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Project-based learning in a computer modelling course

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Abstract. The paper reports authors' experience of implementing educational projects in a computer modelling course offered to the students majoring in "Secondary Education (Computer Science)" at Ternopil Volodymyr Hnatiuk National Pedagogical University. We analyze approaches to teaching mathematical and computer modelling such as: integration of modelling tasks, naturalistic case study, using of role-playing games, possibilities of STEM-education, motivation and positive attitude to modelling training, etc. Then we illustrate the implementation of the project to study the population dynamics of the grape snail Helix pomatia. The implementation of the project splits into several stages: formulation of the problem, presentation of project tasks, brainstorming, development, testing, presentation of results. The study was conducted at Ternopil Volodymyr Hnatiuk National Pedagogical University within the Norwegian-Ukrainian Project "Development of students' mathematical competencies through Digital Mathematical Modelling" (DeDiMaMo) in partnership with the University of Agder (Norway) and Borys Grinchenko Kyiv University.

1. Problem statement

Nowadays computer technology plays an important role in all areas of professional activities and contributes to the economic development. Most modern professions require the knowledge of computer technology and its use in applications. The study of ICT technologies at universities and colleges has a significant impact on the improvement of the quality of higher education. Currently, project-based learning is activities is one of the most effective methods of developing ICT competencies. The implementation of the project work in teaching requires thorough preparation and training of the teacher. S/he needs to develop a detailed plan for studying the topic, design presentations, develop exercises and tasks, define evaluation criteria, etc.

Contemporary problems of the development of mathematics and IT education were investigated in the recent work of Ukrainian researchers Kramarenko [16], Lovianova [51], Ponomareva [31], Rashevska [33], Shokaliuk [32], Soloviev [42], Vlasenko [50], Zhaldak [53] and others. Approaches to the use of software for demonstrations of physical phenomena were suggested by Kravtsov [15], Kuznietsov [18], Merzlykin [14], Moiseienko [9], Velychko [49], Yechkalo [11] and others. The development and implementation of virtual laboratories for process modelling has been the subject of research of Modlo [27], Nechypurenko [26], Semerikov [25], to mention a few. Today, the competency approach is basic in higher education in many countries (e.g., [12], [13], [19], [22], [23], [39], [47]). Its practical implementation actualizes the task of creating for each course a methodological system which should correspond to the model of professional competence.

Many theoretical and practical problems of training IT specialists have been addressed in the research of Semerikov and his colleagues. In particular, they designed the system of general professional competencies which constitute sustainable professional competence of software engineering specialist [37]. Another important component of the methodological system is modern ICT tools. Modlo [21] analyzed mobile Internet devices as a learning tool for Bachelor's of Electromechanics modeling of technical objects. Yashchuk [52] developed model for the professional competence formation of Master's students in Technology education identifying pedagogical (design, interactive, positional, contextual, training) and information (computer multimedia, Web) technologies.

The **purpose of this paper** is to present the authors' experience in using project-based learning methodology. It was used to teach computer modeling to students majoring in "Secondary Education (Computer Science)". The paper contains list of software offered for learning according to the authors` methodology.

2. Theoretical foundations of the research

The literature analysis shows that mathematics and computer modeling courses are important components in the training of a modern IT specialist. The culture of "teacher-student" relations in the educational systems of the European Union is based on the ideas of democracy and cooperation in the teacher-student interaction centered around student learning [54]. In the study "Mathematical modelling in Germany and France", the authors emphasized the significance of the integration of modeling tasks into particular examples from everyday life [8].

Eckhardt et al. [5] examined the effect of support for scientific discovery learning using computer simulations demonstrating that particular instructional interventions for data interpretation and self-regulation can effectively support learning with scientific computer simulations. Srisawasdi and Kroothkeaw [44] explored the learning process with the support of computer simulation and demonstrated its benefits for the development of students' learning of physics.

Buteau et al. [4] present a naturalistic case study of an undergraduate student enrolled in a sequence of three programming, project-based mathematics courses at the Brock University where students learn to design, program, and use interactive environments for the investigation of a mathematics concept, theorem, conjecture, or a real-world situation.

In his article "Quality Teaching of Mathematical Modelling: What Do We Know, What Can We Do?", Werner Blum points out the following important aspects of the teaching methodology for modelling [3]:

- effective and learner-oriented classroom management;
- cognitive and meta-cognitive activation of the learners;
- variety of suitable examples, individual solutions of modeling tasks;
- long-term learning process for development of the competencies;
- parallel development of competencies and appropriate beliefs and attitudes;
- systematic demonstration that digital technologies can be used as powerful tools for modeling activities.

