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Challenges of Digitalization of Small Credit Point Courses for Large Classes

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Abstract

The paper is devoted to the development of digital competences of second year bachelor students at the Faculty of Computer Science and Information Technology of the Riga Technical University for the course in numerical methods. The structure of the course is described in detail. The key component in the organization of the lectures and lab sessions is interactivity. Many interactive components (presentations, tests) in H5P format are available for students. The digital proficiency Levels 7 and 8 in accordance with DigComp 2.1 framework is expected to be achieved by carefully selecting topics and practical tasks to be solved during the course. The e-book written for the course and published by the Publishing house of the Riga Technical University is one of the teaching resources available to students. The course is fully digitalized so that it can be given in any of the three formats: (a) classroom and lab instruction, (b) fully online course or (c) mixed mode (blended learning). The preference is given to option (c). Both synchronous and asynchronous teaching methods are used. The organization of tests and exams (in the form of online tests) allows instructors to organize the grading effectively without spending too much time on it but at the same time effectively testing students' knowledge.

Keywords: digital competence, e-course, numerical methods

1. Introduction

We live in a digital world. The development of digital skills nowadays starts in elementary school and develops continuously throughout all the phases of the educational process: secondary school, high school, and university. (Ferrari et al., 2012) explores how the concept of digital competence is analyzed in different frameworks. European Commission (Carretero et al., 2017) presented the document DigComp 2.1 where eight different digital proficiency levels are defined. The European Recovery and Resilience Facility plan allocates 212.9 million euros to Latvia until 2027 with the objective to strengthen the competitiveness of higher education and science (Latvian Ministry of Higher Education and Science, 2022). Part of this funding (84.7 million euros) goes to the four projects related to the development of the digital skills. The aims of one of these projects (project No. 2.3.1.1.i.0/1/22/I/CFLA/003 “Highly specialized digital skills in high-performance computing”) are: (a) to increase the number of specialists with high-level digital skills (Levels 7 and 8 in accordance with DigComp 2.1 guidelines, see (Carretero et al., 2017)) who would use high technology to develop new products and services and (b) to create a synergy of higher education, science and industry with the objective to promote innovation in various sectors of the economy. Three universities in Latvia are currently participating in the project: Riga Technical University (RTU), Riga Stradins University (RSU), and University of Latvia (LU). The goals of the project would be achieved through the development of new courses at the universities and the modification of the existing ones. The authors of the paper are from RTU and are participating in the project (it has started in May 2023 with the duration of 3.5 years). The work in the project is divided into two main phases: (a) Phase 1 – development of the course with interactive elements in each class, online tests to practice, online tests (graded tests) and online final exam with the objective to develop high-level digital competency (this work should be completed by the end of 2023), (b) Phase 2 – delivery of the course with continuous feedback from the students and improvement (the course will be given not only to RTU students, but also to students from other universities and representatives from industry). Note that the content of the course should include the topics corresponding to the proficiency levels 7 and 8 in accordance with the classification given in (Carrerro et al., 2017): “Resolve complex problems with limited solutions” (Level 7) and “Resolve complex problems with many interacting factors” (Level 8).

The authors are currently teaching basic course in numerical methods for second year bachelor students at the Faculty of Computer Science and Information Technology at RTU. It is a two credit point basic course in numerical methods which includes the following topics: solution of systems of linear algebraic equations, interpolation, approximation, numerical integration, solution of nonlinear equations and systems of nonlinear equations, solution of Cauchy problem for ordinary differential equations. There is one lecture every second week and lab session every second week (32 contact hours per semester in total). The lectures are given in one large classroom which can accommodate up to 500 students while lab sessions are given in smaller groups of 30 students in each. Thus, the challenges that the instructors have are the following: (a) a relatively large number of topics has to be covered during the semester, (b) since the instructor meets with students every second week, there should be a way to keep students active (many things are forgotten very quickly (Bacon & Stewart, 2006), (Murre & Dros, 2015)), (c) asynchronous method of teaching should be employed (Vonderwell et al., 2015) to give students chances to practice themselves between the classes, (d) a good balance between theory and practical exercises should be found.

In addition, second year students had just one course in programming prior to numerical methods course so that some of them still have problems in understanding how basic blocks of any computer language work (for example, loops). This fact has to be taken into account in the design of the course.

