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PAPER

Improving the Quality of Education in the Development of Algorithmic and Critical Thinking of Students of "Applied Informatics" – Case Study

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ABSTRACT

Improving the quality of education is not an easy task, and we believe that it is strongly linked to student motivation. Student motivation is at the centre of events because, without students' internal motivation, it is not possible to effectively achieve educational goals and, ultimately, positive educational results. For this reason, it is necessary to modify the method of education with regard to the current needs of students, and as we demonstrate in the article, it is necessary to continuously control, evaluate and reflect on changes. The introduction of a complex heterogeneous system of education that takes into account the different learning styles of students as well as their individual characteristics proves to be an effective tool. Together with a comprehensive coverage of the issue based on the mediation of materials in various forms of processing, it appears to be a solution.

KEYWORDS

quality of education, algorithmic and critical thinking, complex heterogeneous system, internal motivation, case study

1 INTRODUCTION

As in other European Union (EU) countries, quality assurance in Slovakia plays a decisive role in modernising education and training systems and improving their performance and attractiveness [1]. As Membrillo-Hernández et al. [2] mention, before the pandemic, "in blended learning, the best approach to a global classroom, the digital part was used only for team collaboration". There were no guidelines to define the necessary elements for online experiential learning. Regarding the education system, there is a need to adapt to a new generation Z, making the students the centre of their training and leaving the teacher as a tutor or coach of their learning [3]."The current young generation is often referred to as the Net Generation because it is the first generation to use information and communications technology (ICT) since childhood" [4]. We agree

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with Guraliuk et al. [5] that "the mass introduction of distance education has led to the need to search for methods and technologies that provide an acceptable quality of education and allow this quality to be objectively assessed under the new conditions".

Under the influence of the COVID-19 pandemic and the transition to distance learning, or a combined form of education depending on the current pandemic situation, and on the basis of statistical evaluation of student evaluation results in the monitored subject "Algorithms and Data Structures I", over the past six academic years since the application of the first changes were implemented with the aim of improving the quality of education, we have noticed significant changes. From Figure 1, we can observe that in the academic years 2020/2021 and 2021/2022, the number of students with a F-grade grade dropped significantly. On the other hand, the number of students with an Agrade, which in previous academic years students achieved only rarely, increased significantly. We can observe significantly better evaluation results in other evaluations as well. For example, in the evaluation of the E-grade, we observe a gradual decrease over tendency in the monitored years, which also points to the obtaining of a better evaluation compared to the years when the teaching took place in a traditional face-to-face manner. From the above, it can be assumed that the quality of education during distance and combined forms of education leads to better results. For this reason, we investigated in detail the possible causes of this phenomenon.

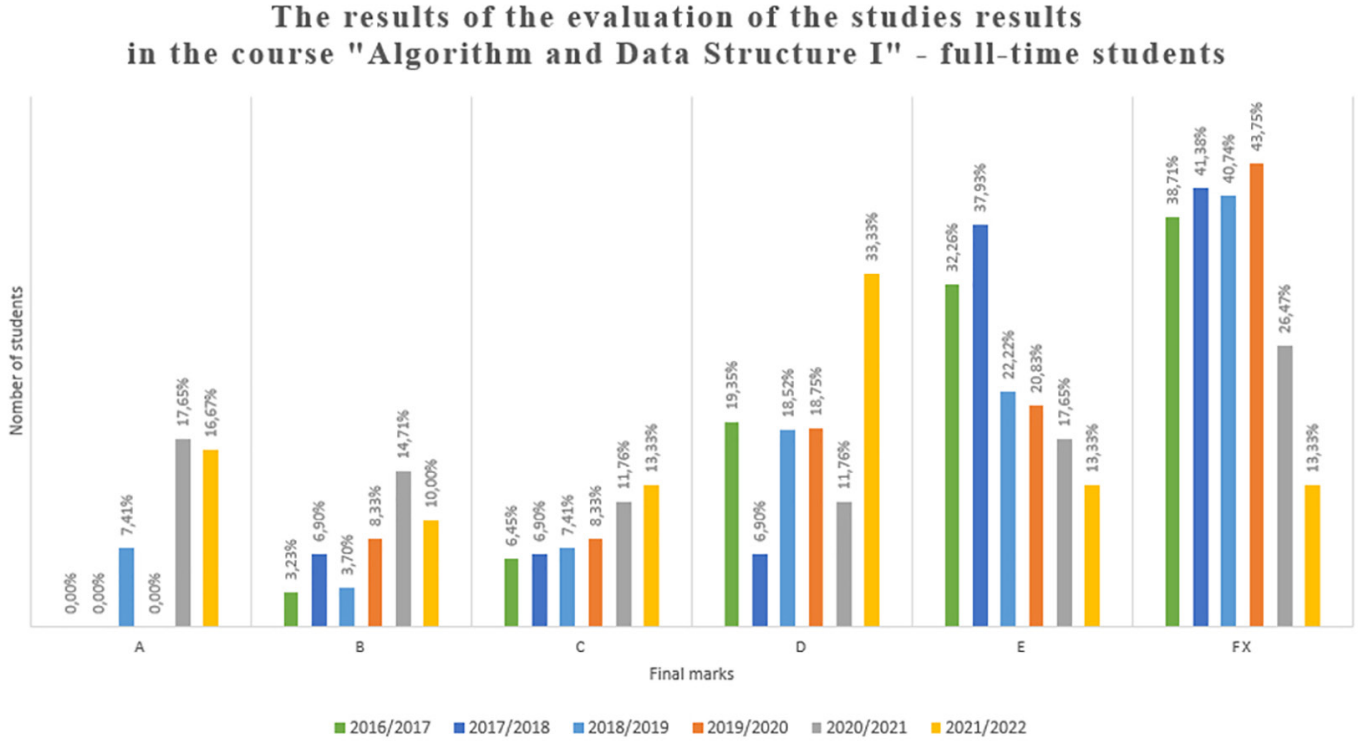

Fig. 1. Data of the success/failure rate at the final assessment of students

We are fully aware that the results presented in Figure 1 may be slightly distorted. They can be influenced by several factors, such as the annual heterogeneity among students (influenced by their previous education as well as practical experience in the given topic, as also stated in [6]), their motivation to devote themselves to the given issue and achieve the best possible evaluation, as well as genetic prerequisites for successful acquisition of algorithmic, critical thinking and programming. The stated results are slightly distorted, even among the students who leave voluntarily,

due to not being able to master other subjects during their studies or failure to cope with the socially demanding situation associated with COVID-19 in the academic years 2020/2021 and 2021/2022, which was already evident during the first semester of their studies. During the evaluation of the possible impact on the presented facts leading to these results, several of the mentioned factors were taken into account and examined in detail with an effort to eliminate them as much as possible. Considering the goal, however, we do not consider them critical, and we are convinced that the facts presented are a relevant indicator of change.

