

PAPER

Emerging Technologies in Engineering Mechanics Education

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ABSTRACT

Engineering mechanics is a fundamental part of many undergraduate programs, but it can also be one of the biggest hurdles at the beginning. This is due to the difficult content but also due to the challenge of conveying the practical relevance to students. The further development of the introductory courses in engineering mechanics has two objectives. The first objective is to offer students a more motivating approach to this challenging subject. This involves working on more practical examples by leaving the classroom and conducting experiments or shifting the focus from tedious calculations with pen and paper to experimenting with solutions. The second objective is to prepare students for the future. Aspects of programming and AI can be covered in separate courses in higher semesters. However, it is more efficient and sustainable to achieve this goal if these topics are already covered in introductory courses like mechanics from the first year onwards. This allows students to become true digital natives over the course of their undergraduate program. This publication takes a closer look at three technologies: virtual reality (VR) applications, the use of smartphones as measuring devices, and the use of numerical algorithms and the Julia programming language in the age of GenAI-Tools. It shows how these three technologies can contribute to the above-mentioned objectives in courses on engineering mechanics.

KEYWORDS

virtual reality (VR), engineering mechanics education, smartphone experiments, generative AI, automatic differentiation

1 INTRODUCTION

Courses in engineering mechanics (often in the sequence statics, mechanics of materials, kinematics, and dynamics) have always been an integral part of undergraduate programs in mechanical engineering and related fields. The courses represent a major hurdle for many students, partly because of the mathematical knowledge required, but also because of the necessary abstraction and modeling skills, which are usually less developed at the start of the program. As engineering mechanics is both important and difficult, much research has been conducted for

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an improvement of teaching. Topics include, but are not limited to, concept inventories to identify major conceptual problems (e.g., the statics concept inventory by Steif and Dantzer [1]), methods of teaching and teaching materials (e.g., peer instruction by Crouch and Mazur [2], the Purdue Mechanics Freeform Classroom by Rhoads et al. [3], and the Picker Engineering Program by Ellis et al. [4]), and students' and educators' views on engineering mechanics education (e.g., Goldfinch et al. [5]).

Teaching in basic courses, such as engineering mechanics, often remains very traditional. Although multimedia content is used, the extent to which new technologies are utilized lags behind current possibilities. Two aspects of using emerging technologies must be considered. First, further development of mechanics didactics should aim to reduce the well-known and long-standing difficulties by utilizing all available resources, such as new materials like screencasts, animations, and interactive apps; new teaching approaches like problem-based learning and inverted classrooms; and, most recently, AI-based tutors. Second, mechanics courses must contribute to preparing students for tomorrow's world of work by helping them gain competencies that extend beyond the immediate subject context. From this perspective, carefully developing mechanics courses further by providing new and better supporting materials might not be enough. A deep reorientation is required in both the selection of material and the methods and tools used. This second perspective leads us to emerging technologies that should be examined for teaching mechanics. In this paper, we will take a closer look at three digital technologies: virtual reality, smartphones as measuring devices, and GenAI tools for programming. Other approaches like augmented reality (AR) and gamification will not be discussed here.

Using virtual reality (VR) instead of a computer for work and learning is particularly useful for tasks where visual/spatial and haptic aspects are also relevant. We describe the use of an app developed at the University of Georgia for VR in mechanics education. This app allows users to work with a theodolite in a virtual environment, independent of costly equipment and weather conditions.

Smartphones are an option for almost everyone these days, but many are unaware of their potential as measuring devices for mechanical parameters. One of the authors teaches a basic course on dynamics in which students carry out simple and practical experiments with their smartphones. We observed that students suddenly became enthusiastic about mechanics.

GenAI tools are improving rapidly and can, to some extent, already be used, with appropriate caution, to tutor students in independent preparation and follow-up work for lectures. However, our focus here is on something else. GenAI tools are well-known for their effectiveness in supporting programming. For the first time, they make it possible to easily integrate programming into first-year engineering courses like engineering mechanics. The use of programming languages in beginner courses affects the nature of a mechanics course much more than it may seem at first glance.

