Experience in training specialists with mathematical computer modeling skills, taking into account the needs of the modern labor market

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Abstract

Today in most countries there is a lack of qualifications in areas, which require specialists with mathematical competencies, despite the high unemployment rate in many countries. At the same time, it is generally recognized that most likely those sciences are developing, the fundamental results of which can be formulated mathematically. Using mathematical methods, researchers draw important conclusions that could hardly be obtained otherwise. Digital transformation of all industries requires specialists with a sufficient level of mathematical competence and skills in ICT tools, including computer modeling using the approach called Inquiry-Based Mathematics Education (IBME).

Keywords

mathematical competence, STEM education, computer modeling, IBME, labor market

1. Introduction

Modern society, digital transformation of all industries require the development of business mindset, innovation, STEM education and science education. These needs of the labor market can be met only with professionals who have an adequate level of mathematical competence.

In the last few years, Ukrainian universities have faced the problem of mathematics' training. Young people do not wish to teach mathematics and have a low level of preparation when they enter the university to master the program in mathematics.

We see a real problem with the study and teaching of mathematics in high school and in universities. One of the reasons for this situation, in our opinion, is the low motivation of students. This happens because students do not see a suitable labor market. There are two ways to solve this problem:

1. Change the methodology of teaching mathematics from passive learning to active activities. This means students are involved in solving theoretical and practical problems using

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the inquiry.

2. Teach students a business mindset. This means the development of their own projects that can become Startups. All with the help of mathematics.

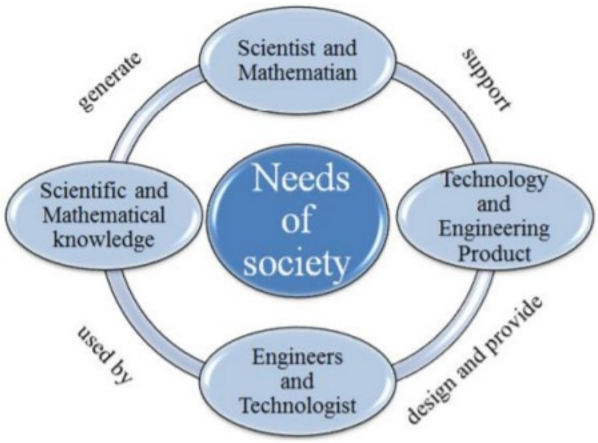

Figure 1: Needs of society.

The problem of the quality of natural and mathematical education in Ukraine as a part of the general world educational space is multidimensional, and numerous academic and journalistic works of domestic and foreign authors are devoted to various aspects of this problem.

The aim of this paper is to show IBME approaches in teaching mathematical modeling considering the demand in the labor market in professions requiring mathematical competence and to analyze European and national approaches to stimulate their use in accordance with the needs of the labor market, and to identify competencies that contribute to an increase in a skilled workforce considering the formation of mathematical competence.

The modern labor market imposes requirements on graduates of higher educational institutions related to the possession of professional (hard skills) and flexible (soft skills) skills, hard skills are determined by professional knowledge, skills that can be clearly demonstrated, necessary for solving specific professional tasks are formed in the learning process.

Knowledge of mathematics is critical for many areas of business: finance, IT, construction, accounting, architecture, mechanical engineering, logistics, medicine, trade and others.

Firstly, mathematical knowledge allows you to learn about the world, and, if necessary, work in other spheres of human activity. For example, a mathematician can easily work as an analyst in various modern companies. This is evidenced by the examples and lives of graduates of other specialities of Borys Grinchenko Kyiv University.

Secondly, the need of modern society for mathematicians, and not only for programmers and economists, is constantly increasing. This affects wages and the ability to work both in Ukraine and abroad.

2. Related work

The shortage of specialists in the labor market with established mathematical competence has been investigated by many scientists. In particular, Levanon [1] analyzed the main analysis on labor shortages in the United States and other advanced economies. The author notes that the risk of labor shortages in mathematics majors is much higher due to the rapid increase in available data at the company level or big data, currently leading to the rapidly growing demand for workers who can help turn this data into business decisions. According to employment forecasts by the Bureau of Labor Statistics, the math professions are expected to grow by 28 percent in 2014-2024 – one of the fastest-growing occupation groups in the entire economy.

To meet the needs of modern society in mathematics, we see the importance of forming mathematical competence [2]. In particular, Onoprienko [3] considers the formation of mathematical competence through competence-oriented problems.