We also presented similar results (Figure 2) in 2016 [7], where our main objective was to identify problematic thematic units within the content of the subject "Algorithmization and Programming", which was taught at the bachelor's level during the first year of study in the winter semesters, with an effort to find solutions that would lead to satisfactory results and to increasing the quality of education. Several conclusions and decisions were drawn from the given findings. The excessive content complexity of the subject was demonstrated, which was one of the factors in student failure due to the time allocated to the course. The content of the subject was therefore re-evaluated, leading to the division of the subject into two independent but closely related subjects: "Algorithms and Data Structures I" and "Programming I", taught in the winter semester of the first year. The issue of sorting algorithms, which proved to be one of the problematic areas, was included in the subject "Algorithms and Data Structures II" taught in the summer semester of the first year. This issue requires basic knowledge of both programming and algorithmic problem solving, which many incoming students lack, and their acquisition and development are expected precisely in the subjects "Algorithms and Data Structures I" and "Programming I". We dare to state that we did not believe that this redistribution could have a significant impact on the achieved results, but the opposite was true. Our sceptical thoughts were based on experience, even if not with a problem-free, functioning system of education, even in such a complexly conceived subject, in previous years. With hindsight, we can conclude that this change significantly contributed to a higher quality of education. The truth is that under the influence of changes in the school system, the heterogeneity of students in the context of mathematical, technical and programming knowledge and skills is getting wider (unfortunately in a negative direction), and the number of students without any programming experience who join the "Applied Informatics" study programme is increasingly higher every year, i.e., the knowledge level of incoming students is completely different than it was 10 years ago. For this reason, it is necessary to reflect on changing realities and approach education in such a way that all students, regardless of their previous knowledge, are able to satisfactorily master the objectives of the course. The division of the subject matter and the higher time allowance dedicated to the issue made this possible.

After continuous monitoring and evaluation of results and reflection on findings from questionnaires within the internal quality system, which is conducted annually at the Faculty of Natural Sciences of the University of Ss. Cyril and Methodius in Trnava, Slovakia, the composition of subjects was reorganised in 2019. The development of algorithmic and critical thinking with an effort to optimise the proposed and implemented solutions, which are the principal goal of the subject "Algorithms and Data Structures I", cannot be effectively implemented without the basics of programming. Therefore, we reconsidered all the available findings and reorganised the composition of the subjects so that first students will be guided to learn the basics of programming in the subject "Programming I" and only then will they be guided to the analysis, design and optimisation of given solutions in the subject "Algorithms and Data Structures I", which has been moved from the winter semester to the summer

semester of the 2020/2021 academic year. Whether this change led to a change in the achieved results or whether they were caused by a change in the forms and methods applied in the distance and combined forms of education, we will only be able to evaluate exactly with the passage of time. In our case, similarly to Al-Mubaid [8] "learning tasks, including class team projects and term paper assignments, have been used to apply and promote critical thinking among the students". "In applying educational technologies and teaching interventions, assessments are commonly involved to help students reflect their understanding of given materials" [9]. In any case, under the influence of social and cultural changes, the character of students is also changing. Therefore, it is necessary to approach them differently and to apply different forms and methods of education than were customary, which was also clearly demonstrated during distance education.

A fundamental difference in the presented data is the fact that in 2016, we presented the results of the assessment of students who obtained the required interim assessment during the semester, which is conditional on participation in the final assessment. In the current statistical overview (Figure 2), we present the evaluations of all students, regardless of whether their success or failure was influenced by their ongoing or final activity, so the results of the F-grade evaluation are not comparable.

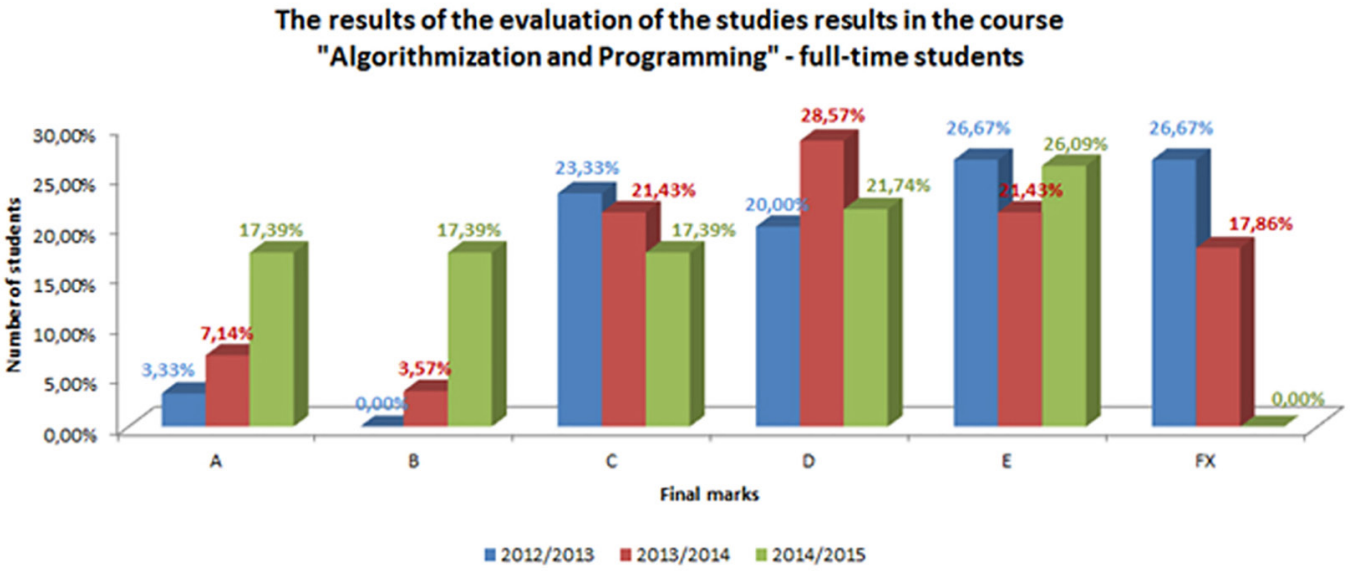

Fig. 2. Data of the success/failure rate at the final assessment of students (Jurinová, 2016)