One of the main factors affecting the efficiency of education in a modern university is the introduction of simulation and role-playing games, various types of models of processes or situations ([45], [46]). We believe that the use of tools for the development of students' project and research activities are important in the methodology of teaching computer modeling. In this context, it is appropriate to use methods and technologies such as project, modular, rating and problem learning; suggestive, cooperative and case technologies ([6], [10], [29], [40]).

In recent years, problem-based and project-based learning technologies have gained popularity in higher education institutions. The implementation of projects using ICT expands the content of learning through the comprehensive mastery of the theory, followed by its further implementation in professional activities [10]. Project work and group learning promote the development of important skills of participants in the educational process teaching them to interact, cooperate and be creative in joint learning activities. At the present stage of education development, STEM-education is a progressive concept which rapidly evolves contributing to the integration of different disciplines in study curricula ([1], [17], [28], [38], [41], [48]). It is in great demand in today's educational world and it often requires creation of a blended learning environment within which students can better understand how to apply scientific methods [2]. Thanks to this combination with blended learning, STEM education becomes more effective through the setting of challenging tasks challenge, high motivation which motivate students and encourage collaboration towards common educational goals [24].

Rogovchenko et al. [34] pointed out the importance of enjoyment component in the process of mathematical modelling. They argue that motivation and positive attitude are especially important for teaching and learning of mathematical modeling where students solve open ended, real-world problems and may experience the whole spectrum of emotions – from curiosity and puzzlement to frustration and despair to pleasure and satisfaction.

The use of the project-based learning method for computer modelling of neural networks has been studied in the paper by Semerikov et al [36]. The authors' methodology in an elective course includes the presentation of individual educational and research projects on the artificial neural networks architecture. The topics for the projects include modelling of continuous, discrete-continuous and discrete neural networks, time series forecasting, pattern recognition, functions approximation, dependency identification, medical diagnostics, decision-making under conditions of incomplete data, data compression, etc. [20].

3. Methodology of using projects for teaching computer modelling

Project-based learning allows students to gain valuable modelling experience, develop research competencies and information processing expertise and improve communication skills related to the modelling of the population size. The feasibility of using the proposed method is justified by the following factors ([7], [43]):

- conducting comparative analysis of mathematical methods by students;
- making decisions on the advantages and limitations of the use of a particular method;
- implementation of joint activities for modelling and development of software applications;
- mutual testing, debugging of developed software products;
- analysis and reporting of results.

During the project work on computer modelling, it is advisable to use the following forms of educational and cognitive activity: a) work in pairs or small groups; b) group work; c) individual work. We have chosen a laboratory workshop as the form of organization of students learning activities. Students may fail to consider many important factors that affect the likelihood of a model. As a result, the model may not meet all the requirements of scientific research. However, the main goals can be achieved through the well-thought and clear distribution of the tasks among students in the project.

The choice of population dynamics for modelling meets the basic requirements for the project-based learning method:

- The presence of a significant problem. In terms of research, the project requires mastering mathematical methods and modern programming tools.
- The tasks of the project are not static, i.e. they can change at the initiative of students.
- Practical, theoretical, and cognitive significance of the expected results of the activity for the environmentalists and ecologists.
- The use of a group work organization with the possibilities for using individual work within the group.
- Defining basic knowledge required for the work on the project.
- Structuring the content of the project.
- Realism of the project, its connection with educational resources.

The students work on the projects in small groups. To achieve the optimal division of the class into small groups, a preliminary survey of students can be conducted to determine individual psychological characteristics and collect information on individual study and work preferences. Each group is responsible for the development of one of the project components:

- Research of the subject area, specification of tasks.
- The choice of modelling approach and its formalization.
- Exploration of the existing software solutions.
- Defining the requirements for the application and its modules.
- Choice of programming tools.
- Direct development.
- Testing applications.
- Analysis of the obtained results, verification of their trustworthiness.
- Presentation of the obtained results.

The prerequisites for the successful work on the projects are the disciplines in computer science where the following components of professional competence must be formed:

- ability to carry out information retrieval activities;
- skills of formalization and design of algorithms;
- knowledge of several programming languages;
- skills of using digital technologies in solving practical problems;
- development of mathematical apparatus and understanding of fundamental mathematical concepts.

The latter competence can be successfully formed in pedagogical universities by combining the subject specialization Secondary Education (Computer Science) with the subject specialization Secondary Education (Mathematics) within one professional educational program (the names of subject specializations correspond to those currently used by the Ukrainian education authorities).