2. The structure of the course

There are different approaches in teaching numerical methods. One is based on detailed theoretical analysis of numerical algorithms with proofs of conditions of convergence of iterative methods and analysis of stability of numerical methods for the solution of ordinary differential equations (see, for example, (Salgado & Wise, 2022)). Taking into account the topics to be covered and the number of contact academic hours allocated to the course this approach cannot be fully implemented. The second option is to have some sort of "user-oriented" approach where theory is explained rather briefly but the emphasis is given to practical implementation of numerical algorithms with analysis of potential problems that can exist in implementation of these methods (for example, divergence of iterative methods or instability of the Thomas' algorithm). Examples of such textbooks include (Lindfield & Penny, 2019) and (Woodford & Philips, 2012). Similar approach is used to deliver numerical methods course at RTU. Detailed structure of the course is described below.

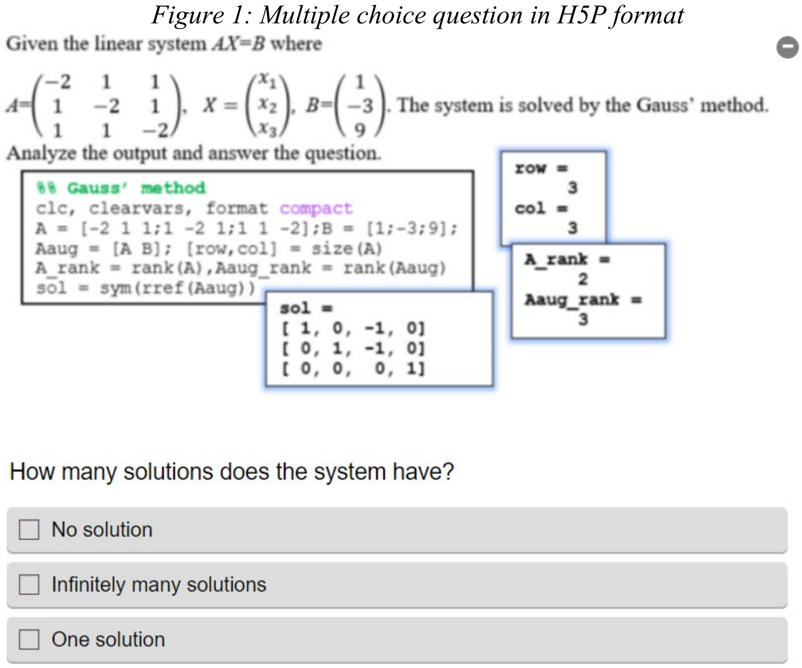
The presentations for each lecture are prepared by the instructor. In addition, short videos (7 – 10 minutes each) are recorded and are available to students before each class. The instructor encourages students to watch these videos before each class. Each video contains the "anchor points" of each lecture so that students can get a general understanding of the topics discussed in each class before the lecture takes place. The length of each video is small since the recent studies suggested that the majority of students do not watch long videos (Power 2022).

In addition, students have the e-book for the course written by the authors and published by the RTU publishing house. The structure of the e-book is as follows. In the beginning of each chapter a brief description of a particular numerical method is given. Next, several examples are solved in Matlab in detail. The students have Matlab scripts, the answers and comments to the solution. Each chapter contains problem set with similar exercises which students can try to solve in the end of each lab session and at home. In some scripts Matlab built-in functions are used so the description of each Matlab built-in function is given. If an algorithm is implemented without the use of Matlab built-in functions the instructors provide the code. These codes are also available in the e-study portal in the form of Matlab m-files. In order to solve other problems students should modify the given m-files accordingly. Thus, we do not ask students to write the codes from scratch but ask them to understand what do the codes do and what needs to be done in order to answer a similar question (what changes in the code are required).

Several interactive questions in the form of a Quiz (Question Sets) are prepared in H5P format. The meaning of H5P is explained on the website (H5P, 2023): "H5P is a plugin for existing publishing systems that enables the system to create interactive content like Interactive Videos, Presentations, Games, Quizzes, and more!". E-study portal at RTU is Moodle (Latvian version of it at RTU is called Ortus). Interactive tools from H5P are integrated with Moodle so that the instructor can select a proper tool among about 50 available options from H5P. We think that a Quiz (Question Sets) option would be the best to achieve the objectives of the course. It allows the instructor to combine different tools from H5P such as Multiple Choice Questions or True/False Question. An example of one multiple choice question is given in Figure 1. Students see not only the problem formulation but also the solution in Matlab. The answer should be based on the analysis of the output.