A method of evaluating subjects, which basically consists of five evaluated activities, which represent the interim as well as the final evaluation, remained essentially unchanged:

1. Active participation in exercises and student activities beyond expectations
2. Homework assignments
3. Two tests were solved in exercises (credit papers)
4. Semester assignments are solved individually and presented in exercises
5. Exam in the form of a written test

The established evaluation system built on a complex heterogeneous evaluation system that takes into account different learning styles and individual characteristics

and needs of students, has proven to be suitable. This was known to students from the beginning of teaching the course. In this way, students can distribute their strengths and take into account their predispositions. The methodology of this approach was also applied to a newly introduced subject of a different nature taught in the second year of master's degree studies, which verified and confirmed its effectiveness and appropriateness, even with regard to the different nature of the subject as well as the students. In this case, they were students in the final year of master's studies and not students in the first year of bachelor's studies. We published more about the evaluation method and new trends in this area in the paper "Development of a Desktop Application for a Complex Heterogeneous Evaluation System" [10]. We paid increased attention to the teaching of identified problematic thematic units that remained within this subject, and we prepared new examples with the aim of better understanding the given issue, together with the visualisation of abstract concepts using available animations and interactive applications. We have also prepared and published two electronic textbooks for students, which provide comprehensive coverage of this issue along with example codes so that they can experiment with and expand on them. Each chapter is supplemented with tasks for the independent practice of knowledge.

The statistical evaluation of the results of the subject "Programming I" (Figure 3) also shows the achievement of better results. Compared to the results of the subject "Algorithms and Data Structures I", these are even better, which demonstrates the positive effect of the introduced changes. An interesting fact in the monitored years is that the percentage of students who did not manage the issue is comparable and considerably high in both subjects. We believe that these results point to the fact that these students do not have sufficient prerequisites to master this issue. It has again been shown that in the academic years 2020–2021 and 2021–2022 the percentage of students who failed has decreased significantly.

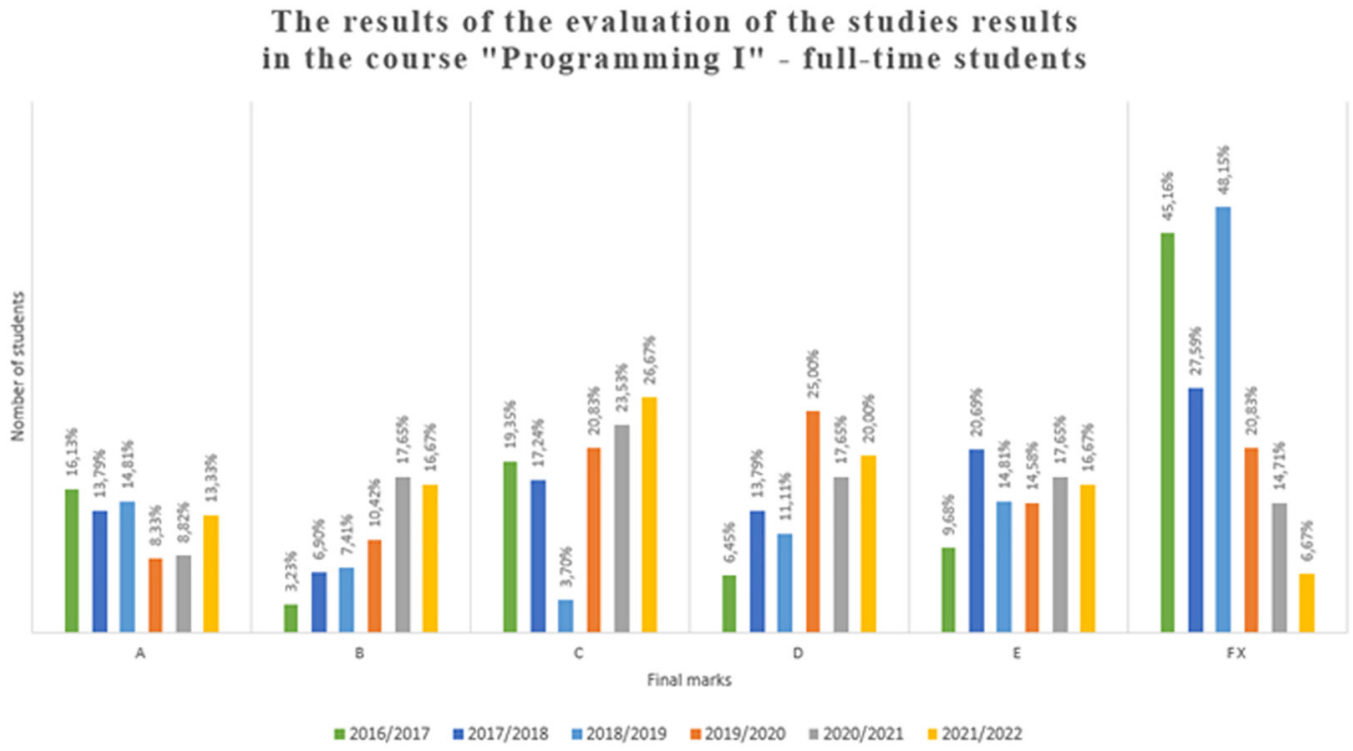

Fig. 3. Data of the success/failure rate at the final assessment of students

2 EXPLANATORY CASE STUDY

As we have shown, the introduced changes have significantly contributed to the quality of education. However, the results achieved in the academic years 2020–2021 and 2021–2022 showed significant differences, so we decided to subject them to a more detailed investigation and search for possible causes. We could therefore formulate the research question as follows: Do different forms of education (traditional face-to-face form, distance and combined forms of education) and the approaches and methods characteristic of each form have different effects on the evaluation results?

2.1 The participants

The research was conducted with 30 participants. Their representation in terms of gender and age is illustrated in Figure 4. It was an available selection. All students enrolled in the subject "Algorithms and Data Structures I" in the academic year 2021–2022 were included in the research.

