Engaging with real-world phenomena through Matlab programming projects

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Abstract

This presentation aims to report a pedagogical experience carried out in a course unit of a graduate programme in Computer Engineering at the University of Minho. The course unit, Numerical Methods and NonLinear Optimization (NMNO), integrates the first semester of the third year. The experience took place in 2021-2022 with 146 students, and it was supported by Centre IDEA-UMinho within the project 2Be-Learning.
The classes were taught face-to-face (theoretical lectures and lab practice) and several strategies were implemented to support learning: ARS, padlet, videos, storytelling, and projects. Assessment was diversified and distributed over time to foster ongoing study and progress. It included two face-to-face written tests, four online multiple choice mini-tests (one per month, lasting about 10 minutes, based on extensive question banks), and one Matlab project. The focus of the presentation is on the impact of Matlab projects in the learning process.
The projects were carried out by teams of 4 students. Each team could choose one of five proposed topics. The main challenge was to search for and select a real-world phenomenon where the chosen topic could be applied and solve a problem that should have an adequate level of complexity. The experience was evaluated on the basis of the quality of projects, students' grades and their perceptions collected in a survey at the end of the course unit. Results show that students developed their creativity through building bridges with other scientific areas and solving problems in innovative ways. Projects promoted their involvement in learning, autonomy, cooperation and the personal construction of knowledge, which are essential competences for lifelong learning. Overall, it can be considered that engaging with real-world phenomena creates conditions for students to connect course-based learning with authentic situations, analyse and solve problems from a multidisciplinary perspective, mediated by digital technologies, and become pro-active learners.

Keywords: real-world phenomena, projects, problem-solving, maths education.

1 Introduction

The Centre IDEA-UMinho (Centre for the Innovation and Development of Teaching and Learning - https://idea.uminho.pt/pt) is an academic development centre at the University of Minho that supports the development of innovative pedagogical projects where faculty assume the role of teacher-researchers, exploring and assessing their teaching experiences with a focus on student learning. These projects represent cases of the Scholarship of Teaching and Learning (SoTL), whereby teachers inquire into their practice and make teaching "community property" by sharing and disseminating results so that others can build on their work (Shulman 2004). By inquiring into teaching, teachers become agents of change and reshape their professional identity, which supports the development of culture of innovation that assigns teaching a more visible role in higher education institutions (Vieira, 2014).
The first author started her journey of pedagogical inquiry in 2020-21, during the COVID-19 pandemics, by exploring a b-learning approach in a course unit of a master's programme in Computer Engineering at the University of Minho, Numerical Methods and Nonlinear Optimization, which is placed in the first semester of the third year of the programme (Monteiro et al., 2021). Her project was supported by the Centre and the second and third authors acted as mentors. The goal was to enhance students' motivation, interaction and participation in learning. Along with the exploration of digital resources, assessment became more diversified and distributed over time to foster ongoing study and progress. It included mini-tests and two Matlab projects carried out in teams with the main challenge of finding a real-world phenomenon for the application of a course concept, which implied connecting conceptual learning with reality and creating bridges with other areas of knowledge. The experience was evaluated on the basis of students' assessment results and their

perceptions collected in a survey. The new approach resulted in high levels of student engagement and satisfaction, promoting cooperation and the personal construction of knowledge, which are essential competences for lifelong learning. Nevertheless, is was concluded that the development of Matlab projects required further improvements, not only as regards support to students but also the evaluation of their impact on learning. Therefore, the project was continued in 2021-22 with a new group of students, and the purpose of the present paper is to report the improvements made and the impact of Matlab projects on learning. This project was also supported by the Centre and accompanied by the same colleagues as mentors.
The paper is organized as follows: section 2 describes the context of the teaching experience and the procedures for developing the Matlab projects; section 3 presents information of those projects, students' assessment results and their perceptions regarding project development and some statistical data; section 4 presents conclusions and future directions.