For the teaching of computer modelling, the following software products and digital technologies are used:

- Programming environments which help teachers and students to design and develop various software products. It should be noted that the use of programming language for achieving these goals requires special knowledge, skills and significant labour costs. Using in their education the languages Python, C#, Java, HTML, PHP master's students majoring in "Secondary Education (Computer Science)" have the opportunity to develop methodological materials for further use at the workplace. Examples of such interactive teaching materials are student-developed projects, project materials, textbooks and monographs containing the materials for a deeper study of selected topics of the school curriculum in computer science, and so on.
- Ready-made software solutions (encyclopaedias, educational programs, specialized mathematical packages Mathcad, MATLAB, Mathematica, Microsoft Office software package, etc.), access to the Internet and reference materials, video tutorials, educational films.
- Cloud services (in particular, Google Suite and Microsoft Office 365 services) for the organization of the students' individual and group work, relevant Web-sites with the materials for the use in the educational process.

We decided to focus our research on the application of project methodology for the development of professional competences of future specialists. One of the characteristics of students' competence is the ability to synthesize the knowledge and use the skills acquired in the disciplines "Programming", "Computer Graphics", "Applied Software", "Graph Theory". The most efficient training of future specialists in computer science is achieved through the interdisciplinary integration implemented with the support of information and communication technologies.

4. Practical aspects of the project implementation

The project-based learning in computer (mathematics) modelling classes can be successful when it fits students' general and specific intellectual skills. This can be done at different levels: individual work, discussions and work in small groups, presentation of individual and small group results to the whole class. Students mostly complete the project independently (both individual and group work are used), but the teacher monitors the work, advises, monitors, adjusts and evaluates. All projects are stored in the database of student works at the department. The implementation of the project splits into several stages.

Stage 1: formulation of the problem. The project work starts with the formulation of the task of the project aimed at the development of the computer model to study the dynamics of the population. In the process of formulation, the teacher suggests possible ways to approach the task.

- conceptual – models of population dynamics (Malthusian model, Verhulst model, Ricker model, Leslie model) including theoretical substantiation of the advantages of the Leslie model;
- organizational – creation of working groups (teams) for the implementation of the parts of the project and setting of specific tasks for each group;
- technological – selection of the necessary specialized software and digital technologies for each group.

The teacher informs students about the knowledge and skills they should acquire in the process of project implementation.

Stage 2: presentation of project tasks. The purpose of this stage is to introduce the object of the study to students. It is important to draw students' attention to the need for joined collective efforts to achieve the desired results. Preliminary preparation of project participants is also required; students have to review relevant research literature and available software solutions. The easiest way to get useful tips and guidance is to talk to teachers who have previously worked with the project participants.

Stage 3: brainstorming. Students put forward general ideas regarding the project implementation, discuss the possibility and necessity of using certain tools and technology, suggest approaches to tackle the task. All student proposals must be thoroughly explained and carefully substantiated; the ideas that are approved should be mapped onto the project's timeline to achieve their feasibility. As a result, several ideas that can potentially lead to the solution to the problem are selected. Due attention should be paid to the design and graphical presentation of the results in the project. To this end, it is preferable to form a dedicated group of students dealing with this task. Interim and final results are recorded, organized and substantiated.

Stage 4: development. In order to structure the educational process in the project-based learning, the workshop can be organized in the form of laboratory work with the tasks as parts of the project. The teacher offers two components of the project organization: invariant and variable.

Stage 5: testing. Based on the requirements of the practical usefulness of the project results, its implementation requires not only the functionality of the software components, but also the verification of the results. To this end, the results of the population forecast are compared with real data. If needed, the model should be adjusted and tested again.

Stage 6: presentation of results. In our opinion, it should be organized in the format of a seminar or mini-conference. For example, during the work on the project "Application of the Leslie model to the study of dynamic systems" students used the service http://www.easel.ly to prepare infographics that can be used for a variety of purposes: drawing attention to the problem; a quick overview of the topic; explanation of a complex process; presentation of research results; report generation; comparison of results. This and similar services facilitate the presentation of project results, ideas and related concepts.

The students' programming knowledge and skills are formed in a sequence of course distributed through the study program. First year students study programming in Python and application packages Mathcad, MATLAB, from the second year they start working with computer graphics in 3DS Max and Web-programming. All computer simulation projects must be accompanied by relevant graphs or charts. Therefore, the Mathcad system and the Python programming environment remain popular. In the Mathcad system, calculations were performed using the knowledge of linear algebra; the results of these calculations are further used in the developed software applications. In our case, students found the eigenvalues and eigenvectors of the matrices of the orders three to seven, seventh and eighth powers of matrices.