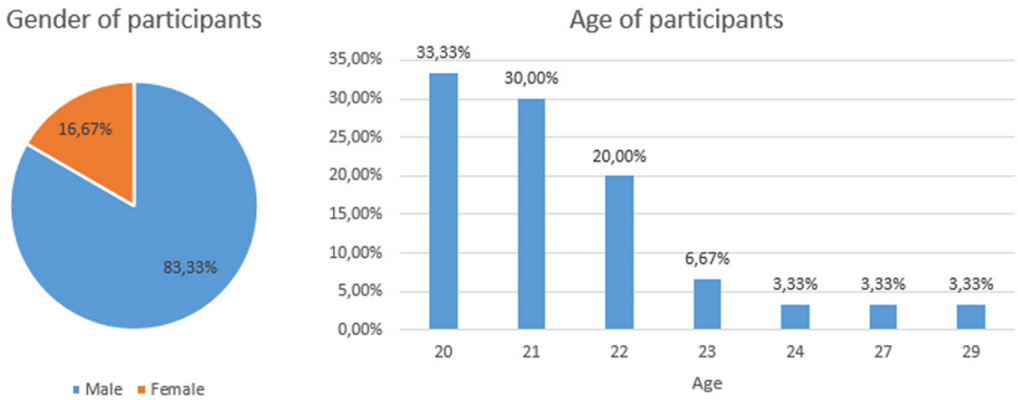

Fig. 4. Gender and age of participants

2.2 Methods

We sought answers to this question based on the development of education and student activities and from student evaluations in two academic years. After the end of the academic year 2020–2021, in which the teaching took place purely in the distance form, we observed changes in the assessment. These were positive, so we did not pay more attention to them. However, during the transition to the face-to-face form of education from the distance form in the academic year 2021–2022, we noticed significant negative changes in the ongoing evaluation of students from the first credit test. And that's why we started to investigate these phenomena in detail. We obtained data in relation to the research question in various ways: survey, observation, content analysis of documents, and individual and group interviews.

2.3 Results and discussion

The transition to distance learning naturally required certain changes in the pedagogical process, which were mainly conditioned by the transition of education to the online space. These were implemented particularly in three areas.

1. **Changes in the process of education.** In teaching, we started applying the flipped classroom approach [11].
2. **Changes in the process of evaluation.** We modified the interim and final assessments by reversing their principles. The original model required 40% of the grade to be obtained on the interim assessment and 60% on the final assessment. Due to the exclusion of writing tests online in real-time, which constitutes a significant part of the continuous assessment, in distance learning due to the low possibility of checking whether the student actually processes the task independently without other direct or indirect help, we increased the difficulty, number and point evaluation of the continuous tasks, which were entered and evaluated along with individual feedback for each student each week. Finally, we thus increased the quality of so-called self-regulated learning [12] [13], the goal of which is to motivate students to meet their own needs for education and overcome obstacles. Similar to our idea for a model of student assessment, Abu Salem et al. [14] claim that "assessment of student contribution carefully considers the contents and their quality, timeliness of achievements, and professionalism. Assessment tools are deployed to measure indicators within specific criteria. For increased reliability of measurements, tools are carefully selected to enable multiple sources of measurements". Providing individual feedback to each student significantly influenced students' motivation to solve and eliminate their own mistakes, in contrast to the way in which students' outputs are evaluated only by points, and the provision of feedback is usually implemented in the form of joint brainstorming with students directly during face-to-face teaching when there is no time to comment on all the mistakes of all students. Therefore, we cannot fail to draw attention to the time-consuming nature of this approach for the teacher.

   We have also expanded the semester assignment, which requires the processing of documentation regardless of the form of education, due to the exclusion of non-independent work by students.

   This year, the number of students who transferred to the summer semester was relatively low, and due to the distance form of education, in which it is not necessary to teach practical exercises in groups, this method was feasible, even if sometimes at the expense of the teacher's free time. Therefore, its use with larger groups of students is to be considered. Tasks had to be submitted with commented code or together with documentation that described the principle of the solution in order to further reduce the possibility of fraud and evaluate the students' real knowledge.
3. **Changes in the process of teaching.** Each lesson started with brainstorming, which led to the presentation of possible solutions to the given task directly by the students (the teacher, based on the already completed evaluation, had a pre-thought-out method in which students would present their solutions). The teacher only moderated this activity and supplemented it as appropriate. This method could be used to easily identify whether the submitted solution by the students was processed independently or not. Among other things, the students' professional and terminological ability to express

themselves has significantly increased. The very work with textbooks as a model of approach and problem-solving, as well as the necessity of describing task solutions, undoubtedly contributed to this. Szőköl [15] states, based on the results of research conducted on students at secondary vocational schools, that self-regulation works better for girls than boys. We agree with this conclusion. Although the representation of the female gender among the students of the "Applied Informatics" study programme is low, the effect of the applied changes can always be observed significantly better on them compared to representatives of the male gender.

New findings. Applied changes lead to new findings that are described below. We replaced the written test, which forms the final assessment in the original model, with an oral exam in which students were tested in any area within the entire subject, but in the context of their semester assignment. The detailed method of processing and evaluation was always known to the students in advance. It was these modifications that influenced the significant drop in students with a F-grade. With such an evaluation system, students had a clear idea of what was expected of them and if the semester assignment was accepted (based on an individual evaluation by the teacher before it was presented). The possibility of failure was reduced to a minimum. In contrast to the written test during the exam period, students may be surprised by the necessity of solving a problem that they do not know, even though they would methodologically and professionally know how to solve the given problem. It also emerged from the students' statements that the uncertainty and fear of the exam in this form were significantly lower. We can characterise this evaluation method as an open-book exam [16] [17] [18]. The conclusions of the authors [19] [20] point to the fact that no significant difference was demonstrated in the obtained evaluation score due to the applied form of student evaluation. Considering the research carried out, we cannot unequivocally confirm this fact, but neither can we refute it. Based on the findings, Struyeven et al. [20] recommend using a combination of different evaluation methods in view of the established goal, which is respected by the complex heterogeneous evaluation system applied in our case. Vyas [19] shows that there was a considerable difference in the anxiety scores. The finding shows that those who appeared in the exam without books showed more anxiety than those who appeared in the exam with books. This is comparable to our research.

Another fact that positively influenced student evaluation was the provision of materials as well as lecture notes recorded by the teacher to all students centrally. We used the OneNote tool, which served as an interactive whiteboard, where we used a graphics tablet to illustrate the concepts discussed and solved during the online teaching. The codes of the programmes that were solved in the exercises were also published to the students. We came to these conclusions based on a fact that was proven retroactively at the moment of the transition to a full-time form of education (with regard to the semester combined). In this form of education, students naturally record their own notes during the exercises, and programmed solutions to the examples are part of them. When evaluating the credit test from the subject "Algorithms and Data Structures I", we encountered an absolutely non-standard situation that had not occurred in the last 10 years of teaching. This pointed to the failure to master the problem in the sectional parts of the solved examples, while the problems that are solved have logical and sequential continuity, so it is illogical that there are errors only in certain

parts of the solution. That's why we searched for possible causes. Based on this, we carried out the survey.