2 The development of Matlab projects

The experience took place with 146 students in the first semester of the academic year 2021-2022. The course unit has 5 ECTS (European Credit Transfer System) with 140 working hours and consists of two modules: Numerical Methods and Nonlinear Optimization. The learning outcomes are the following: applying computer tools to model physical problems; developing and applying numerical skills to analyse systems; comparing different solutions for numerical problems; selecting, using and comparing different optimization algorithms; developing critical evaluation of results; and using computational tools.
The course unit is taught 4 h a week: 2 h of theoretical lessons and 2 h of practical lessons, all face-to-face. Five practical lessons were carried out in computational laboratories with about 30 students per group, involving four teachers. In these classes, the students solve exercises using the calculator and the software Matlab. The Blackboard eLearning platform (Bb) was used to support the learning process.
One of the learning tasks to assess students on the Matlab programming component is a Matlab project. This project entails linking conceptual learning with reality and is aimed at promoting problem-solving abilities, interdisciplinary learning and cooperation, which are important elements of active learning (Graaff & Kolmos, 2003; Prince, 2004). Connecting the curriculum with real world problems enhances authentic learning and deep understanding (McGregor, 2020), and cooperative learning is especially effective in problem-solving tasks that involve dealing with multiple sources of knowledge and require students to negotiate ideas and decisions (Johnson & Johnson 2014).

The projects were carried out outside the classroom in teams of four elements, formed by the students. Five topics were proposed by the teacher and each team should select one according to their preference.
Project development involved several phases, requiring students to negotiate decisions, do research work, solve problems by applying mathematical knowledge creatively, analyse results and report their work:

- Project guidelines placed on the Bb platform
- Topic selection (one of the five indicated by the teacher)
- Searching for a real-world phenomenon, using several sources
- Mathematical modelling (complexity analysis and adequacy)
- Matlab programming using the corresponding routine
- Numerical experiments to obtain results
- Critical analysis of results
- Report writing (three pages)
- Electronic submission with deadline on the Bb platform

The main challenge of the project, which students usually find to be rather difficult, is finding a real-world phenomenon for the application of a course concept. This was observed in the first experience in 2020/21, where students had to develop two projects, which proved to be time-consuming and too demanding for many of them. This time, they only had to do one project, and before they began, the teacher explained the task requirements as usual, but she also showed them examples of well designed projects developed by former students, increasing student's awareness regarding the quality criteria their projects were expected to meet, and giving them a more concrete sense of the type of work they were expected to do. During project development, she held regular support sessions as usual, both online and face-to-face, to help students monitor their progress and overcome difficulties. These procedures were useful to develop students' assessment literacy and self-regulation skills (Evans, 2003; 2021). In the end, each team presented a 3-page report where they synthesized their project.

3 The nature and impact of Matlab projects

A total of 33 project reports were concluded. In this section, we present the topics and the phenomena they explored, as well as assessment results and the students' perceptions about the competences they developed.

3.1 Topics and real-world phenomena explored

The five topics teams could choose from are presented in Table 1, as well as the corresponding Matlab routines, the week when the topics were proposed, which depended on when they were explored in class, and the number of projects per topic. The first two topics were chosen by a large number of students (79 %). They found them interesting and it was easier to find real-word phenomena related to them; moreover, the fact they were proposed earlier in the semester also gave students more time to explore them. The topic Numerical integration was not chosen, perhaps because it is more difficult to find a real-world phenomenon; also, the fact that it is very easy to use the corresponding MatLab routine makes it more difficult to be creative and obtain a good grade, since creativity is one of the assessment criteria.

Table 1. Topics and Matlab routines

Topic	Matlab routine	Week (1-15)	Projects
Nonlinear equations	fsolve	4	16
Splines	spline	5	10
Numerical integration	trapz, quad	6	0
Least squares approximation	polyfit, lsqcurvefit	7	4
Nonlinear optimization	fminunc, fminsearch	12	3

As pointed out above, the main challenge of the project was to find a suitable real-world phenomenon where the chosen topic could be explored. Despite the strategies used to support the students, this difficulty was mentioned in all the reports and the students complained about it during project development, asking for the teacher's help. Some ideas were suggested to them by referring to books, articles, magazines, other course units, databases, etc. The identification of a taught concept (topic) in the in the real-world is a mechanism to facilitate conceptual understanding, although it may be quite demanding.

Table 2 shows the variety of real-world phenomena explored for each topic and the scientific areas with which bridges were established. It illustrates the potential value of projects in promoting the connection between theoretical learning and reality, as well cross-disciplinary learning,

Table 2. Real-world phenomena and scientific areas in Matlab projects

Topics	Phenomena	Scientific area
Nonlinear equations	Carbon 14 dating	Chemistry
	Global Positioning System (GPS) using satellites signals (2)	Spatial engineering
	Temperature distribution in a wire	Materials engineering
	Tank sizing	Civil engineering
	American soccer ball throw	Physics
	Electric circuits (2)	Electrical engineering
	Concentration of a polluting bacteria in a lake	Environment
	Location of a bridge over a river	Civil engineering
	Orbit of celestial bodies	Astronomy
	Electrical power system planning	Electrical engineering
	Efficient square root calculation	Mathematical computational
Splines	Objects design	Computer graphics
	Pathfinding (2)	Video games
	Cryptocurrency price	Economy
	Apparent visual magnitude of a star	Astronomy
	Portuguese students in higher education	Sociology

