SIMULATION-BASED MATH IN THE FACULTY OF ENGINEERING AND BUSINESS

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ABSTRACT

The world today needs rapid innovation, product development and consideration of sustainability. Different types of models are efforts used to forecast the future, for climate, economy, and population growth, to name but a few, as the information does not exist otherwise. In general, use of simulations and various computer aided methods play a key role, as they are efficient in developing, evaluating, and comparing different solutions. The “simulation-based math” standard is a corner stone in providing engineering students with the skills and mindset to respond to modern world challenges in their future careers. At Turku University of Applied Sciences (Turku UAS) the implementation of the latest simulation-based mathematics -standard started collectively in the faculty of Engineering and Business in spring 2021. The first step was to examine to what extent computational methods are present in education. This survey was done in four different departments. Each department explored their course selection and based on how much and how systematic the use of computer-aided mathematics in the courses was, defined the initial stage in the rubric. The survey showed that the initial state at different departments varies notably. Some departments clearly have more structure in utilizing the methods whereas others had not yet started any thorough process of implementing the new standard. A common goal is to synchronize the practices and create a learning curve that starts from the basic courses with simple tasks and continues until the later stages of studies with more complex problems. This paper discusses the review process, its’ findings, and the ideas how to start improving the implementation of simulation-based math-standard in separate courses and at the programme level through the whole faculty. In addition, challenges and the concrete next steps will be outlined.

KEYWORDS

Math, Simulations, Numerical methods, Standards: Optional standards 2

INTRODUCTION

Whereas the framework and standards for CDIO were established already more than a decade ago (Brodeur and Crawley, 2005), the optional standards are a rather new issue. The idea of optional standards was first introduced in the paper by Malmqvist et al (2017) where the authors discussed the need of educating engineers with new competences, thematically linked with the current societal issues such as sustainable development, internationalization, innovation, and multidisciplinary problem solving. In addition to these competences Kamp (2016) emphasized the need for an attitude for life-long learning, reflecting on the fact that the operating environment and the challenges we are facing are constantly changing, both locally and globally. In addition to preparing engineers with the field-specific competence, but they also need to be able to provide creativity and innovations even outside the engineering discipline, consider the needs of the society and to be able to communicate their achievements to public. The drivers and the need for revision of the CDIO standards were discussed also in Malmqvist et al. (2019) and Malmqvist et al. (2020). Besides these generalized skills, the mindset and internal and external drivers, Enelund et al. (2011) pointed out a concrete trend of increased use of computational and numerical methods in real-world engineering problem solving, and that these skills should also be included in engineering education. In their case, the use of computers and numerical exercises as complementary tools for traditional symbolic mathematics assisted students in learning and understanding math. The use of numerical methods and simulations enables much better possibilities for studying real-world engineering problems than basic pen and paper exercises and via them, more complicated mathematical methods can be used. The suggested new standards act as a complementary set up to serve as a guideline for possible specialization in the curriculum, whereas the original twelve standards form the fundamental basis for CDIO. However, not to only be applicable in a very limited context, the optional standards are suited to be used widely in various fields of engineering and thus, acts as one of the generalized transferrable skills needed in many tasks and careers.

The selection of optional standards serves this need well, considering the four themes selected for the standards. Especially sustainable development is one of the core competences today, being also promoted by the UN, that has set seventeen different goals to be achieved. Globalization has made the world greatly flexible what comes to the place where the work is done and by whom. In addition, considering the manufacturing industry, the supply chains can be rather complex and often require international mobilization of goods and people. From that perspective, it is justified to have had added the fourth optional standard. There has been plenty of discussion nationally and worldwide (e.g., EU, OECD) about how the work and employment will change in the future, so it is important to include entrepreneurship studies in engineering education too. The simulation-based math standard can be neatly used in many of these aspects too. Being often highly independent from place, it can be utilized not only from the mobilization point of view but also from the sustainability aspects, since it enhances resource efficiency and guides for clever product development from the very beginning.

The simulation-based math standard is an excellent addition to the standard since the use of simulations in industry is increasing and the need of innovations require research. In both of those, the knowledge and understanding of the relevant phenomena and processes are essential but it is also equally important to be able to test and verify possible new ideas and assumptions reliably. In the past, the testing phase often included massive prototyping, which was slow and costly. As the simulation and numerical tools and computers keep evolving it makes sense to utilize them more extensively. As they are quite sophisticated and involve complex mathematics, it is good if students can get in touch with these tools during their studies. Especially if one wishes to pursue simulations as their career, the earlier these topics and methods are introduced, the better it is for development of their expertise and understanding. Not only to consider the standard just being promoted in math but it should be utilized in other courses too, such as physics and possible lab projects.