Research survey. Students were asked the question "Which materials did you use to prepare for the credit test?" where they could mark several answers through a survey directly in the e-course of the subject mediated through the learning management system (LMS) system Moodle. The students also had the opportunity to freely comment on their answers. We present the given findings in Figure 5, from which it is clear that the students used their notes and published lectures to study the subject matter.

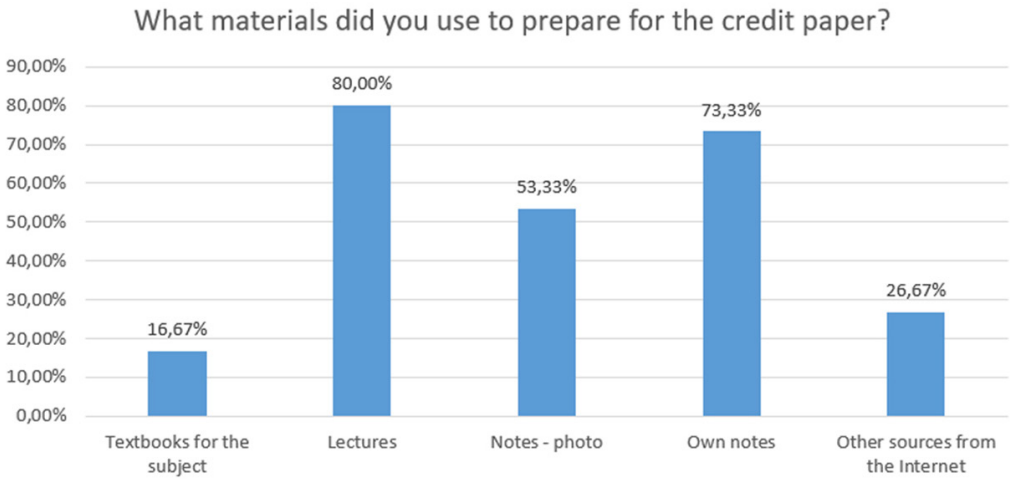

Fig. 5. Materials used to prepare for the credit paper (test)

In principle, these resources are not bad, but the lectures, in addition to theoretical starting points, often contain incomplete and not always ideal solutions to the presented problems for the purposes of clarification and explanation directly during the lesson, together with the possibility of editing and expanding the examples by students as part of the self-education process. On the other hand, the textbooks are processed in such a way that they comprehensively understand the entire issue, including the theoretical background and examples in an ideal state. However, it rarely used by students. We were also surprised to find that students turned to other sources on the Internet because we believe that the amount of material needed to prepare for the credit test is sufficient. We naturally expect students to work with other resources, but rather when working out homework or a semester assignment. The possibility of using photo notes, which represent photos taken by smartphones of the written notes from the board at the exercises (Figure 6), has also been found to have considerable representation as a substitute for electronic notes that were published by students during distance learning. We have been exploring the possibility of publishing notes from the course of our teaching for several years. Only their character changes. During face-to-face teaching, we try to convey the solved problem, regardless of the subject, in such a way that we use one or two whiteboards, and the students can take pictures of them. We assume that they will use this photo documentation for editing, supplementing, or checking their notes. However, these assumptions are only shown by the teacher's expectations. At best, students use this photo documentation as full-fledged notes that they only look at again and do not actively work with; at worst, they only take up memory space on their smartphones.