The nice feature of the Quiz (Question Sets) is that the instructor can add comments and hints in case a student incorrectly answered the question. This is one of the components of asynchronous teaching which we think would certainly help students to learn the material better.

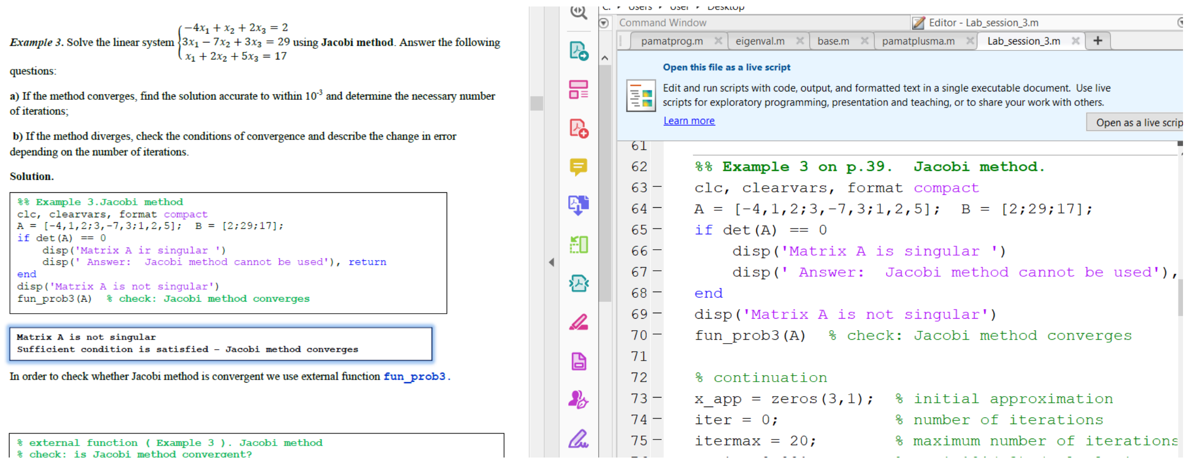
Figure 1: Multiple choice question in H5P format



3. The structure of the lab sessions

As it is mentioned earlier, all lab sessions are conducted in computer labs (each lab has 30 computers in it). Before the start of each lab session we ask students to open both the e-book and the m-file so that the screen should look like shown in Figure 2.

Figure 2: E-book and m-file for lab sessions



Note that Matlab scripts in the e-book are the same as prepared in the corresponding m-files. This means that the student can follow both explanations from the instructor during the lab session and the explanations from the e-book, run the codes and make the necessary changes in the codes. Obviously, such type of an activity can be repeated and performed at home (in case a student missed the class or wants to repeat the material). The lab session is organized in such a way that the last 15-20 minutes of it is devoted to practice problems similar to the ones discussed during the lab session. The formulations of all problems suggested for practice (with answers) are available in the e-book (about 10 to 15 problems for each section). The students use examples of similar problems solved earlier and available in the form of the m-files to modify the scripts with the objective to solve other problems.

At the end of each lab session a student should have a working m-file with many solved examples that are related to the particular topic. We encourage students to write as many comments in the m-files as possible so that they can easily understand what does a particular module do. These m-files can be used by students later during the tests and final exam.

4. Knowledge control and marking scheme

There are two major components in the marking scheme: online tests (three tests in total during the semester) and the final exam. Both online tests and final exam are open book tests. The students are allowed to use the m-files, the e-book and other teaching materials. However, we try to limit the resources available to students in particular, ChatGPT which is known to be very good in generating codes in different programming languages. Thus, only stationary computer in the computer lab is allowed to use (no phones or tablets). The software Veyon Master (Veyon, 2023) installed in each computer lab allows the instructor to see each monitor in the lab and control what do the students do.