To start better utilizing the possibilities the simulation-based math standard enables, four different departments in the faculty of Engineering and Business at Turku University of Applied

Sciences started mapping their current state of methods and practices as compared with the simulation-based math standard self-assessment rubric. The departments participating in this survey were Chemical Engineering, Information and Communications technology, Mechanical Engineering and Logistics, Services and Industrial Management. Each department selected a group of people working with mathematics and physics courses to evaluate the content and practices in their department. The courses are rather similar and thus, it was good a basis to start internally discussing and sharing the practices and ideas. In addition, the possibilities to collaborate and synchronize the methods were also recognized. In this paper the findings and the future development for increased implementation of the simulation-based standard is introduced as a case study at one faculty and its departments.

CURRENT STATUS

Background

The education at Turku University of Applied Sciences is based on so-called innovation pedagogy where the goal is to prepare students with the skills needed for future engineering work. There are many similarities between Innovation Pedagogy and the CDIO concept such as active learning and teaching methods, working life orientation and flexible curricula (Konst et al., 2014). Because of this novel pedagogical strategy, that neatly complements the CDIO standards, it is reasonable to set goals and synchronize the curriculum with respect to the “simulation-based math” -standard jointly at four different departments educating engineers at Turku University of Applied Sciences.

Findings and discussion of the survey

As a starting point we used the self-assessment rubric presented in Figure 1, to start mapping the level on which each department thinks they are at utilizing methods that are related and can be linked to the simulation-based math standard. It was found that all the departments have activities and tasks that contribute to the standard as indicated in Table 1.

5	The course/module and programme learning outcomes for mathematical programming, modelling and simulation are regularly evaluated and revised, based on feedback from students, instructors, and other stakeholders.
4	There is documented evidence that students have achieved the intended learning outcomes for mathematical programming, modelling and simulation.
3	Course and/or programme learning outcomes for mathematical programming, modelling and simulation are validated with key programme stakeholders, including faculty, students, alumni, and industry representatives and levels of proficiency are set for each outcome.
2	A plan to incorporate explicit statements of learning outcomes at course/module level as well as programme outcomes for mathematical programming, modelling and simulation is accepted by programme leaders, engineering faculty, and other stakeholders.
1	The need to create or modify learning outcomes at course/module level and programme outcomes for mathematical programming, modelling and simulation are recognized and such a process has been initiated.
0	There are no explicit programme learning outcomes at course/module level nor programme outcomes that cover mathematical programming, modelling and simulation.

Figure 1. Rubric for self-assessment of Simulation based mathematics- Standard.

Table 1. Simulation-based math standard self-assessment rubric levels in the different departments.

Department	**Current level**	**Goal level (near future)**
Chemical Engineering	1	2–3
Information and Communications Technology	1–5	2–5
Logistics, Services and industrial Management	1	2–3
Mechanical Engineering	1	2–3

However, the practices and methods used vary notably between the departments. One common element in many of the courses are Matlab and Simulink and the learning material provided with the software supplier (e.g., Matlab and Simulink online courses). In addition to Matlab, Excel is often being used. For both software, there are campus-wide packages that are also available for students, so it makes sense to utilize them heavily. In addition to these common solutions, each department has its own specialized tools, including machine learning, different gaming applications, CFD and FEM for simulating 3D physics-based problems, for example. Besides these more field-specific tools, common programming languages such as Python, and some online tools like WolframAlpha, are utilized. Some of these tools are introduced in the first courses and some of them are used in the later stage studies and courses. In most of the departments a complete learning path from the beginning of the studies to the graduation stage doesn't yet exist. On the other hand, since the study programme and curriculum in each department is different, it does not surprise that the practices are not convergent. The tools and methods that are most useful and should be included in the studies also depends on the career the students will pursue after graduation. It may not be reasonable to make all the students go through the same learning curve in terms of using computer aided-methods.