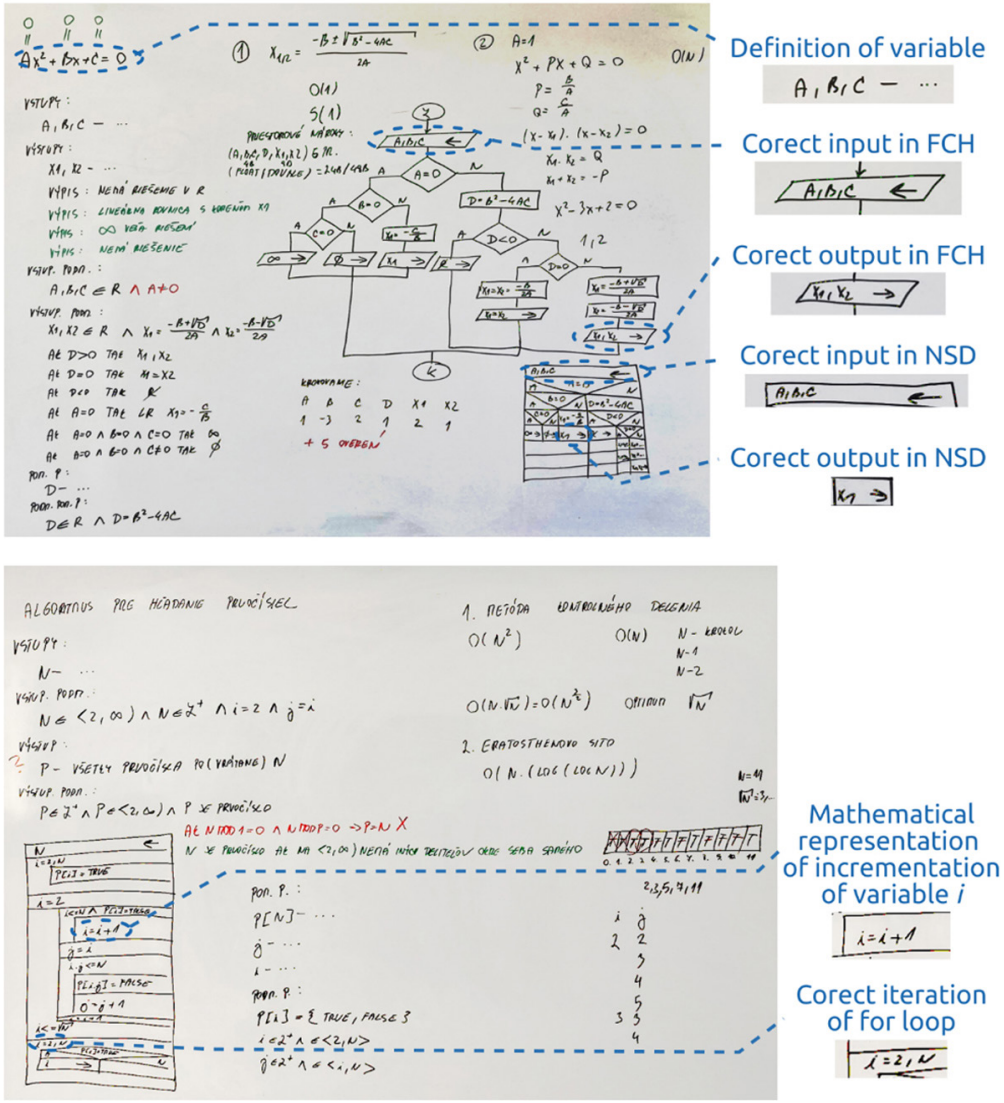

Fig. 6. A sample of the whiteboard teacher's notes from the lesson

We subjected the responses from the survey to a more detailed examination in the form of a group interview directly during the lesson. It was proven that only one respondent continuously edited his notes based on photos from the lesson and other sources and worked with them while preparing for the credit test. The two participants prepared for the credit test individually and then together, where they jointly solved the parts that were a problem for them during individual education. Three participants used their classmates' notes. It indirectly pointed to the students' comfort and their inactive approach to education. Two participants stated that they had no need to prepare extra for the credit test. These were really students who did not have a significant problem with the subject, which was also reflected in their results from the credit test. We identified as a serious problem that the students until then did not use the textbook, which is intended for them and contains a complex concept of the issue, unlike lectures. We asked about the reasons for this fact and received different answers. The main finding was that this generation of students is not taught to work with textbooks, and certainly not in the field of information technology (IT). However, this opinion significantly changed to a positive attitude after the time when the students were specifically motivated to work with the textbook.

Since most students reported that they learned from their own notes, we asked students to send a photocopy of them. Exactly half of the students did that. When asking back about the sending of the notes of the remaining students, it was proven that several students did not have their own notes and that they considered the materials published from teaching in a joint group to be the notes. We subjected the sent notes to content analysis. Many notes were incomplete and even incorrect.

From the content analysis of the students' notes from the lesson, we came to several conclusions that had a direct impact on the results of the credit test. When analysing the notes of participant AB, we came to the following conclusions:

- Nassi-Shneiderman diagram (NSD) is a graphical design representation for structured programming. It is an alternative notation for the process flowchart. The flowchart is an oriented graph that has a beginning and an end, and individual activities are connected by connectors, unlike NSD, which is formed as one continuous block, i.e., without using connectors. Participant AB's notes (Figure 7) illustrate a kind of hybrid visual representation of NSD with flowchart elements (connectors). In the figure, we can observe that the given participant does not pay enough attention to drawing the connections of individual activities even in the flowchart, which clearly violates the property of finiteness and determinism of the algorithm.
- The visual representation of the algorithm, whether using a flowchart or NSD, is a representation that should be independent of the solver and of the specific programming language in which the given algorithm will be implemented. For this reason, mostly mathematical, generally valid notations are used, in contrast to the use of operators typical for programming languages, such as the iteration operator "++", the decrement operator "––", the shorthand assignment operator "+=", etc., which participant AB often uses in his notes. When using the "for" loop, the participant does not use general notation but again reaches for the syntax of the programming language. We can observe these shortcomings in Figure 7.

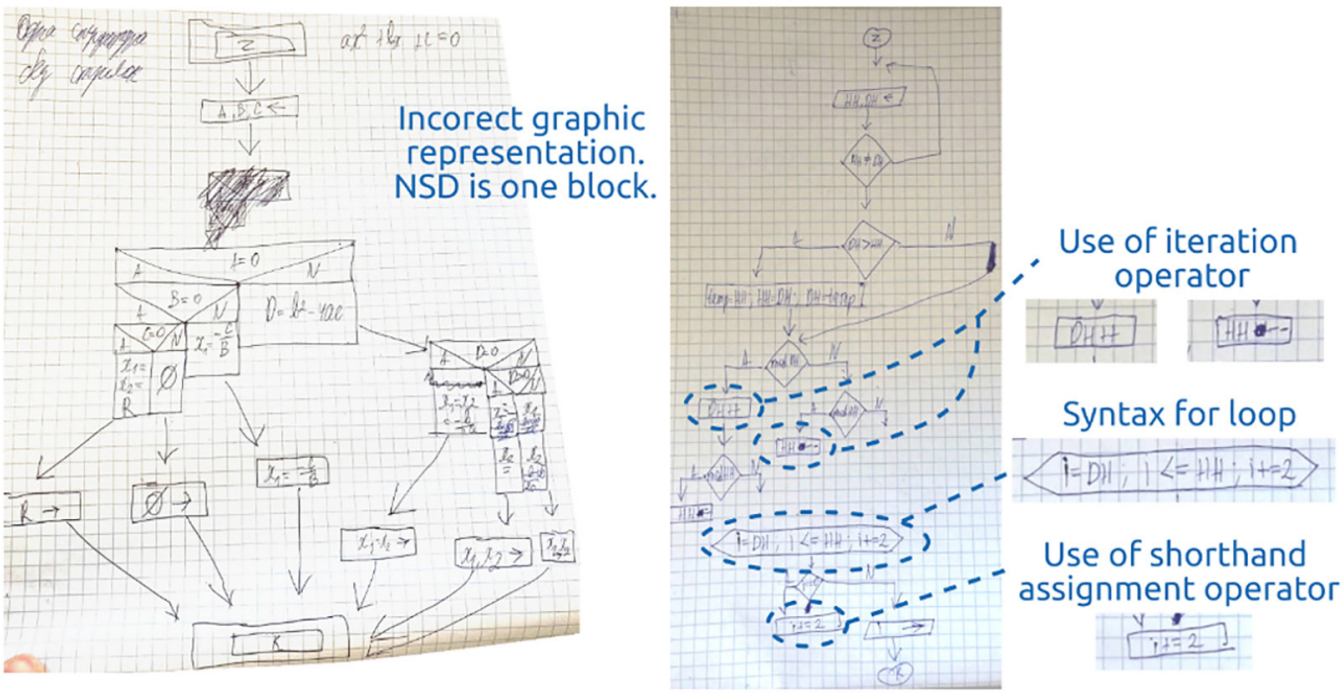

Fig. 7. Notes of participant AB–drawing errors and incorrectly used operators

From the results of the credit test (Figure 8), we can observe that participant AB converts mistakes from notes here as well. This mainly concerns the incorrect use of signs and their graphic design, as well as the use of operators typical for a programming language.