The system approach is presented in the works of Fayzullaev [4], Khomiuk [5], Striuk et al. [6]. The formation of professional and mathematical competence of students in the field of technical training on the basis of interdisciplinary integration of mathematics and computer science is considered by Vasileva et al. [7]. Astafieva et al. [8] substantiated the approaches to the effective use of the advantages and minimized the disadvantages and losses of e-learning as a means of forming the mathematical competence of students in the context of a research-oriented educational process.

To increase the motivation of students in the study of mathematics, one way is to demonstrate the connection with real life. The method of studying processes or phenomena by creating their mathematical models and studying these models is mathematical modeling. A great contribution to the study of teaching mathematical modeling has also been made by Flehantov and Ovsiienko [9], Kaiser [10], Lvov et al. [11], Riyanto et al. [12], Teplytskyi [13].

3. Research methods

Teachers of the Department of Computer Science and Mathematics also conduct ongoing research in the direction of the quality of science and mathematics education. As part of an international project ERASMUS+ Platinum a survey of employers of the modern labor market in Ukraine and graduates of the University was conducted in order to compare on the one hand the needs of employers in specialists with mathematical competencies, on the other – self-assessment of graduates on the level of relevant competencies, Inquiry-Based Mathematics Education (IBME) used in the teaching of mathematical disciplines, in which students are invited to work in ways similar to how mathematicians and scientists work. In our project, we conducted a survey of employers and business leaders.

The task of the survey was to analyze what qualities employers expect and what students lack when they get a job. The survey was attended by employers in Kyiv, whose areas of activity are different in figure 2.

To the question "Do your company employ specialists with higher education, an important component of whose professional training were mathematical disciplines?" all respondents answered "yes". At the same time, 68.8% of participants answered in the affirmative about the

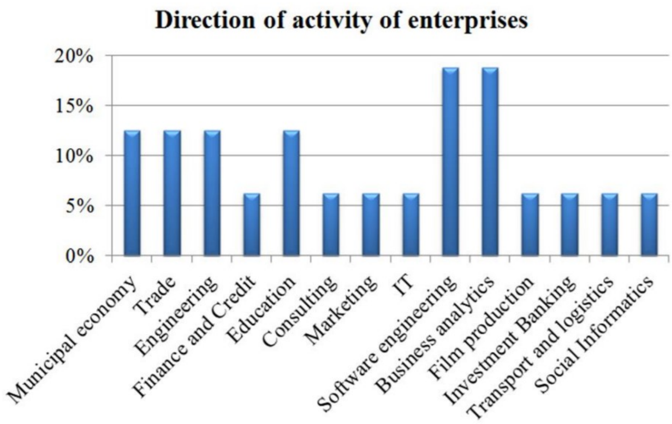

Figure 2: The direction of activity of the surveyed employers.

need for such specialists at their enterprise, 12.5% need professional mathematicians and 12.5% need situationally and then specialists are involved on a project basis.

The labor market needs for specialists in whom mathematical competencies are formed is also indicated by the answer to the question "Are you satisfied with the level of mathematical training of specialists working at your enterprise?" 43.8% answered "yes", 43.8% -"need a special preparation for the tasks of the organization", 12.5% – "suits, because a personnel policy is being carried out to select the appropriate stuff".

The survey also shows us which competencies are important for mathematicians from the point of view of the job market: the importance of competencies for mathematics specialists for business; use the Web resources to solve professional problems; ability to apply mathematical knowledge and models in real-life contexts.

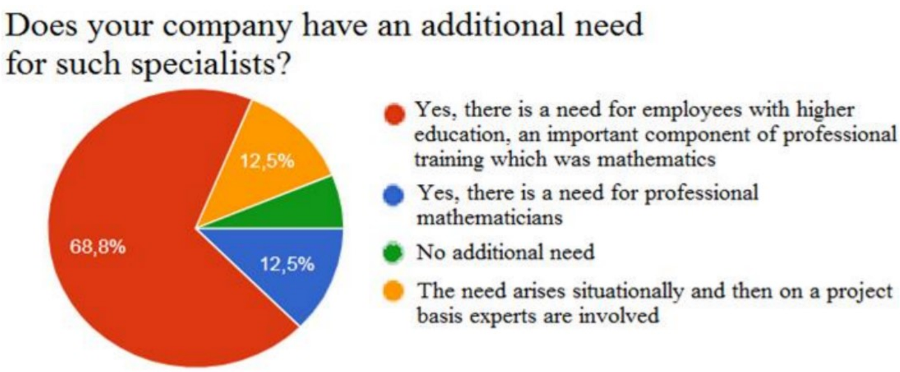

Figure 3: The result of a survey on the need for mathematicians.