2 THREE TECHNOLOGIES TO ENHANCE ENGINEERING MECHANICS EDUCATION: VR, SMARTPHONES, AND GENAI

2.1 VR for spatial or haptic problems in engineering mechanics education

Modern technologies are a promising additional tool for university teaching and offer students the chance to prepare for their future working lives. Many of these technologies, such as AR and VR and interactive 360° videos, as well as remote laboratories, allow students to complete tasks independently in an engaging manner, particularly when used as serious games (Damianova et al. [6], Spangenberg [7]).

Furthermore, students can acquire knowledge and practice their skills at times that suit them best. The associated skills, including innovative thinking, problem solving, creativity, and analytical thinking, will be indispensable in the future working world [8]. Important goals for universities include reducing costs while improving the student experience and enhancing learning outcomes.

Overview. Immersive digital applications are particularly well-suited to STEM subjects that require spatial understanding or involve teaching abstract content [9], [10]. Consequently, they are particularly useful in disciplines such as architecture, engineering, geometry, chemistry, and the natural sciences in general [11], [10], [12].

In order to successfully utilize VR applications in university teaching, the barrier to entry must be low. This was the objective of the “Interactive Teaching in Virtual STEM Labs” project at Berliner Hochschule für Technik (BHT, University of Applied Sciences). As part of the project, the campus library has set up a VR zone where university members and visitors can give various VR applications a trial, independently or with technical support. Furthermore, in April 2025, the library began lending out head-mounted displays. This allows teachers and learners to solve tasks independently, experience other applications, and even develop VR learning environments for their purposes (if they have the necessary programming skills).

Several Immersive VR Learning Environments (IVRLE) were developed, and access to further IVRLE was organized, including ENGREDUVR from the University of Georgia (see next section). As part of the project, an IVRLE for the representation and analysis of functions of several variables was developed in order to illustrate complex mathematical relationships and promote spatial visualization [13], [14]. Similarly, an IVRLE was developed for acquiring skills in statics [15]. This IVRLE enables students to experience the theoretical content of engineering mechanics lectures for event technology (e.g., lamps, cameras, speakers) in an immersive practical approach. In contrast to reality, the shear force and bending moment curves are visualized in real time together with the supporting structures.

VR in a laboratory course on mechanics of materials. The IVRLE ENGREDUVR from the University of Georgia [20] was developed as an open educational resource and is therefore free for other universities to use. It is currently easily accessible via the Meta Store. Furthermore, the team from the Interactive Teaching in Virtual STEM Labs project provides access to technical equipment and offers training in the technology, as well as general didactic support, quality evaluation, and technical assistance. Thus, it is easy for lecturers to use as part of courses.



Fig. 1. Real experiment with a theodolite—measuring the deflection of a crane bridge

As part of a course on stress measurement (experimental exercise in strength of materials), students examine a crane bridge for deflection and mechanical stress, among other things. They use strain gauges to determine the mechanical stresses. They measure the geometric dimensions of the crane bridge and its deflection under load with a theodolite (see Figure 1). An additional exercise using the theodolite involves a VR exercise with the land surveying app from the University of Georgia.

The app with an immersive VR training simulator had been designed and implemented to replicate the equipment and social experience of land surveying for undergraduate students. The background to this is the fact that performing accurate and efficient land surveys through hands-on laboratory experience takes time, space, and expensive equipment [20].

Although the specific application at BHT does not involve land surveying, students have provided very positive feedback on the use of the app in the course. In addition to having the opportunity to practice working with a theodolite, students also praise the opportunity to practice using virtual reality.