To illustrate the methodology used in the project-based course, we discuss as an example one of the projects where students worked within the laboratory workshop.

Assignment. Suggest a realistic Leslie model for the population of the grape snail *Helix pomatia* (*Helicidae*, *Gastropoda*, *Mollusca*) in the vicinity of the village Velyki Chornokintsi in Chortkiv district located on the Ternopil plateau and investigate the dynamics of this population based on the following demographic table.

Table 1. Demographic table for the population of the grape snail *Helix pomatia*.

Age group	2017	2018	2019
1	181	157	144
2	118	104	97
3	104	89	86
4	95	82	80
5	79	68	66
6	68	53	55
7	53	47	40
Total	698	600	568

The population is divided into 7 age groups. At each fixed point in time, it can be characterized by a column vector

$$X(t) = (x_1(t);\ x_2(t);\ \dots\ ;\ x_7(t))^T,$$

where $x_i(t)$ – the number of *i*-th age group at the time t.

To build the Leslie model, one uses the data from the table to calculate the survival rates based on the formula:

$$x_{i+1}(t+1) = S_i \cdot x_i(t),\ S_i = \frac{x_{i+1}(t+1)}{x_i(t)},$$

where *t* is the year 2017 or 2018.

As a result, one obtains $S_{1\ (2017-2018)} = \frac{104}{181} = 0.57$; $S_{2\ (2017-2018)} = \frac{89}{118} = 0.75$; $S_{3\ (2017-2018)} = \frac{82}{104} = 0.79$; $S_{4\ (2017-2018)} = \frac{68}{95} = 0.72$ etc.;

$S_{1\ (2018-2019)} = \frac{97}{157} = 0.62$; $S_{2\ (2018-2019)} = \frac{86}{104} = 0.83$; $S_{3\ (2018-2019)} = \frac{80}{89} = 0.9$; $S_{4\ (2018-2019)} = \frac{66}{82} = 0.8$ etc.

Table 2. Survival rates.

Survival rates	2017-2018	2018-2019	Average value
S_1	0.57	0.62	0.6
S_2	0.75	0.83	0.8
S_3	0.79	0.9	0.85
S_4	0.72	0.8	0.76
S_5	0.67	0.81	0.74
S_6	0.69	0.75	0.72

The fertility rate for the first age group is assumed to be 0, for all other classes – the fertility rates are equal and are calculated with the help of the formula

$$x_1(t+1) = \sum_{i=1}^{n} b_i x_i(t); \qquad b_i = \frac{x_1(t+1)}{\sum_{i=1}^{n} x_i(t) - x_1(t)}.$$

Consequently, the fertility rates for two years are given by

$$b(2018) = \frac{157}{698-181} = 0.3; \quad b(2019) = \frac{144}{600-157} = 0.33$$

and the average value of the fertility rate equals $\frac{(0.3+0.33)}{2} \approx 0.32$.

The Leslie matrix for a homogeneous model has the form

$$L = \begin{pmatrix} 0 & 0.32 & 0.32 & 0.32 & 0.32 & 0.32 & 0.32 \\ 0.6 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.85 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.76 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.74 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.72 & 0 \end{pmatrix}$$

The first row in this matrix contains fertility rates for all age groups, the numbers below the main diagonal represent survival rates for the respective age groups, all other entries in the matrix are zeros. The structure of the matrix is determined from the assumptions that during a period of time, individuals from the *j*-th age group move to the next, (*j*+1)-th age group. During this period, some individuals die and the offspring are born for individuals in the *i*-th group.

The age structure of the population for a homogeneous model of Leslie is given by the formulas

$$X(t_1) = L \cdot X(t_0); \;\; X(t_2) = L \cdot X(t_1) = L^2 \cdot X(t_0); \;\ldots\; X(t_i) = L \cdot X(t_{i-1}) = L^i \cdot X(t_0)$$

For the initial distribution, data from table 1 are used: $X(t_0) = (181;\ 118;\ 104;\ 95;\ 79;\ 68;\ 53)^T$.