As part of the project, we conducted a survey of our graduates of programs in mathematics. One of the questions in the survey was about what skills they needed.

In particular, they noted that they lack: the ability to adapt mathematical knowledge to the

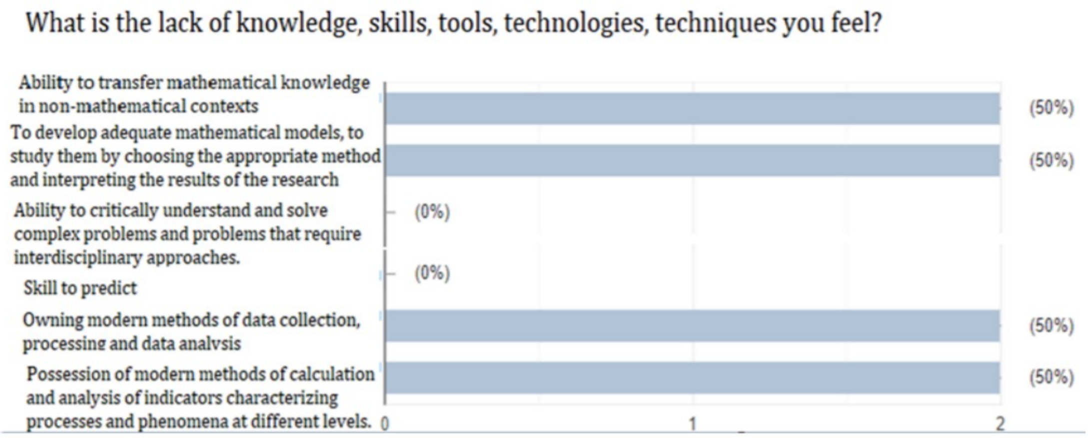

Figure 4: The result of a survey on the lack of knowledge, skills, tools, technologies.

context, the ability to use modelling in practice and research.

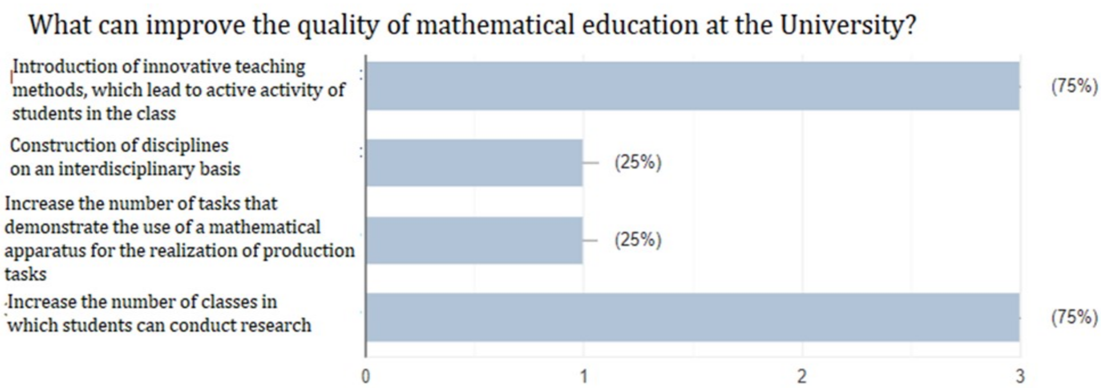

Figure 5: The result of a survey about improving the quality of mathematical education.

Another question was "What can improve the quality of teaching mathematics?". The answers were: innovative teaching methods, elevation of research-based learning.

The results of a survey of teachers, graduates and employers showed that Mathematical Education needs:

- Changes in teaching: using IBL, active learning, flipped learning.
- Design and redesign of practical problems for teaching mathematics (creation of a system of modeling problems)
- Improving motivation to study mathematics. This means to demonstrate applied mathematics and to involve students in business activities using modeling tasks.

That is why the University began to implement:

- The new innovative method of teaching mathematics (based on the introduction of IBL – inquiry-based learning)
- Develop business mindset for business professions, but for mathematics too. This means:
  - to teach mathematical modeling related to the inquiry;
  - to use mathematical models to solve practical problems;
  - to implement innovations by involving the students to develop the startups.