Based on the review of discussion in each department, it was rather straightforward to recognize the main challenges and problems regarding applying and utilizing the simulation-based math standard. The first and biggest challenge is that students' math skills are very heterogenous. Some students know and can use more advanced mathematics, but a relatively large number has problems with basic algebra. The reason for this is the variety in the students' background. Some of them have been already in working life concentrating on practical work and are now, at a more mature age, re-educating themselves. For many of them, the earlier qualification is from vocational education, where mathematics is not being taught at a very advanced level. Many of the younger students also have their initial qualification from vocational school and their competence in mathematics is not very good. In addition to these students, there are some students who come from general upper secondary school, where it is possible to choose the advance syllabus in mathematics. Thus, some of these students are quite skilled and able to deal with more difficult topics. This makes the realization of all the math courses cumbersome, because some students find it hard to learn even the very basic issues and need lots of support to do so, whereas more skilled students may find it frustrating to use plenty of time on a very basic level when they would have the competence to go further and learn more difficult subjects. This fact brings us the question about how to implement simulation methods as complementary tools in math courses when the math needed to understand and perform the simulations is not on solid and advanced enough level? This discrepancy suggests that there should be many different learning paths for mathematics itself. Learning skills related to simulations and using computer aided tools should reinforce the learning of basic mathematics. Division should be made in a way that all the students should be provided with basic skills and more difficult practice should be introduced only for more advanced students so that the simulation-based math approach would give the additional value in its full potential. Even when the same pedagogical strategy is used throughout Turku UAS, there are many different methods and practices used at the four departments on which this analysis was performed. When working towards common goals it might be problematic to have plenty of versatile practices and methods in use.

OUTCOME AND FUTURE DEVELOPMENT

In all the departments the need for deeper application and integration of simulation-based math was identified. It was agreed, since campus licenses for Matlab exist, that it should be used through the studies, starting already from the first year. Efforts to increase the use of Matlab were already made during the spring of 2021. Turku UAS is using an online learning environment called itslearning (itslearning) where a self-paced Matlab -course was created. It’s based on the Matlab Onramp -course (Mathworks) and in addition to its content, extra exercises were created on the course platform. The course was created in a way that it is possible to do it independently or it can be included as a part of some other relevant course. This course was already included as a part of a basic math and IT course in mechanical engineering in fall 2021, for example. In these courses there were altogether about 150 students. Based on the feedback collected, there was variation in how students experienced the course and learned the software. Some of the students found the course and software interesting and learned it well, whereas some of them reported that it was very difficult and that they are not interested in learning any software in general. One might speculate that the background of the students plays a role in this, but the feedback survey did not ask about the students’ background, so this cannot be concluded. If the information were available, it would be worthwhile to compare the answers with the earlier education of the students. Further development of this action is to collect more feedback and create more examples and assignments that can be used to deepen learning and give opportunities to apply these methods for more complex real-world problems.

In general, it was discussed that the departments should collaborate closely in these development efforts to create a database for different types and levels of assignments and exercises that can be used in different courses. However, due to the issues regarding the students’ variable math skills, it is complicated to create anything that could emphasize the learning for all students. Thus, it was agreed that as a starting point, the focus should be on basic simulation skills and that the good, existing practices should be shared and synchronized throughout the departments. This means also that these learning outcomes and aims should be clearly indicated and be written in course and programme descriptions. To be able to induce more advanced learning and provide students with versatile simulation skills, the very basics should be at strong enough level so that students would benefit from these actions. Thus, it may not be reasonable to heavily implement simulation-based math in all the courses and study programmes but to educate the very basic methods and then create alternative or optional courses or program for the students who are interested in learning these skills and have the necessary competence to adopt and understand them. This seems plausible, since not all the students will need these skills in their working life. In addition, universities of applied sciences tend to be more practical compared with universities, so the curriculum for these skills could justifiably be more pragmatic but still it should give the basis, that would enable the adaption of more progressive learning and knowledge.

CONCLUSIONS

This review reveals the very heterogeneous practices at different departments and the challenge in comprehensive implementation of simulation-based math standard in one faculty. Due to the differences in study programmes, it may be difficult to create very intensely synchronized, common practices that would fit everyone and all programmes. It is also worth noticing that all members of the teaching personnel are not familiar with the principles that are needed in educating ideas of simulations, either, and thus to incorporate these methods in all the courses might be too ambitious. Instead, efforts should be put in sharing the best practices and in creating manners that would be suitable for as many as possible to take advantage of additional value that the simulation-based math standard offers. For those who wish to pursue extensive knowledge of simulations there should be optional courses or exercises which would reinforce learning and give the ability to apply these methods in practice. As a conclusion it can be also stated that none of the departments will set any specific level where to aim but will concentrate more on the methods and best practices that can enhance the learning of these skills.

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