The organization of online tests is as follows. There are many built-in functions in Matlab that require only basic input so that the user may treat these functions as "black boxes" with provided input and output generated by Matlab. One example is the function ***fzero*** for root finding in Matlab. Suppose that the user wants to find the roots of the equation

$$f(x)=0.$$

The standard procedure consists of two steps: (a) plot the graph of the function $f(x)$ in order to locate the roots and (b) choose the initial approximation to the root from the graph and use one of the available methods (for example, Newton's method) to calculate the root with the required accuracy. If Matlab function ***fzero*** is used, the user should define the function $f(x)$ and the initial approximation to the root, but he or she does not even know what kind of numerical method is used by Matlab. One example is shown in Figure 3 for the solution of the equation:

$$e^x = 3 - x.$$

Figure 3: Solution of the nonlinear equation with fwero

```
f=@(x)exp(x)-3+x;          ans =
x0=-20;
fzero(f,x0)                       0.7921
```

The user has to define the function $f(x) = e^x - 3 + x$ and the initial approximation to the root (which should be read from the graph). However, even blindly chosen initial approximation (in our example $x_0 = -20$ which is very far from the root) gives the correct answer. In this case the student does not learn anything. In order to avoid this situation, we ask students to provide intermediate results obtained with the use of the specified numerical method. For the problem described above the formulation may be the following: Find the approximate solution of the equation $e^x = 3 - x$ using Newton's method after two iterations assuming that the initial approximation is $x_0 = 0.5$. Note that we are not asking to give the final result, but just the numerical value of the approximate solution (which is impossible to guess). Many problems for online tests in the course have similar formulations. Thus, the marking scheme is binary for each question: the student get one point in case his/her numerical answer coincides with the correct one, and zero point otherwise. In addition, the student would know the score on the test as soon as the test is completed. Note that the instructor will go through all the answers manually (to fix some technical problems, for example, in case of incorrect rounding) and may change the grades. Taking into account the large size of the class, such a marking scheme allows to save a lot of time for the instructor (since the tests do not need to be graded manually). Of course, it takes time to prepare all the exercises for the tests. For example, the first online test consists of six questions. We have 14 versions of each question so that the total number of different question sets is quite large:

$14^6 = 7529536$ and certainly can be applied for the class of 400 students.

The final exam is organized similarly (in the form of an online test). However, the marking scheme is not binary anymore since students are asked to submit not only the numerical answers to each question but also the m-files where all the calculations are done. Hence, the instructor can follow student's logic, run the code and see what kind of mistakes the students have made (as a result, the student can get partial marks for incorrectly solved questions).

Each instructor who gives labs, has weekly office hours so that students can come and ask questions. Some instructors also organize WhatsApp groups to speed up the learning process.

5. Conclusions

The structure of the course "Numerical methods" as well as the teaching tools and materials developed for the course are discussed in the paper. The course is designed with the objective to develop students' digital skills in accordance with the proficiency levels 7 and 8 of DigComp 2.1 framework. Proficiency levels 7 and 8 will be achieved during the course by considering 2D versions of the methods analyzed in the course in one dimension. For example, different one-dimensional approximation methods are analyzed in the course where fitting is performed with polynomials and other linearly independent functions. By analogy, fitting methods in 2D are also implemented in Matlab. This fact allows the instructor to introduce response surface methodology (Myers et al., 2016). As an example, one can consider a process of a chemical reaction where the amount of mass of a certain substance depends on temperature (T) and pressure (p). Using approximation by a second-degree polynomial in T and p one can find the maximum of the approximating function and, as a result, specify optimal conditions for the process. Similarly, numerical solution of Cauchy problem for ordinary differential equations is considered in the course. Using Matlab built-in module pdepe the instructor can discuss with students the solution of boundary value problems for partial differential equations (for example, distribution of temperature in a thin rod). The additional level of complexity comes from the two aspects: (a) the solution of boundary value problem instead of the solution of initial value problem is considered, and (b) partial differential equation is solved instead of ordinary differential equation. Of course, detailed analysis of numerical solutions of partial differential equations is not possible in a two-credit point course. However, experience shows that students can learn things rather quickly using analogies so that brief introduction to numerical techniques of solutions of partial differential equations can be considered as a good starting point for future studies.

The course is fully digitalized so that depending on different factors it can be given either online or in the classical “classroom-based” format. Our intention, however, is to use it in the mixed mode where both synchronous and asynchronous activities are combined. This is achieved, in particular, by offering students a large number interactive exercises where the student is advised how to approach the problem if an incorrect answer to test question is chosen. Two types of tests are offered in the course: interactive tests for checking the knowledge (the tests can be taken any time) and online tests (with grades) that are given at the specified time. The final exam is prepared also in the form of online test where only numerical answers to all questions are expected.

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