$$X(t_1) = L \cdot X(t_0) = \begin{pmatrix} 0 & 0.32 & 0.32 & 0.32 & 0.32 & 0.32 & 0.32 \\ 0.6 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.85 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.76 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.74 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.72 & 0 \end{pmatrix} * \begin{pmatrix} 181 \\ 118 \\ 104 \\ 95 \\ 79 \\ 68 \\ 53 \end{pmatrix} = \begin{pmatrix} 165 \\ 109 \\ 94 \\ 88 \\ 73 \\ 58 \\ 49 \end{pmatrix};$$

$$X(t_2) = L^2 \cdot X(t_0) = \begin{pmatrix} 150 \\ 98 \\ 87 \\ 80 \\ 68 \\ 53 \\ 42 \end{pmatrix}; \quad X(t_3) = L^3 \cdot X(t_0) = \begin{pmatrix} 137 \\ 91 \\ 80 \\ 74 \\ 61 \\ 49 \\ 38 \end{pmatrix};$$

$$X(t_4) = L^4 \cdot X(t_0) = \begin{pmatrix} 125 \\ 82 \\ 72 \\ 67 \\ 56 \\ 45 \\ 36 \end{pmatrix}; \quad X(t_5) = L^5 \cdot X(t_0) = \begin{pmatrix} 115 \\ 76 \\ 64 \\ 62 \\ 52 \\ 42 \\ 33 \end{pmatrix}; \text{ etc.}$$

At the nineth iterate, stabilization will take place for a homogeneous model, after which one can use the formula

$$X(t) = \lambda^t \cdot X(t_0),$$

where λ is the eigenvalue of the Leslie matrix for predicting the population dynamics.

The characteristic equation for the Leslie matrix assumes the form

$$\begin{vmatrix} 0-\lambda & \frac{8}{25} & \frac{8}{25} & \frac{8}{25} & \frac{8}{25} & \frac{8}{25} & \frac{8}{25} \\ \frac{3}{5} & 0-\lambda & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{4}{5} & 0-\lambda & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{17}{20} & 0-\lambda & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{19}{25} & 0-\lambda & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{37}{50} & 0-\lambda & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{18}{25} & 0-\lambda \end{vmatrix} =$$

$$= -\lambda^7 + \frac{24}{125}\cdot\lambda^5 + \frac{96}{625}\cdot\lambda^4 + \frac{408}{3125}\cdot\lambda^3 + \frac{7752}{78125}\cdot\lambda^2 + \frac{143412}{1953125}\cdot\lambda + \frac{2581416}{48828125} =$$

$$= \frac{-1}{44828125}\cdot(48828125\cdot\lambda^7 - 9375000\cdot\lambda^5 - 7500000\cdot\lambda^4 -$$

$$-6375000\cdot\lambda^3 - 4845000\cdot\lambda^2 - 3585300\cdot\lambda - 2581416 = 0.$$

According to the Perron-Frobenius theorem [30], the Leslie matrix has a single positive eigenvalue λ such that for any other eigenvalue r of the same matrix the condition $|r| \leq \lambda$ holds. This eigenvalue is called dominant (major) and characterizes the rate of population reproduction.

If all elements of the matrix are constants, depending on the dominant value λ, one of the three scenarios of population dynamics is possible. If $\lambda < 1$, then the population size will decay to zero, if $\lambda > 1$, it will increase indefinitely. If $\lambda = 1$, starting from some point in time, the population size will approach the constant value and the ratio between different age groups will stabilize. In reality, birth and death rates can depend on the total population, the ratio of its components, as well as changes in habitat conditions.

In our case, the dominant eigenvalue $\lambda = 0.914$. This means that the population size will decline over time.

As can be seen from figure 1, according to the Leslie model, the population of snails in the coming years will decline and in 2020 will be 450 and in 2021 – about 400.

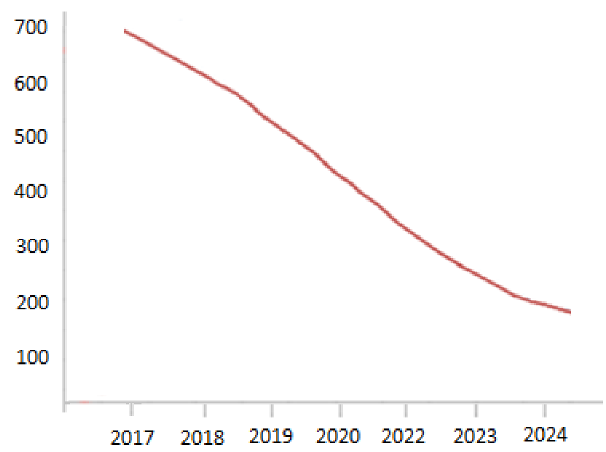

Figure 1. Forecasted population size data.

