 shows the descriptive statistics from the initial test to investigate the team problem solving competence of the experimental group.

	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	CPS
Valid	132	132	132	132	132	132	132	132	132	132	132	132	132
Mode	28.022	100.000	28.994	27.314	23.959	45.137	39.962	46.520	32.700	53.040	37.117	42.858	14.853
Median	54.784	53.149	47.697	29.714	33.868	43.619	55.340	46.520	43.952	48.115	44.706	44.394	47.527
Mean	54.661	52.309	46.903	29.867	34.788	42.717	55.707	47.089	45.115	46.022	44.388	43.247	45.234
Std. Error of Mean	1.604	1.530	1.450	0.981	1.089	1.250	1.637	1.462	1.435	1.666	1.504	1.363	1.286
95% CI Mean Upper	57.805	55.307	49.744	31.790	36.923	45.168	58.916	49.954	47.928	49.288	47.337	45.919	47.755
95% CI Mean Lower	51.518	49.311	44.062	27.943	32.652	40.266	52.498	44.224	42.301	42.756	41.440	40.574	42.714
Std. Deviation	18.427	17.576	16.654	11.276	12.517	14.367	18.809	16.796	16.491	19.145	17.284	15.665	14.774
95% CI Std. Dev. Upper	20.708	20.223	18.976	12.700	14.165	16.350	21.417	18.915	18.995	21.757	20.039	17.491	16.534
95% CI Std. Dev. Lower	15.805	14.634	14.050	9.694	10.649	12.003	15.958	14.505	13.704	16.018	14.524	13.520	12.777
Coefficient of variation	0.337	0.336	0.355	0.378	0.360	0.336	0.338	0.357	0.366	0.416	0.389	0.362	0.327
95% CI Variance Upper	428.829	408.972	360.100	161.279	200.634	267.320	458.699	357.790	360.816	473.357	401.547	305.947	273.380
95% CI Variance Lower	249.786	214.151	197.402	93.974	113.399	144.074	254.645	210.403	187.790	256.582	210.946	182.794	163.255
Range	97.641	95.664	93.146	58.858	67.702	83.396	92.066	86.813	96.835	99.011	99.087	76.401	68.929
Minimum	2.359	4.336	2.814	2.502	7.650	3.703	7.934	5.568	3.165	0.989	0.913	4.082	14.853
Maximum	100.000	100.000	95.960	61.360	75.352	87.099	100.000	92.380	100.000	100.000	100.000	80.482	83.782

Figure 18 Descriptive statistics from the initial test of the team problem solving competence of the experimental group

Let's look at the test statistics to determine the entry level of the team problem solving competence of the experimental group. Each skill is rated on a scale from 0 to 100. The mean scores (average) continue to be close to the median for all skills, indicating an even distribution of scores. The mode, or most frequent value, varies between skills. Standard deviations are high for most skills, indicating a wide variation in student performance. Minimum and maximum scores for all skills are varied, with maximum scores for some skills being high and for others being low. The coefficient of variation (the ratio of the standard deviation to the mean) is relatively stable for all skills. This indicates that the variation in scores is similar across skills. When comparing the results of the experimental group with the control group at their entry level, it can be seen that they are very similar, which means that the two groups are equivalent in terms of their competence for team problem solving. The mean scores of the experimental group are similar or slightly lower than those of the control group in most skills. The standard deviations of the experimental group were as high, if not higher, than those of the control group, which also indicates a large variation in the student performance of the experimental group. The maximum and minimum scores for the experimental group are just as varied as for the control group, indicating that in both groups some students score very high while others score very low. The mode, or most frequent value, for the experimental group is very similar to the control group, again showing the similarity between the two groups. From the statistics examined, we can conclude that the two groups are equivalent and have a very similar level of competence for team problem solving.

Figure 19 shows the descriptive statistics from the final test to examine the team problem solving competence of the experimental group.