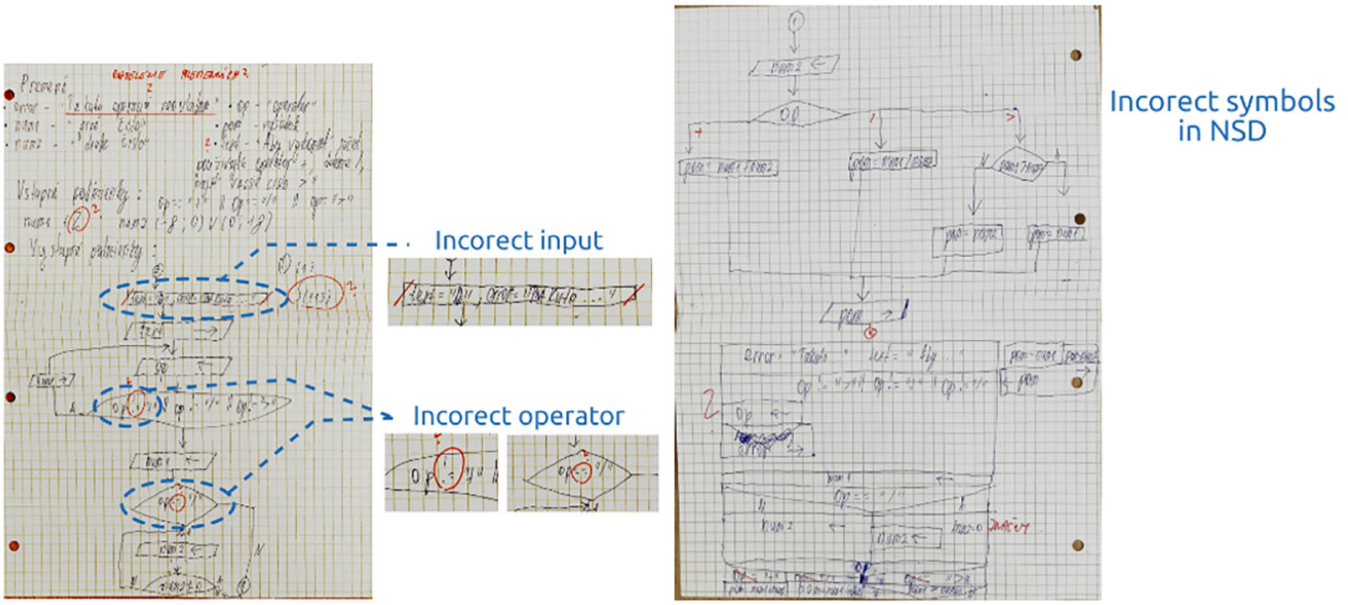

Fig. 8. Credit test of participant AB

From the notes of participant LL (Figure 9), we can observe his inconsistency when drawing the rectangle that represents the command and the rhomboid that represents the input/output when using the flowchart. Given that one and the same mark is used in the flowchart for input and output, it is necessary to distinguish this fact by using a keyword, e.g., “input”, “output”, or the arrow symbol as used in the NSD. Participant LL also made similar mistakes on the credit test (Figure 10a).

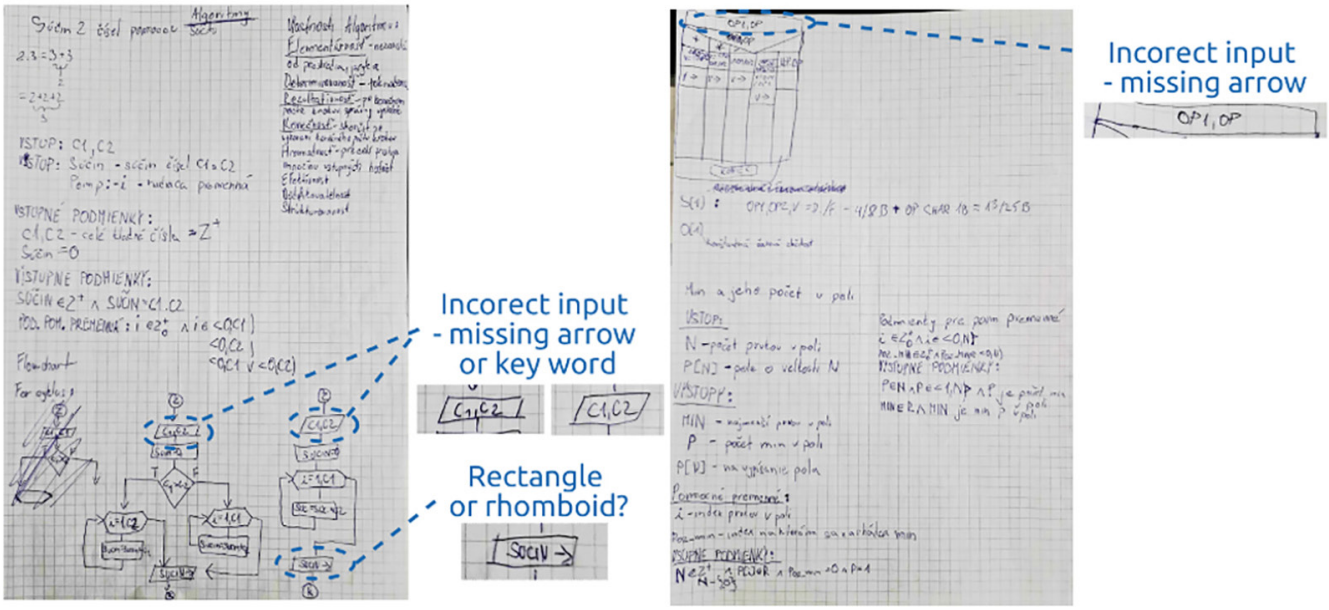

Fig. 9. *(Continued)*

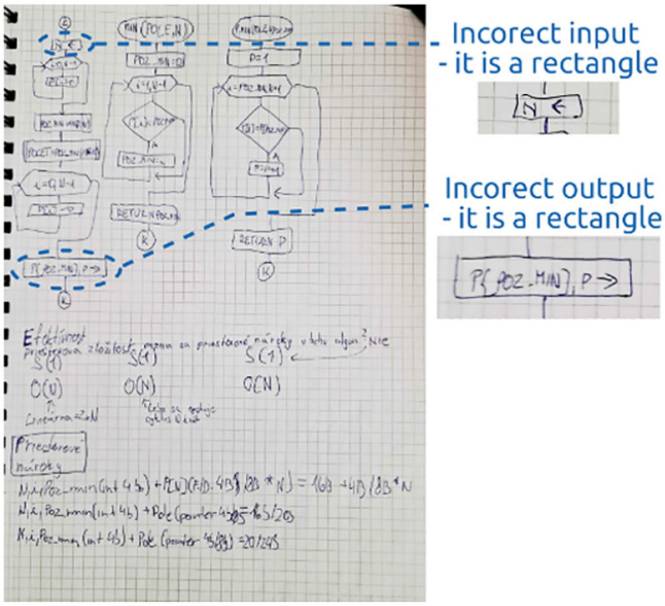

Fig. 9. Notes of participant LL–inconsistency in drawing in the flowchart and NSD