5. Conclusions

Project-based learning is widely used in higher education. The use of information and communication technologies is an integral part of the modern educational process. In combination with the use of modern technology, it contributes to the formation of professional-oriented experience. The use of correct methodology for applications of digital technologies in the classroom and students' individual work is nowadays an important competence for teachers, lecturers and computer science specialists. In this paper, we report the use of information and communication technologies in the education of students majoring in Secondary Education with the specialization in Computer Science. The methodological features of the organization of information and communication support of the educational process are illustrated on the example of the project on computer modelling of the population dynamics.

Project work best fits into the competency approach, which includes the development of the ability to work with and critically assess different sources of information, ability to work efficiently in a group and individually. Therefore, the project-based learning allows to personalize the educational process providing students with the opportunities of independent planning, organization and control of their educational activities. The application of project methodology in the classroom stimulates and maintains a long-lasting interest in computer modelling, deepens and systematizes students' knowledge of various subjects and contributes to the formation of a holistic perception and integrated approach to the scientific analysis of phenomena and processes in the world.

References

[1] Balyk N, Barna O, Shmyger G and Oleksiuk V 2018 Model of Professional Retraining of Teachers Based on the Development of STEM Competencies *CEUR Workshop Proceedings* **2104** 318–331

[2] Balyk N, Shmyger G, Vasylenko Ya, Oleksiuk V and Skaskiv A 2019 STEM-Approach to the Transformation of Pedagogical Education *E-learning and STEM Education (Electronic Materials* vol 11*)* ed Smyrnova-Trybulska E (Katowice – Cieszyn: University of Silesia) chapter I pp 109–25

[3] Blum W 2015 Quality Teaching of Mathematical Modelling: What Do We Know, What Can We Do? *The Proceedings of the 12th International Congress on Mathematical Education* ed Cho S (Cham: Springer) pp 73–96 URL https://doi.org/10.1007/978-3-319-12688-3_9

[4] Buteau C, Muller E, Marshall N, Sacristán A I and Mgombelo J 2016 Undergraduate Mathematics Students Appropriating Programming as a Tool for Modelling, Simulation, and Visualization: A Case Study *Digital Experiences in Mathematics Education* **2** 142–66 URL https://doi.org/10.1007/s40751-016-0017-5

[5] Eckhardt M, Urhahne D, Conrad O and Harms U 2013 How effective is instructional support for learning with computer simulations? *Instructional Science* **41** 105–24 URL https://doi.org/10.1007/s11251-012-9220-y

[6] Glazunova O G, Parhomenko O V, Korolchuk V I and Voloshyna T V 2021 The effectiveness of GitHub cloud services for implementing a programming training project: students' point of view *Journal of Physics: Conference Series* In press

[7] Glazunova O, Kuzminska O, Voloshyna T, Sayapina T and Korolchuk V 2017 E-environment based on Microsoft SharePoint for the organization of group project work of students at higher education institutions *Information Technologies and Learning Tools* **62** 98–113

[8] Hankeln C 2020 Mathematical modeling in Germany and France: a comparison of students' modeling processes *Educational Studies in Math*ematics **103** 209–29 URL https://doi.org/10.1007/s10649-019-09931-5

[9] Holub O, Moiseienko M and Moiseienko N 2020 Fluid Flow Modelling in Houdini *CEUR Workshop Proceedings* **2732** 909–17

[10] Horbatiuk R M, Bilan N M, Sitkar O A and Tymoshchuk O S 2021 The formation of educational environment in foreign language training of energy engineering students by means of project technology *Journal of Physics: Conference Series* In press