	Parachuting jump	Physics
	Electrocardiographic heart rate monitoring	Electronics
	Graphic contour of the heart left ventricle	Biomedicine
	Cod fishing in northeast Atlantic ocean (1960-2019)	Business
Least-squares	Average temperature in Lisbon since 1960	Environment
	Portuguese population 1960-2020	Sociology
	Microchip and processor industry (Moore's law)	Electronic engineering
	Soccer players running speed	Sports
Nonlinear optimization	Evaluation of optimization algorithms	Informatics
	Iron barrel sales	Business
	Truck and sedan resale prices	Retail

3.2 Assessment results

In each team, all members had the same mark. This was assumed in the beginning of the semester, but it was also pointed out by a few students as a negative factor in the final assessment, because it did not take account of individual differences among team members regarding their investment and contribution to projects.
The assessment criteria were explained to the students. A scale from 0 to 3 points was used (the course unit has a scale from 0 to 20, the project is worth 15 % of the final grade). The quality of projects was assessed taking into account their originality, complexity, creativity and the computing experiences. Reports were assessed in terms of rigour, ability to synthesize, organization, presentation and the final conclusions. Grading projects is not an easy task and has to be done in comparative terms, i.e., each project is compared with the others, which makes it an iterative, time-consuming process.
The distribution of grades is presented in Figure 1 – 9 teams (27 %) obtained the maximum grade (3). The lower grading in 8 projects (below 1,5) is related to factors such as inappropriateness of the topic to the phenomenon, low complexity, or low commitment to report writing. Overall, students' results were positive and demonstrate that the learning outcomes for this task were globally achieved.

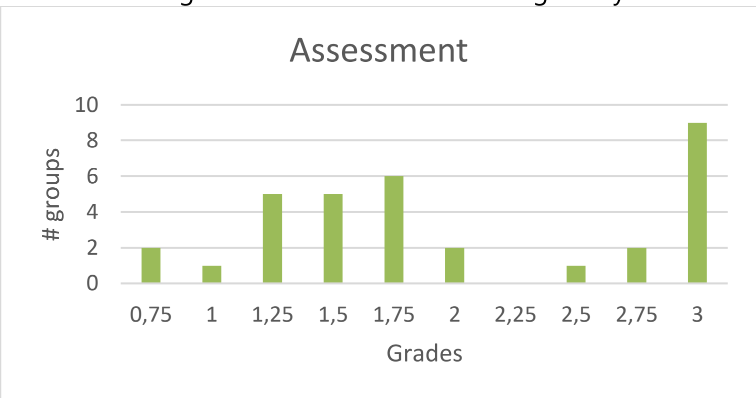

Figure 1. Project grades

The students' final grades showed an approximately normal distribution (Fig. 2), but project grades were not normally distributed (Fig. 3). We used a non-parametric test to look for correlations between the two sets of data. We calculated the Spearman correlation coefficient using ranked project grades and ranked final grades. The result was 0.52. This means that there is a moderate monotonic relationship between project grades and final grades. While both grades tend to go up in relation to one another, this relationship is not very strong because there is a significant number of cases where this is not true.