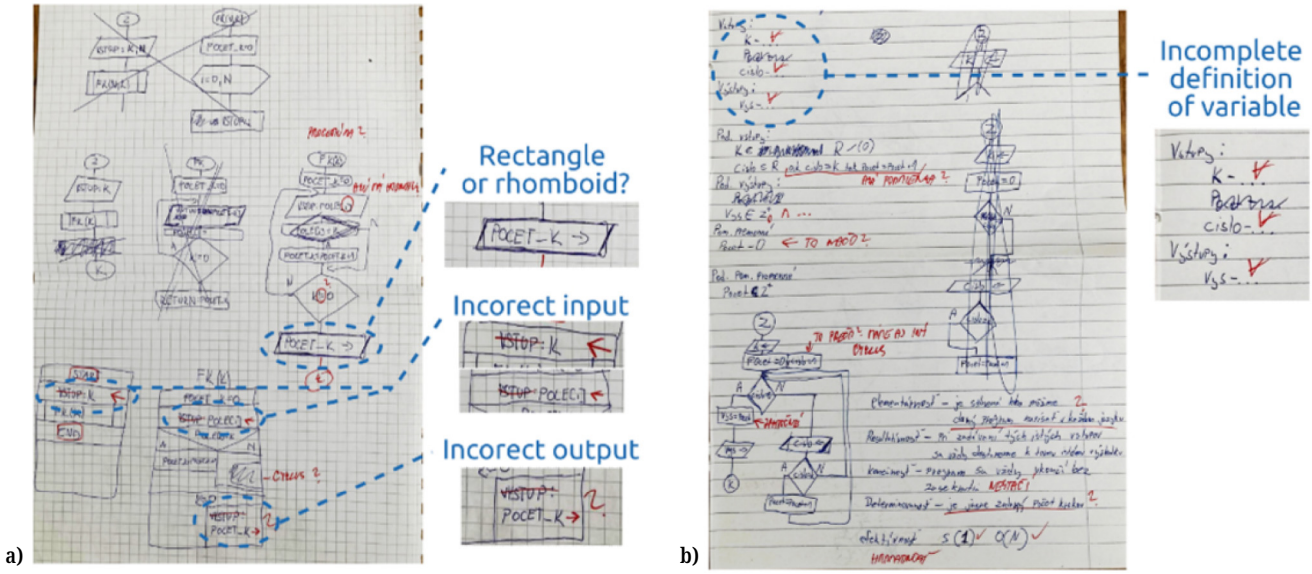

Fig. 10. Credit test of participants LL (a) and AM (b)

The last evidence that we decided to present is the result of the credit test of participant AM (Figure 10b), who used the symbol "..." when defining the variables instead of their unambiguous description, which we often use in teaching as a symbol that we are continuing the definition. However, we do not record this on the board (Figure 6), but represent it verbally, usually in several possible variants, so that the students choose the one that suits them best and write it down in their notes. We are of the opinion that these facts clearly point to the fact that inconsistent note-taking by students affects the results achieved.

2.4 Conclusion of case study

The facts only confirm that systematic management and regular monitoring of students' activities are more or less necessary for achieving satisfactory educational goals, which is in accordance with [21]. Indirectly, this proves the validity of using a complex heterogeneous evaluation system, which is laborious from the point of view of the teacher's work but clearly leads to results, as well as the validity of publishing as many materials as possible. The students declared that with the evaluation system built in this way, there was no problem studying things even in their absence, which they appreciated very positively.

3 CONCLUSION

We followed several authors who shared their experience in adapting and setting the forms and methods of education for students of computer sciences during the COVID-19 pandemic [4] [21] [22] [23] and compared the results of their studies with ours. The comparison proved the right way we set up the quality of assessing the students. According to Silapachote et al. [24], computational thinking "is a powerful cornerstone for cognitive development, creative problem solving, algorithmic thinking and designs and programming. How to effectively teach computational thinking skills poses real challenges and creates opportunities". Studies by other authors [25] [26] [27] support the solutions proposed and implemented by our study. An indisputable fact that had an impact on the results of education was the inability of students to adapt from online education to face-to-face education and thus the need to record their own notes and be focused during education. Since they were first-year students, their experience with online education from secondary schools was different and significantly influenced their activity. During the transition to the university method of study, they did not develop the necessary habits under the influence of online education, which led to hypoactivity, passivity and comfort.

We also demonstrated that the results achieved in the subject "Programming I" compared to the results of the subject "Algorithms and Data Structures I" were significantly better. Based on the mentioned research results, we believe that the fact that the students' notes on this subject, which represent directly programme codes, where it is possible to immediately determine their correctness or incorrectness by compiling and testing the solution, compared to the notes from the subject "Algorithms and Data Structures I", the evaluation of which requires students' knowledge, may be the reason for this fact.

We have also shown that students tend to provide the widest possible amount of materials to educators, which, however, does not always have to be justified, and therefore it is more than important to verify the materials, tools and methods, as well as their effectiveness, used in the educational process. This fact was also confirmed for us in the current academic year, when in the subject "Intelligent Techniques in E-Learning" we involved students in the process of creating questions specifically for problematic thematic units taught in the studied subjects. These were thematic units: functions, dynamic memory allocation and basic abstract data types. The goal was for students to design questions of different types for each area (T/F; Multiple Choice; Multiple Response; Fill-in-the-Bank; Word Bank; Matching Drag-and-Drop; Matching Drop-down; Sequence Drag-and-Drop; Numeric; Hotspot) so that the questions cover all levels of the Niemerko taxonomy of learning objectives. The task of the students was not only to propose the question but also the proper solution in cases of correct

as well as incorrect answers. When checking this task, the students themselves began to ask what we would do next with the given questions. When we explained to them that after professional editing they would be included in the prepared e-course primarily intended for secondary school students, they all unanimously expressed that such an e-course or even such a database of questions would certainly help them in their first year of bachelor's studies. They declared that it was only after such a change of role that they were essentially put in the role of a teacher, and thanks to the provision and detailed analysis of the positive and negative aspects of the questions proposed by them, they realised and finally understood many professional facts.

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