[11] Hruntova T V, Yechkalo Yu V, Striuk A M and Pikilnyak A V 2018 Augmented Reality Tools in Physics Training at Higher Technical Educational Institutions *CEUR Workshop Proceedings* **2257** 33–40
[12] Kazhan Yu M, Hamaniuk V A, Amelina S M, Tarasenko R O and Tolmachev S T 2020 The use of mobile applications and Web 2.0 interactive tools for students' German-language lexical competence improvement *CEUR Workshop Proceedings* **2643** 392–415
[13] Kholoshyn I V, Bondarenko O V, Hanchuk O V and Shmeltser E O 2019 Cloud ArcGIS Online as an innovative tool for developing geoinformation competence with future geography teachers *CEUR Workshop Proceedings* **2433** 403–12
[14] Kiv A E, Merzlykin O V, Modlo Ye O, Nechypurenko P P and Topolova I Yu 2019 The overview of software for computer simulations in profile physics learning *CEUR Workshop Proceedings* **2433** 352–62
[15] Kozlovsky E O and Kravtsov H M 2019 Multimedia virtual laboratory for physics in the distance learning *CEUR Workshop Proceedings* **2168** 42–53
[16] Kramarenko T H, Pylypenko O S and Zaselskiy V I 2020 Prospects of using the augmented reality application in STEM-based Mathematics teaching *CEUR Workshop Proceedings* **2547** 130–144f
[17] Kramarenko T H, Pylypenko O S and Zaselskiy V I 2020 Prospects of using the augmented reality application in STEM-based Mathematics teaching *CEUR Workshop Proceedings* **2547** 130–44
[18] Kuznietsov V S and Moiseienko N V 2018 Development graphic shell for the program calculations of physical properties of solids *CEUR Workshop Proceedings* **2292** 156–61
[19] Leshchenko M P, Kolomiiets A M, Iatsyshyn A V, Kovalenko V V, Dakal A V and Radchenko O O 2021 Development of informational and research competence of postgraduate and doctoral students in conditions of digital transformation of science and education *Journal of Physics: Conference Series* In press
[20] Markova O, Semerikov S and Popel M 2018 CoCalc as a Learning Tool for Neural Network Simulation in the Special Course "Foundations of Mathematic Informatics" *CEUR Workshop Proceedings* **2104** 388–403
[21] Modlo Ye O and Semerikov S O 2018 Xcos on Web as a promising learning tool for Bachelor's of Electromechanics modeling of technical objects *CEUR Workshop Proceedings* **2168** 34–41
[22] Modlo Ye O, Semerikov S O, Shajda R P, Tolmachev S T, Markova O M, Nechypurenko P P and Selivanova T V 2020 Methods of using mobile Internet devices in the formation of the general professional component of bachelor in electromechanics competency in modeling of technical objects *CEUR Workshop Proceedings* **2643** 500–34
[23] Moiseienko M V, Moiseienko N V, Kohut I V and Kiv A E 2020 Digital competence of pedagogical university student: definition, structure and didactical conditions of formation *CEUR Workshop Proceedings* **2643** 60–70
[24] Morze N, Gladun M and Dziuba A 2018 Formation of key and subject competences of students by robotic kits of STEM-education *Information Technologies and Learning Tools* **65** 37–52
[25] Nechypurenko P P and Semerikov S O 2017 VlabEmbed – the New Plugin Moodle for the Chemistry Education *CEUR Workshop Proceedings* **1844** 319–26
[26] Nechypurenko P P, Selivanova T V and Chernova M S 2019 Using the Cloud-Oriented Virtual Chemical Laboratory VLab in Teaching the Solution of Experimental Problems in Chemistry of 9th Grade Students *CEUR Workshop Proceedings* **2393** 968–83
[27] Nechypurenko P, Evangelist O, Selivanova T and Modlo Ye 2020 Virtual Chemical Laboratories as a Tools of Supporting the Learning Research Activity of Students in Chemistry While Studying the Topic "Solutions" *CEUR Workshop Proceedings* **2732** 984–95
[28] Osadchyi V V, Valko N V and Kuzmich L V 2021 Using augmented reality technologies for STEM education organization *Journal of Physics: Conference Series* In press
[29] Pavlenko M and Pavlenko L 2021 Formation of communication and teamwork skills of future IT-

specialists using project technology *Journal of Physics: Conference Series* In press

[30] Pillai S U, Suel T and Seunghun Cha 2005 The Perron-Frobenius theorem: some of its applications *IEEE Signal Processing Magazine* **22** 62–75 URL https://doi.org/10.1109/MSP.2005.1406483

[31] Ponomareva N S 2021 Role and place of Informatics in the training of future teachers of mathematics *Journal of Physics: Conference Series* In press

[32] Popel M V, Shokalyuk S V and Shyshkina M P 2017 The Learning Technique of the SageMathCloud Use for Students Collaboration Support *CEUR Workshop Proceedings* **1844** 327–39

[33] Rashevska N V, Semerikov S O, Zinonos N O, Tkachuk V V and Shyshkina M P 2020 Using augmented reality tools in the teaching of two-dimensional plane geometry *CEUR Workshop Proceedings* **2731** 79–90

[34] Rogovchenko Yu, Viirman O and Treffert-Thomas S 2020 Joy of Mathematical Modelling: A Forgotten Perspective? *Mathematical Modelling Education and Sense-making. International Perspectives on the Teaching and Learning of Mathematical Modelling (Electronic Materials)* ed G Stillman G Kaiser and C Lampen (Springer, Cham) pp 95-106

[35] Semerikov S O, Teplytskyi I O, Soloviev V N, Hamaniuk V A, Ponomareva N S, Kolgatin O H, Kolgatina L S, Byelyavtseva T V, Amelina S M and Tarasenko R O 2021 Methodic quest: reinventing the system *Journal of Physics: Conference Series* In press