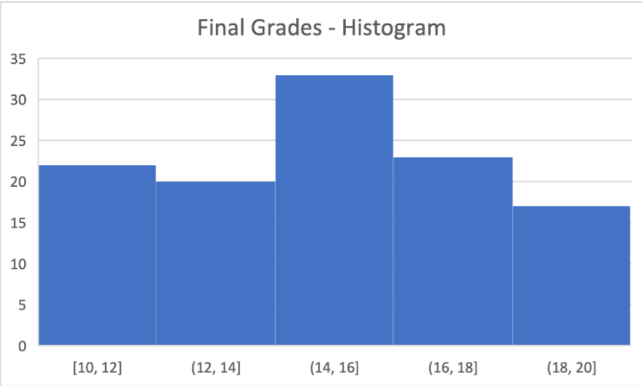

Figure 2. Final grades histogram

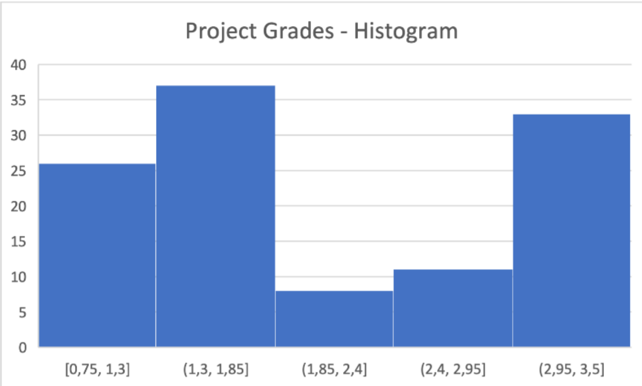

Figure 3. Project grades histogram

However, when we consider the project grades average for each range of final grades: [18,20], [14,17], [10,13], <10, we find out that final grades and project grades are strongly related. An increasing monotonic relationship between the two sets of values is shown in the Table 3. In other words, if a final grade *x* is higher than a final grade *y*, then the project grades average *Ax* corresponding to the range to which *x* is belongs is never lower than the project grades average *Ay* corresponding to the range to which *y* belongs.

Table 3. Project grades average per final grades range

	Project grades average ([0,3]) per final grades range			
Final grades range	[18,20]	[14,17]	[10,13]	<10
Project grades average	2.769	1.877	1.695	1.583

A relationship was found in the results concerning the project topics (cf. Table 1). On average, Splines projects were much better than any other projects. The difference between the average grade for Splines projects, 2.82, and the average grade for Nonlinear optimization projects, 1.75 (the second best group of projects), is approximately 1. On the other hand, the average grade of Nonlinear optimization projects differs only 0.08 and 0.3, respectively, from the average grades of Nonlinear equations projects and Least-squares projects. This may be due to the fact that Splines are important and useful concepts for the Computer Graphics course and their application on various areas is easily understood by students.

Another interesting relationship concerns project grades average for a given topic and final grades average of the students that chose that topic. There is an increasing monotonic relationship between the two sets of values, as shown in Table 4. In other words, if project grades average for topic *x* is higher than project grades average for a topic *y*, then - on average - students who chose topic *x* got higher final grades than students who chose topic *y*.

Table 4. Grades per topic

Topic	Project Grades Average per topic	Final Grades Average per topic
Nonlinear equations	1.673	13
Splines	2.824	16
Numerical integration	-	-
Least squares approximation	1.45	12
Nonlinear optimization	1.75	14

3.3 Student's perceptions

In the end of the semester, in order to identify the impact of the teaching approach and to collect some information and suggestions for improvement, a short Google forms survey with some questions was implemented. 60 students answered the survey (around 40 %). The survey included two questions on the impact of projects, which were not asked to the students from the previous experience.

One of the questions was related with the usefulness of the project in learning. Students were asked to indicate how useful the project was for their learning in the course unit, using the following scale: 'a lot', 'a little', 'not at all'. 38 % answered 'a lot', 47 % 'a little' and 15 % 'not at all'. These are not very positive findings. However, the findings from another question regarding cross-disciplinary competences developed through projects suggest otherwise. That question presented a set of six competences related to project development and students were asked to indicate whether they developed those competences by doing the project, using the same scale: 'a lot', 'a little', 'not at all'. The results are presented in Table 5.

Table 5. Competences developed through projects: students' perceptions (n=60)

Competences	A lot %	A little %	Not at all %
Autonomy	51.7	41.7	6.7
Cooperation	55	41.7	3.3
Creativity	63.3	33.3	3.3
Building bridges with other scientific areas	53.3	40	6.7
Personal construction of knowledge	58.3	35	6.7
Solving problems	63.3	33.3	3.3

Around half of the students answered 'a lot' on all competences, and almost all students felt they developed them to a higher or lower degree ('a lot' or 'a little'), which is quite expected given the variability and idiosyncrasy of competence development. The number of students who answered 'not at all' is minimal. These findings appear to suggest that students acknowledged the role of these projects in developing cross-disciplinary competences that are crucial for lifelong learning, namely creativity, personal knowledge construction and problem-solving. A majority of students also considered to have developed autonomy, cooperation and multidisciplinary learning through projects.