	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	CPS
Valid	132	132	132	132	132	132	132	132	132	132	132	132	132
Mode ᵃ	100.000	100.000	100.000	3.481	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	18.956
Median	70.425	72.618	65.648	41.717	47.594	58.013	73.270	60.851	61.943	64.782	61.277	58.776	63.284
Mean	70.255	68.932	65.639	43.507	50.990	58.663	71.907	62.349	62.807	62.419	59.884	58.055	61.284
Std. Error of Mean	2.109	2.140	2.287	1.792	1.840	1.925	2.130	2.167	2.065	2.336	2.096	2.059	1.569
95% CI Mean Upper	74.388	73.127	70.121	47.018	54.596	62.436	76.081	66.597	66.854	66.997	63.992	62.090	64.358
95% CI Mean Lower	66.122	64.737	61.157	39.995	47.384	54.890	67.733	58.102	58.760	57.841	55.777	54.019	58.209
Std. Deviation	24.226	24.590	26.276	20.586	21.139	22.116	24.467	24.897	23.723	26.834	24.077	23.653	18.023
95% CI Std. Dev. Upper	26.713	27.090	28.762	22.833	23.274	24.233	27.090	27.073	26.378	29.678	26.780	26.161	20.070
95% CI Std. Dev. Lower	21.436	21.962	23.482	18.125	18.754	19.512	21.483	22.274	21.027	23.458	21.125	20.791	15.613
Coefficient of variation	0.345	0.357	0.400	0.473	0.415	0.377	0.340	0.399	0.378	0.430	0.402	0.407	0.294
95% CI Variance Upper	713.579	733.855	827.263	521.324	541.686	587.238	733.848	732.925	695.786	880.782	717.156	684.414	402.805
95% CI Variance Lower	459.513	482.323	551.381	328.506	351.711	380.719	461.514	496.110	442.148	550.266	446.286	432.269	243.770
Range	95.493	92.869	95.506	96.519	90.973	96.087	92.727	94.989	96.044	98.831	98.541	96.272	77.395
Minimum	4.507	7.131	4.494	3.481	9.027	3.913	7.273	5.011	3.956	1.169	1.459	3.728	18.956
Maximum	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	96.350

Figure 19 Descriptive statistics from the final test of the team problem solving competence of the experimental group

In analyzing the results of the final test of the experimental group of students, we can draw the following conclusions. The average score is the highest for the skills A1 (70.255), C1 (71.907) and A2 (68.932). These are discovering perspectives and abilities of team members, communicating with team members about the actions to be/being performed, and discovering the type of collaborative interaction to solve the problem, along with goals. The lowest mean score is for skill B1 (43.507), which is forming a shared understanding and discussing the nature of the problem. The standard deviation is highest for D1 (26.834), indicating a wide variation in student performance on this skill, which is monitoring and adjusting for shared understanding of the nature of the problem.

Let's compare the experimental group's performance on the entry and exit tests. The average score improved in all skills, with the greatest improvement in A1, A2, A3 and B1. These are the skills of understanding team members' perceptions and abilities, understanding the nature of collaboration and goal formulation, understanding each team member's role in problem solving, and forming a shared understanding and discussion of the nature of the problem. The distribution of scores (as shown by the standard deviation) is broader, indicating that students have more diversity in their abilities after the course.

Let us also compare the final results of the experimental and control groups. The data shows that the mean scores of the experimental group are significantly higher than those of the control group for all skills. The skills with the largest differences in mean scores are A1, A2 and C1. These are understanding the perceptions and abilities of team members, understanding the nature of collaboration and goal formulation, and discussing with team members what actions should be taken to solve the problem. And the skills with the smallest differences are A3, D1 and C2. These are understanding each team member's role in solving the problem, monitoring and adjusting the shared understanding of the nature of the problem, and proposing an action plan.

In this dissertation, a statistical test is performed to show whether there are statistically significant differences between the control and experimental groups. The statistical software JASP was used to perform the statistical test of significance of the results.

The null hypothesis in our experiment states that there is no statistically significant difference in the means between the two groups, control and experimental, before and after the experimental group is trained on the platform. Before testing the hypothesis, we check for normality and equality of variances. There are significant results suggesting deviation from normality for all variables from A1 to D3 in the initial and final tests for the control and experimental groups. Because of the deviations from normality, the Mann-Whitney U test for equality of means is selected as appropriate without the need to test for equality of variances.

We choose a t-test with one-sided criterion for independent samples. From the results of the statistical test we can draw several conclusions. First, we see that there is no statistically significant difference between the prior means ($p>0.025$), while all differences from the next test are statistically significant ($p<0.025$). Therefore, we must accept the alternative hypothesis that the means of the control group are lower than those of the experimental group. The effect size of the differences for the Mann-Whitney U-test is determined by the rank-biserial correlation. All values were between 0.3 and 0.5, corresponding to medium effects. The largest difference is at C3 (post-test) with $|r|=0.446$, related to the task completion skills undertaken by team members. This was followed by B2 (post-test) ($|r|=0.431$), related to improving the skills of identifying and allocating tasks within the group, then D1 (post-test) ($|r|=0.388$), related to improving feedback among team members, and D2 (post-test) ($|r|=0.381$), related to improving the skills of evaluating the results of problem solving. The lowest performance was for C2 (post-test), where $|r|=0.322$, related to plan execution skills.