The first stage of the development of the university into a business university is the creation of a student business incubator. The challenge for universities is to change approaches to teaching mathematics.

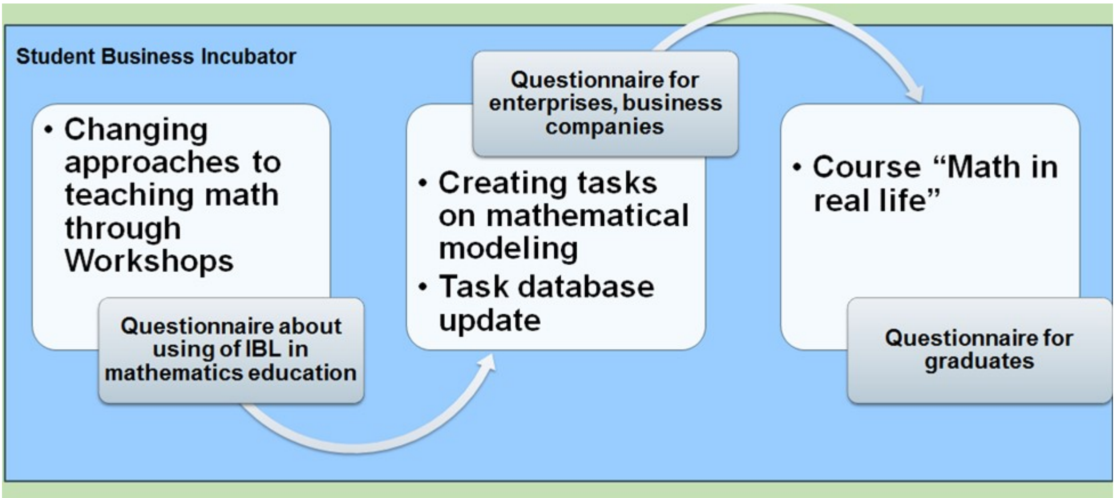

Figure 6: Development of student business incubator.

4. Application of IBME approaches in computer mathematical modeling

The problem of modeling is that the student must use the basic knowledge gained in the study of previous disciplines, and gain new knowledge needed to study the process and further modeling. The inquiry approach provides insight into the use of fundamental concepts and knowledge but plays a special role in acquiring new approaches and methods of knowledge. In the course of work on the PLATINUM project, we identified the main features that are present when solving modeling problems.

Ability to form several hypotheses, understanding the conditions of the problem.

- There are several ways to solve the problem.
- The presence of a technical, natural science, economic sense of the problem in the context of professional orientation.

- The complexity of mathematical knowledge, methods and procedures are based on “analysis by synthesis”.

IBME teaching encourages students to take a different look at previously studied material, see fundamental concepts applied, and find knowledge gaps that they have forgotten or overlooked. If in teaching fundamental mathematical disciplines a query is used to obtain new knowledge (hypotheses, consequences, etc.), then in mathematical modeling the query is used at each stage of modeling.

Students have to formulate a mathematical model, hypotheses are put forward (students put forward their own hypotheses).

At this stage, students offer different hypotheses and, during the discussion, they will come to a choice. It is necessary to answer the questions: what is the problem?

- the problem is open and students must develop their own protocols;
- the problem is partially open and students have to deal with limited materials;
- the situation for students is new. They need to find a way to solve the problem.

The teacher provides the relevant material to make a request:

- What are the components of the system process, how do they interact?
- Which compounds are harmful, which interfere, which are neutral, and which are useful?
- What parts and what can be replaced and what not?

An important stage of modeling is the *interpretation of the results* in terms of the relevant subject area. And the ability to formulate a problem based on a real situation, just means that the problem is based on the properties of the mathematical model of this situation, which allows it to be interpreted. Thus, the design of problems, based on the query, can be considered as a technology of mathematical modeling, which directs the study of the mathematical model by finding the most realistically interpreted results.

Our observations highlight that students can:

- participate in research on the basis of inquiries;
- use existing models in their queries;
- participate in a query that results in a revision of the model, use models to construct explanations,
- use models to “unify” their understanding and argue.

Students use ICT tools to interpret the simulation results, as exploring the model takes time and effort. In addition, a model is created, as a rule, it is a simplified prototype of a modeled process (or system), the use of ICT technologies makes it possible to study the model by increasing the number of parameters and additional conditions that affect it.