It is possible that, in assessing the usefulness of projects for their learning in the course unit, the students were thinking more about disciplinary competences, namely those needed for exams and tests, which may explain the less positive findings on that question. If this is so, then we need to ask whether the students really valued cross-disciplinary competences in their learning, even though they realised to have developed them. Perhaps the fact that these projects were not rated high for their overall grades (3 points in 20) conveyed a conflicting message about their value for learning. These students also took two tests and 4 short multiple choice tests, which accounted for most of their final grade. One needs perhaps to reconsider the relative weights of assessment tasks and whether they are aligned with the value assigned to the various competences those tasks are expected to promote

Let [0,2] be the range of values that represent the degree of students' perceptions of competence development in projects, where 0 stands for "no development", 1 stands for "a little development" and 2 stands for "a lot of development". In this range, a competence is considered relevant if its value is no less than 1.5. Table 6 describes how the students of four different grade ranges ([18,20], [14,17], [10,13], <10) evaluated the development of the several competences through projects.

Table 6. Average *development* of different competences per *final grades range*, where *development* ∈ [0,2]

	Degree of involvement ([0,2]) of each competence per final grades range			
Competence	[18,20]	[14,17]	[10,13]	<10
Autonomy	1.563	1.536	1.222	1
Cooperation	1.563	1.607	1.333	1.167
Creativity	1.688	1.714	1.444	1
Building bridges with other scientific areas	1.563	1.464	1.556	1
Personal construction of knowledge	1.75	1.464	1.444	1.167
Solving problems	1.75	1.571	1.667	1.167

For students in the highest range of grades, all competences were solidly developed through projects. Problem-solving and personal knowledge construction scored rather higher than others. For students in the [14,17] range, all competences were developed, with creativity scoring rather higher than others. For students in the lowest range of grades, only two competences were solidly developed: multidisciplinary learning and problem-solving. Creativity and personal knowledge construction were fairly developed, but autonomy and cooperation less so. These findings indicate differentiated perceptions of learning in the three student groups, suggesting that those who had higher grades also perceived a higher degree of competence development through projects

Let students' perceptions of motivation be represented in the scale [0,4], where 0 stands for "not motivated at all", and 4 corresponds to maximum motivation. As it would be expected, perceptions of motivation and final grades are strongly correlated. As motivation increases, final grades increase as well (Table 7).

Table 7. Average *motivation* per *final grades range*, where *motivation* ∈ [0,4]

	Degree of motivation ([0,4]) per final grades range			
Final grades range	[18,20]	[14,17]	[10,13]	<10
Motivation	3.25	2.893	2	1.333

4 Conclusion

The findings showed that project development enacted some of the conditions for creating 'situated learning environments' in higher education as pointed out by Herrington (2006):

- an authentic context that reflects the way knowledge will be used in real life: by identifying real-world phenomena and applying acquired knowledge to solving problems, projects enhanced students' ability to use that knowledge in an authentic context, and also to undertake interdisciplinary learning;
- authentic activities which have real-world relevance, and which present a single complex task to be completed over a sustained period of time: project development integrated a set of tasks that can be transferred to other real-life situations (negotiating decisions, team-building, solving problems, etc.);
- collaborative construction of knowledge, along with coaching and scaffolding by peers and teachers: in developing their projects in teams and with regular teacher support, opportunities for cooperative learning were created, which enhanced students' confidence and motivation;
- authentic assessment by integrating learning and assessment into the same task: projects were learning tasks and also learning products to be assessed, which means that the focus was not only on assessing outcomes but also, and most importantly, on creating conditions for the development of disciplinary and cross-disciplinary competences.

The changes made in students' preparation for projects were useful, yet they still had difficulties in relating course contents with real-life phenomena at the initial state of their projects. Further support might be needed at that stage and during project development, for example through joint seminars on theory-practice integration with realistic examples. Nevertheless, it is also our conviction that students' struggle to make connections between concepts and real life is a necessary part of 'learning beyond the classroom'.

Assessment results and students' perceptions of learning through projects were globally positive. However, more thought is needed on the importance they give to cross-disciplinary competences, and on the role that assessment might play in valuing those competences in grading systems. These concerns may be the starting point for further developments in the teaching approach, which may require the involvement of students in discussing these issues among themselves and with the teacher during the development of projects.
By supporting the development of teaching projects, the Centre IDEA-UMinho enhances collaborative forms of SoTL where mentors act as critical friends. This process creates conditions for the professional development of both the teacher and mentors, who in this case belong to different disciplinary fields. It also favours the enactment of two basic principles of good SoTL practice pointed out by Felten (2013): inquiry focused on student learning and conducted in partnership with students. The process of sharing experiences and interpretations with others increases our attention to learning and our ability to develop dialogic pedagogies.

Acknowledgments
This work has been supported the Centre IDEA-UMinho and by FCT – Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020. The authors are grateful to the reviewers for their valuable comments.

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