Differences between boys and girls in the experimental group were examined. The Shapiro-Wilk test for normality showed a normal distribution for both groups for A1 (pretest), B2 (pretest), C2 (pretest), B1 (posttest), B2 (posttest), B3 (posttest), and D3 (posttest). Lewin's test for equality of variances showed homogeneity of groups ($p>0.05$ in all pre-tests or post-tests of the variables. As a result of the assumption checks, we choose the Stuart test for equality of means for the above seven variables that are normally distributed and the Mann-Whitney test for the remaining variables. The effect size values are low, i.e., less than 0.3. We have a reduction in the performance differences between boys and girls in the experimental group for A1, A3, B1, B2, C1, C2, C3, D1, D2 and D3. Increasing differences we have at A2 and B3. Initial tests show that girls score higher than boys in collaborative problem-solving competence, which is consistent with PISA 2015 results. But with training, these differences narrow.

Conclusions

Based on the analyses conducted from the research results, the following conclusions can be drawn:

- **Working with the information system improves students' team problem-solving skills;**
- **Working with the information system improves students' teamwork skills;**
- **Working with the information system improves students' problem-solving skills;**
- **Working with the information system narrows the gap in mastery of team problem-solving competency.**

Conclusion

Main results of the study

- International concepts and frameworks for implementing 21st century skills in educational settings are explored and described. The frameworks are compared, and the common and distinguishing characteristics are described.
- International concepts and frameworks for the implementation of team problem-solving competence are explored and described. The international frameworks of PISA, CRESST and ATC21s are described. The frameworks are compared, and the common and distinguishing features are described.
- International best practices in the implementation of information systems in educational environments are studied and described.
- A methodology for assessing team problem-solving competence is described. The competency is divided into twelve skills. These skills are understanding the perceptions and abilities of team members, understanding the nature of collaboration and goal formulation, understanding the role of each team member in solving the problem, forming a shared understanding and discussing the nature of the problem, defining and presenting the tasks to be accomplished, defining the role of each team member and team organization , discussing with team members what actions should be taken to solve the problem, proposing an action plan
- We describe the methodology for creating and implementing an information system to improve team problem-solving competence.
- The system has been developed and implemented in the school's physics and astronomy and information technology courses in grades from seventh to tenth in 125th school "Boyan Penev" in Sofia.
- A didactic experiment was conducted with control and experimental groups with seventh to tenth grade students from 125th "Boyan Penev" High School.

Key findings from the study

- When an information system is appropriately selected and implemented, students' team problem-solving skills improve.
- With an appropriately selected and implemented information system, students' teamwork skills are improved.
- With an appropriately selected and implemented information system, students' competence in team problem solving is improved.
- Girls were found to perform better on tests of team problem-solving competence. However, when students work with the information system, the difference in the degree of mastery of team problem solving competence between boys and girls decreases.

Prospects for future research development

The work on this dissertation can be developed in the following directions.

1. The methodology is developed for team-based physical problem solving. A methodology can be made for team solving interdisciplinary problems. On the one hand this will make the model more complex, but on the other hand the problems will be closer to real examples.
2. The research could focus on the question of the influence of age in the development of team problem solving competence in physics. More schools should be selected for this purpose, which again makes the study more complex in terms of organisation and resources required.

Contributions

Theoretical

1. A model for team problem solving in physics is created. Basic teamwork skills are formulated and serve as performance indicators.
2. Designed an information system based on the teamwork model to examine teamwork and physical problem-solving skills.
3. Criteria are formulated for the degree of skills formation.

Applied

1. A toolkit has been developed for the team activity information system.
2. Testing and refining the platform for its full deployment in a school environment.
3. Implementation of the platform in a real school environment in compulsory and optional education.

Publications related to the dissertation

Conferences:

1. Building a Network to Support and Improve High-School Physics Education, Harvard University and National Science Foundation (NSF), 13-17 July 2020, Collaborative Problem Solving, Fabien Kunis.
2. 48th National Conference on Physics Education on "Nuclear Physics and Energy in Physics Education" 2-4 October 2020, Sofia. "The use of interactive simulations, videos and animations in the teaching of atomic and nuclear physics in the school course", Fabien Kunis
3. 49th National Conference on Physics Education "Physics in STEM Education in Secondary and Higher Education" June 4-6, 2021, Vidin. "The use of mobile devices in the school experiment in physics and astronomy in curricular and extra-curricular school activities", Fabien Kunis.
4. 49th National Conference on Physics Education "Physics in STEM Education in Secondary and Higher Education" June 4-6, 2021, Vidin. "Opportunities and Practices

in Implementing Teamwork in STEM Learning Environments", Fabien Kunis, Maya Gaidarova