Task. Students were asked to simulate the development of a viral disease at the university. Dynamics of the number of cases $I(t)$ by days is presented in table 1. $S(t)$ - the number of healthy, not yet sick students.

Students make an analysis of the development of the disease and forecast its development for the future.

Table 1
Statistics of the sick and recovered

Day	2	3	4	5	6	7	8	9	10	11	12	13	14
$S(t)$	762	740	650	40	250	120	80	50	20	18	15	13	10
$I(t)$	1	20	80	220	300	260	240	190	120	80	20	5	2

Viruses epidemic model

Among students due to contact with an infected possible transmission of infection to a healthy student and how consequence, his illness. Infected students with get well over time. After recovery, students can acquire immunity and no longer get sick. Students do not come into contact with other infected people outside the school. Contacts with teachers are not taken into account.

Model parameters:

- The number of students in the institution.
- The likelihood of illness.
- The likelihood of recovery.

The mathematical model of the development of the epidemic can be represented by a system of three differential equations first order

$$\begin{cases} \frac{dS}{dt} = -aSI \\ \frac{dI}{dt} = aSI - bI \\ \frac{dR}{dt} = bI \end{cases} \tag{1}$$

1st equation – the rate of illness in healthy students, the number of which decreases, the likelihood of illness;

2nd equation – the rate of change in the number of cases, recovered and recovered with probability b;

3rd equation – the rate of change in the number of students who have been ill and recovered.

$$R(t) = 763 - S(t) - I(t) \tag{2}$$

is the number infected recovered and not yet ill. It is necessary to determine the probability coefficients of states a and b.

Linear interpolation gives values for a and b coefficients 0.0036 and 0.94, respectively.

Simulation algorithm

Let us construct a procedure for calculating the right-hand side of the system.

The results are presented in figure 10. The graphs compare the theoretical curves and experimental values shown by the “o” markers.

Model exploration inquiry method

1. Plot the function $R(t)$, reflecting the dynamics of the number of students who have had a viral disease.

```
>> S = [ 762 740 650 400 250 120 80 50 20 18 15 13 10];
I = [1 20 80 220 300 260 240 190 120 80 20 5 2];
days = [0 3 4 5 6 7 8 9 10 11 12 13 14];
for k = 1:10
 y(k) = (1/I(k+2))*(I(k+3)-I(k+1))/2;
 x(k)=S(k+2);
end
plot(x,y,'o')
>> |
```

Figure 7: Experimental dependence graph.

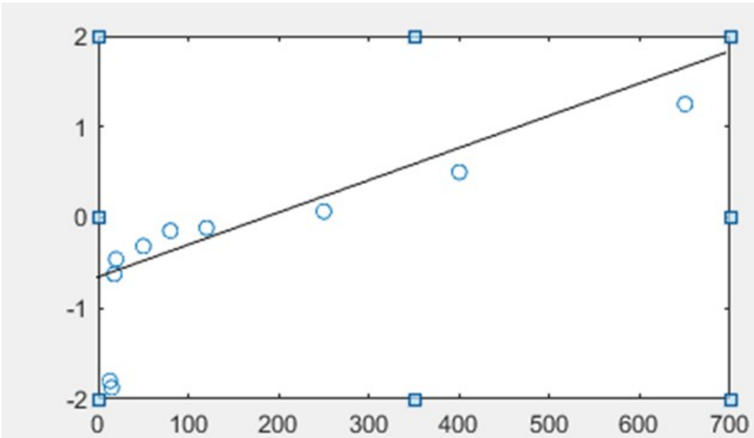

Figure 8: Linear interpolation.

2. Suppose that you have succeeded in analyzing an epidemic for a population of a small town. Build a mathematical model.
3. Get the curves of the development of the epidemic. What are the benefits of knowing the peak of the epidemic?

Students can present their own experiences. In order to interpret the simulation results, students can use various ICT tools: spreadsheets, application packages MATLAB, Mathcad, FreeMat, Mathematica and others. Students choosing their way of interpreting the results.