2.2 Smartphone as a sensor for engineering dynamics

The Phyphox app, developed by RWTH Aachen University, provides an easy way to conduct physics experiments using the built-in sensors of smartphones. Detailed information on Phyphox and references to many papers can be found on the website <https://phyphox.org/de/referenzen/>. Among numerous publications, we would like to refer to [21] (literature review) and [22] (use in physics lessons at school).

The Phyphox app was originally conceived as a tool to support physics lessons in schools. However, it is also useful for engineering programs at the university level. Basic courses in engineering mechanics often lack laboratory exercises, yet every student has a smartphone. Using the app provides students with the valuable experience of conducting their own experiments without the need for laboratory equipment or staff. Of course, this requires teachers to provide well-founded tasks, at least initially.

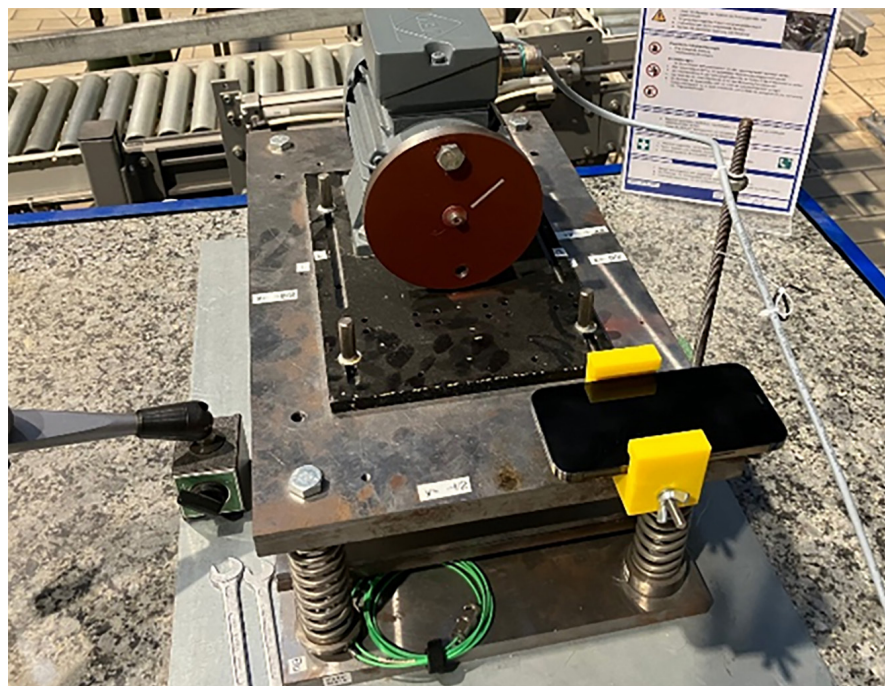


Fig. 2. Test bench for investigating foundation vibrations

One of the authors uses the app in the basic courses of kinematics and dynamics (engineering mechanics 2 or 3, depending on the specific program) and in advanced courses. One example for the basic course is the elevator experiment. Students are supposed to find an elevator in a tall building and record the time sequences of height (from a barometer), velocity (time derivative of the height signal), and acceleration (from an acceleration sensor). They then numerically integrate the acceleration signal over time using the Julia programming language and finally compare it with the velocity signal. In another experiment, the smartphone is mounted on a test bench using a specially made cell phone holder (see Figure 2). The accelerations and angular velocities of the mechanical system when it is bumped are recorded with the Phyphox app. A fast Fourier transformation of the signals is then performed with Julia with the aim of identifying the natural frequencies of the system.

2.3 GenAI for programming as a game changer for engineering mechanics education

Learning engineering mechanics using only pen, paper, and a pocket calculator, thereby avoiding programming in the introductory mechanics courses—is that still appropriate to date? The authors think “No.”

Preparing students for the working world of tomorrow, a reorientation is proposed that closely links the three subjects of mechanics, programming, and mathematics. The use of a programming language from the first year opens up new possibilities in the mechanics courses and for the entire program. The programming skills taught are not aimed at training software developers. Rather, it is about the skills required for processing simple and moderately difficult mechanics assignments, including the evaluation and visualization of measurement data. To emphasize it again: it is about using the programming language Julia as a powerful scientific calculator. It is not about developing software.