5. Harvard Summer 2021 Free Virtual Conference: PoLS-T Exchange: 'Building a Global Network of High School Physics Teachers', How to Engage Students in Collaborative Learning, Fabien Kunis, 29.06.2021 - 01.07.2021
6. National Conference with International Participation "Educational Technologies 2021", Possibilities for analysis of damping vibration through a partially computer-based learning experiment in physics, Konstantin P. ILCHEV, Fabien T. KUNIS, Vesela V. DIMOVA, Christina A. MARKOVSKA, 06.09.2021 - 09.09.2021
7. National Conference with International Participation "Educational Technologies 2021", Improving students' understanding of kinematic and dynamic description of acceleration through partially computer-based learning experiment in physical experiment, Konstantin P. ILCHEV, Fabien T. KUNIS, Vesela V. DIMOVA, Christina A. MARKOVSKA, 06.09.2021 - 09.09.2021
8. The Ninth International Conference "Modern Trends in Science" (FMNS-2021), Analysis of problem-based learning in physics from the perspective of integrated STEM education, Ivelina Kotseva, Maya Gaydarova, Fabien Kunis, Konstantin Ilchev, 15.09.2021-19.09.2021, Blagoevgrad, Bulgaria
9. The Ninth International Conference "Modern Trends in Science" (FMNS-2021), Applying collaborative activities in high school physics course during hybrid model of learning, Fabien Kunis, Ivelina Kotseva, Maya Gaydarova, 15.09.2021-19.09.2021, Blagoevgrad, Bulgaria
10. 2022 Annual Meeting of the International Physics of Living Systems (iPoLS) Network, May 31 - June 3 2022, Montpellier, France, Think globally, act locally, Collaborative problem solving, Fabien Kunis.
11. 50th National Conference on Physics Education "Climate Change and Physics Education", June 2 - 5, 2022, Varna, Bulgaria, Paper on "Improving Teamwork Skills in Climate Change Education in Physics Education", authors.
12. 50th National Conference on Physics Education on "Climate Change and Physics Education", June 2 - 5, 2022, Varna, Bulgaria, Paper entitled: "Applying the e-research approach to the study of climate change" by Fabien Kunis.
13. 48th International Conference Applications of Mathematics in Engineering and Economics, 7 - 13 June 2022, Sozopol, Bulgaria, Improving Collaborative Problem-Solving Competency through Information Systems in Physics Education, Fabien Kunis, Maya Gaydarova, Ivelina Kotseva
14. 11th International Conference of the Balkan Physical Union, 28 August - 1 September 2022, Belgrade, Serbia, Report on Improving the Students' Learning of Optics and Atomic and Molecular Physics by Computer-assisted Spectroscopic School Experiments (S14-PEHPP-104)
15. Merry V. Dimova, Milena K. Stoyanova, Konstantin P. Ilchev, Fabien T. Kunis, Bozhidar N. Bozov, Christina A. Markovska, "Possibilities for improving the learning of mechanics material through a partial computer-based learning experiment in physics" (Vesela V. Dimova, Milena K. Stoyanova, Konstantin P. Ilchev, Fabien T. Kunis, Bojidar N. Bozov, Christina A. Markovska, "Opportunities for improving the learning of mechanical course material through partiallt computer-based physics learning experiment"), Announcements of Union of Scientists Sliven, vol. 37 (1), pp. 160-165 (2022)
16. Fabien Kunis, Konstantin Ilchev, Milena Stoyanova, Vesela Dimova, Tsanislava Genova, Stefan Valkov, Christina Andreeva, "Improving the students' learning of optics and atomic and molecular physics by computer-assisted school experiments",

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Scientific papers:

1. Kunis, F., & Dimitrov, M. (2020). Investigating the Lotka-Volterra model using computer simulation. Open Schools Journal for Open Science, 3(10). doi:https://doi.org/10.12681/osj.24890
2. Ivelina Kotseva, Maya Gaydarova, Fabien Kunis, Konstantin Ilchev, Analysis of problem-based learning in physics from the perspective of integrated STEM education, Bulgarian Chemical Communications, Volume 54, Special Issue B2, 2022
3. Fabien Kunis, Ivelina Kotseva, Maya Gaydarova, Applying collaborative activities in high school physics course during hybrid model of learning, Bulgarian Chemical Communications, Bulgarian Chemical Communications, Volume 54, Special Issue B2, 2022
4. Kunis, F. T., Dimitrov, M., & Markova, D. (2022). Simulating Predator-Prey System by Cellular Automata. Open Schools Journal for Open Science, 5(2). https://doi.org/10.12681/osj.31250
5. Teodora Vasileva, Fabien Kunis, "Manipulating Pixels, Graphic Images and Video Using Javascript", Science, Engineering & Education, Volume 7, Iss. 1, 2022, ISSN 2534-8507 (print), ISSN 2534-8515 (on line)
6. Daniel Kolev, Martin Kostov, Fabien Kunis, "Creating a Physical Wallet for Cryptocurrencies", Science, Engineering & Education, Volume 7, Iss. 1, 2022, ISSN 2534-8507 (print), ISSN 2534-8515 (on line)
7. Fabien Kunis, Ivelina Kotseva, Maya Gaydarova, Improving Collaborative Problem-Solving Competency through Information Systems in Physics Education, AIP Conference Proceedings, under review.

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