5. Conclusions

Employers and analysts argue that due to changes in the nature of activities, traditional approaches to professional skills training may be ineffective in the future. Given the growing pace of change and uncertainty in the workplace, young people will be better prepared, even for entry-level positions and, of course, for career advancement, if they have a basic understanding of the scientific, mathematical, social and even cultural aspects of working within their jobs. professional competencies. This leads to a change in approaches to the teaching and

```
viral.m  ×  viral1.m  ×  +
clear, clc
S = [ 762 740 650 400 250 120 80 50 20 18 15 13 10];
I = [1 20 80 220 300 260 240 190 120 80 20 5 2];
days = [0 3 4 5 6 7 8 9 10 11 12 13 14];
y0 = [762 1 0];
dt = [0 14];
[t, y] = ode45('viral', dt, y0, [],  [0.0026 0.51]);
subplot(2,1,1)
plot(t, y(:,1), days, S, 'o', 'LineWidth', 2)
title('Function graph for the risk group','FontName','Arial Unicode MS')
ylabel('number of students at risk','FontName','Arial Unicode MS')
subplot(2,1,2)
plot(t, y(:,2), days, I, 'o', 'LineWidth', 2)
title('Function graph of the infected','FontName','Arial Unicode MS')
ylabel('number of infected','FontName','Arial Unicode MS')
xlabel('time, days', 'FontName','Arial Unicode MS')
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Figure 9: Main m-file of computer modelling.

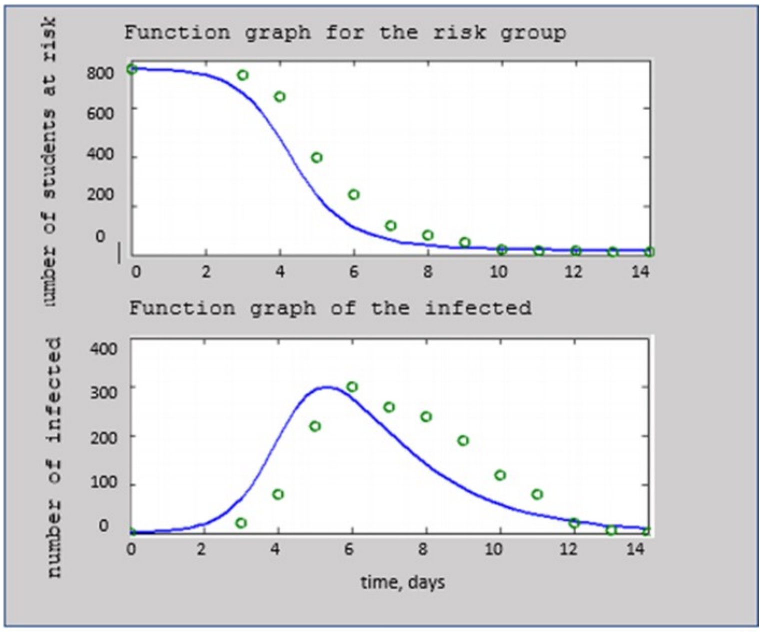

Figure 10: Results of modelling.

learning of mathematical disciplines, increasing the emphasis on the integration of academic and professional education.

Mathematical competence is an integrated dynamic property of the student's personality, which characterizes his ability and willingness to use mathematical methods of modeling in professional activities. Mathematical competence integrates mathematical knowledge and skills, as well as general cultural and professional competencies that are projected into the subject area of mathematics – their core is the ability and willingness of the graduate to apply this knowledge in professional activities.

To solve the problems of mathematical modeling, students must translate real situations, which are usually presented in text form, into mathematical models. To complete the translation process, the problem solver must first understand the real situation. Thus, reading comprehension can be considered as an important part of solving modeling problems, and the development of reading comprehension can lead to increased competence in modeling. In addition, it was found that ease of understanding and engagement increases interest in learning material, and thus improving reading comprehension can also increase interest in modeling.

Motivation of students plays a decisive role in the process of teaching mathematics. One of the important motivational variables is the interest of students both in the educational material and in the use of the acquired competencies in professional activities, and computer modeling has a very important role.

Standards and expectations from students should be high, but this is only part of the solution. The more important part is developing teaching techniques and methods that will help all students (not just a small fraction) to achieve these high expectations and standards. This will require some changes in teaching and learning mathematics.

Effective education must pay clear attention to the connection of the real-life context with the subject content for the student, and this requires more "interconnected" approaches to teaching mathematics disciplines.

Teaching query-based modeling improves students' research skills and helps build math competence. The model query activates students' conceptual knowledge if they have it and finds out gaps in knowledge that have been forgotten or lost. Work on the PLATINUM project has increased the interaction of teachers who teach basic disciplines of higher mathematics and applied disciplines.

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