Typical use cases for programming are solving systems of linear equations (for example, in the first statics course), plotting diagrams (throughout all courses), or solving initial value problems (for example, in the first dynamics course). Figure 3 shows an example from a mechanics of materials course: the shear stress distribution in a column with a rectangular cross section under torsional load is plotted, providing students much more insight than the two formulas for the shear stresses.

Using numerical methods and programming might not be new; however, two aspects are new: the easy availability of GenAI tools for programming support and the easy availability of automatic differentiation in programming languages such as Julia or Python. GenAI tools are game changers when it comes to programming. While many people might have software developers in mind, programming has become much easier for engineers and students in engineering programs. With appropriate methodological support, students can develop a working code in a short amount of time. Problems such as the kinematics and dynamics of a four-bar-mechanism can be quite easily studied when programming skills and a suitable programming language such as Julia are at hand.

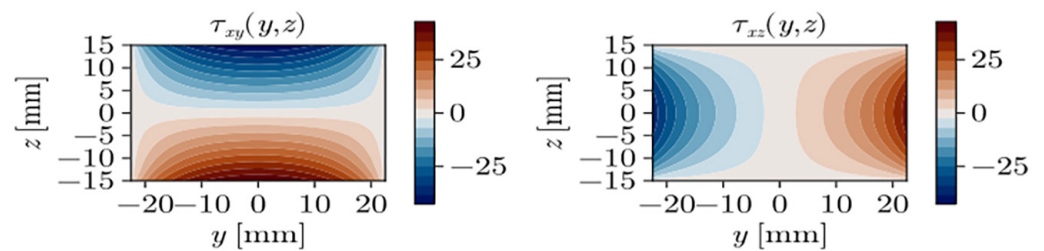


Fig. 3. Shear stress distribution in a column with a rectangular cross section under torsional load—plotted with Julia

Automatic differentiation, the third method for calculating derivatives alongside numerical and symbolic differentiation, is hardly used in engineering mechanics courses but has the potential to have a lasting influence on the teaching of mechanics. Derivatives are required in many areas of mechanics. For example, in the basic course on dynamics, they are used to determine velocity and acceleration from the distance-time law. Derivatives are used in all kinematic analyses, whether for mechanisms, robots, or machine drive trains. In addition to calculating (angular) velocities and (angular) accelerations, automatic differentiation can also help solve nonlinear constraint equations. When setting up equations of motion using Gauss's principle, the restraint or compulsion function (in German: Zwang) must be differentiated with respect to the generalized accelerations. Here as well, automatic differentiation can be very handy. Many examples can be found in the dynamics textbook written by one of the authors, Geike [23]. The book chapter by Geike [24] provides a more in-depth discussion on why programming should be used, accompanied by many examples from engineering mechanics and tribology, including initial value and boundary value problems as well as analysis of measured data.

A side note: In our experience, the use of programming languages in basic courses often fails because installing and setting up the necessary programming environment on students' computers is time-consuming and sometimes even fails completely. The Julia programming language, together with the Pluto Notebook, seems to be the answer here. In fact, a fully functional working environment can be created in just a few minutes. Julia is available free of charge for virtually all relevant operating systems. The Pluto Notebook takes care of package management. In addition to the easy installation, using Pluto makes it easy to create documents that contain explanatory text, computer code, pictures, and diagrams.

3 RESULTS AND DISCUSSION

How can we determine that the teaching concept works and delivers better results than traditional mechanics courses? First of all, the course evaluations indicate that students are motivated by the practical examples and that they spend slightly more time on the courses overall. However, the increase in time is relatively small compared to the additional content. This means that we can assume that the new content takes up some of the time previously spent on pencil-and-paper exercises.