[36] Semerikov S O, Teplytskyi I O, Yechkalo Yu V, Markova O M, Soloviev V N and Kiv A E 2019 Computer Simulation of Neural Networks Using Spreadsheets: Dr. Anderson, Welcome Back *CEUR Workshop Proceedings* **2393** 833–48

[37] Semerikov S, Striuk A, Striuk L, Striuk M and Shalatska H 2020 Sustainability in Software Engineering Education: a case of general professional competencies *The Int. Conf. on Sustainable Futures: Environmental, Technological, Social and Economic Matters* **166** 10036

[38] Shapovalov Ye B, Shapovalov V B, Andruszkiewicz F and Volkova N P 2020 Analyzing of main trends of STEM education in Ukraine using stemua.science statistics *CEUR Workshop Proceedings* **2643**, 448–61

[39] Shokaliuk S V, Bohunenko Ye Yu, Lovianova I V and Shyshkina M P 2020 Technologies of distance learning for programming basics on the principles of integrated development of key competences *CEUR Workshop Proceedings* **2643** 548–62

[40] Shuhailo Ya V and Derkach T M 2021 Project-based learning for undergraduate engineering students minoring in textile technology and design *Journal of Physics: Conference Series* In press

[41] Shyshkina M P 2018 The Problems of Personnel Training for STEM Education in the Modern Innovative Learning and Research Environment *CEUR Workshop Proceedings* **2257** 61–5

[42] Soloviev V N, Moiseenko N V and Tarasova O Yu 2020 Modeling of Cognitive Process Using Complexity Theory Methods *CEUR Workshop Proceedings* **2393** 905–18

[43] Spirin O, Oleksiuk V, Balyk N, Lytvynova S and Sydorenko S 2019 The Blended Methodology of Learning Computer Networks: Cloud-based Approach *CEUR Workshop Proceedings* **2393** 68–80

[44] Srisawasdi N and Kroothkeaw S 2014 Supporting students' conceptual development of light refraction by simulation-based open inquiry with dual-situated learning model *Journals of Computers in Education* **1** 49–79 URL https://doi.org/10.1007/s40692-014-0005-y

[45] Tokarieva A V, Volkova N P, Harkusha I V and Soloviev V N 2019 Educational digital games: models and implementation *CEUR Workshop Proceedings* **2433** 74–89

[46] Vakaliuk T A, Kontsedailo V V, Antoniuk D S, Korotun O V, Mintii I S and Pikilnyak A V 2020 Using game simulator Software Inc in the Software Engineering education *CEUR Workshop Proceedings* **2547** 66–80

[47] Vakaliuk T, Kontsedailo V, Antoniuk D, Korotun O, Semerikov S and Mintii I 2020 Using Game Dev Tycoon to Develop Professional Soft Competencies for Future Engineers-Programmers

CEUR Workshop Proceedings **2732** 808–22
[48] Valko N V, Kushnir N O and Osadchyi V V 2020 Cloud technologies for STEM education *CEUR Workshop Proceedings* **2643** 435–47
[49] Velychko V Ye, Fedorenko E H and Kassim D A 2018 Conceptual Bases of Use of Free Software in the Professional Training of Pre-Service Teacher of Mathematics, Physics and Computer Science *CEUR Workshop Proceedings* **2257** 93–102
[50] Vlasenko K, Chumak O, Lovianova I, Kovalenko D and Volkova N 2020 Methodical requirements for training materials of on-line courses on the platform "Higher school mathematics teacher" *E3S Web of Conferences* **166** 10011 URL https://doi.org/10.1051/e3sconf/202016610011
[51] Vlasenko K, Volkov S, Sitak I, Lovianova I and Bobyliev D 2020 Usability analysis of on-line educational courses on the platform "Higher school mathematics teacher" *E3S Web of Conferences* **166** 10012 URL https://doi.org/10.1051/e3sconf/202016610012
[52] Yashchuk I 2007 Features of pedagogical interaction in the conditions of humanization of educational process of higher educational institution *Pedagogical discourse* **1** 153–6
[53] Zhaldak M I, Franchuk V M, Franchuk N P 2021 Some applications of cloud technologies in mathematical calculations *Journal of Physics: Conference Series* In press
[54] Zhernoklieiev I 2011 The democratic basis of the process of training future technology teachers in the north countries of Europe *Sci. J. of the National Pedagogical Dragomanov University (Series 5. Pedagogical sciences: realities and prospects)* **30** 61–8