Under the new teaching concept, exams consist of written tests taken in class (as a final exam at the end of the semester or as tests accompanying the lectures) and homework assignments. The results of the written exams show no change compared to previous sessions (with the same lecturer). This suggests that the introduction of programming and additional experiments (with the Phyphox app) has

no negative impact on the ability to solve standard problems with pen and paper. The fear of sacrificing basic skills in order to introduce new content seems unjustified. Instead, it is possible to teach additional content without losing the standard skills everybody would expect after taking the respective courses. One explanation, as indicated above, is that the new content provides a boost to motivation and that the opportunity to experiment with solutions is conducive to understanding. This compensates for the reduced time available for practicing with pen and paper.

The homework assignments show that students are able to solve problems using appropriate programming languages even in their first year. In some cases, programming (including the processing of measurement data) presents a major hurdle for students. However, based on numerous assessments and feedback discussions, it can be concluded that the greatest hurdle in homework assignments is the correct application of mechanical laws (and not the struggle with the programming language).

In contrast to the traditional approach with pen and paper, students are now able to perform technical calculations using a suitable programming language at the end of the courses. In dynamics, they are able to solve initial value problems and non-linear constraint equations numerically. Students also report that they were able to use the acquired skills to solve practical mechanics problems in subsequent courses.

In his own courses in higher semesters, one of the authors also notes that students have better skills in solving complex technical calculations when they took mechanics courses with programming included. Students who attended the combined course (mechanics with programming) outperformed students who took traditional mechanics courses and a separate programming course. In fact, pure programming courses for engineers are often not very effective if the skills learned are not immediately applied in engineering courses.

The impact of immersive technologies on learning success in higher education is currently evaluated positively [9], [10], [11], [16], [17], and comprehensive overviews are published [18], [19]. However, this has not yet been thoroughly researched, so it cannot be answered in general terms. Instead, it must be evaluated on a case-by-case basis.

In the Interactive Teaching in Virtual STEM Labs project, the impact of the mathematics VR application for presentation and analysis of functions of several variables (see above) was investigated. It became apparent that learning in a VR environment can be more fun compared to other digital learning experiences. An experimental study with 41 students showed that students learning multivariable functions with a Mathematics VR application rated this learning experience as significantly more fun and interesting. They perceived their own competence significantly higher than students who solved exercises on a comparable two-dimensional tablet application. However, this study was not able to show significant differences between the two groups regarding knowledge gain (as measured by comparing individual test scores before and after the learning experience), topic-specific intrinsic motivation, or perception of usefulness [13].

4 CONCLUSION

This paper explores how emerging technologies can enhance engineering mechanics education, a field often perceived as difficult by undergraduate students due to its abstract and mathematically demanding content. Traditional teaching approaches struggle to motivate learners and demonstrate practical relevance.

To address these challenges, the authors propose integrating three technologies into introductory mechanics courses: VR, smartphones as measuring devices, and programming supported by GenAI tools.

VR: Immersive environments allow students to interact with complex mechanical concepts and laboratory tools in accessible, cost-effective ways. It is particularly relevant when haptic tasks are to be trained (e.g., working with a theodolite) or spatial visualization is needed.

Smartphones as sensors: Using apps such as Phyphox, students can conduct hands-on experiments in kinematics and dynamics without the need for expensive equipment. This makes experimentation more accessible and engages students in real-world problem-solving.

GenAI-supported programming: Introducing programming from the first year enables students to tackle complex problems beyond pen-and-paper methods, such as solving differential equations, analyzing experimental data, and visualizing numerical results. GenAI tools lower the barrier to coding by providing scaffolding and accelerating problem-solving. The Julia programming language and the Pluto notebook are very well suited also for first-year students.

The use of these technologies not only makes learning more motivating but also prepares students for a digitalized engineering profession. Early exposure to programming, GenAI tools, VR, and smartphones as experimental tools fosters digital literacy, creativity, and analytical skills.

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