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# Combining mathematical revision courses with hands-on approaches for engineering education using web-based interactive multimedia applications

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**Abstract**

In engineering education, it is beneficial for students to acquire practical experiences with real-world relevance. Although solving engineering problems requires the comprehension of the mathematical backgrounds, many practice-oriented teaching approaches concentrate on the practical engineering part, but neglect the underlying theory. This work combines enhanced theoretical learning with practical experiences through interactive multimedia applications in the context of robotics. It consists of a blended learning scenario which offers at least a threefold benefit: It supports teaching of theoretical and methodological aspects. Required background knowledge in mathematics and physics is directly available. And acquired knowledge can be brought to life by programming tasks and visualizations. Interactive 3D visualizations and web applications illustrate complex technical facts and Matlab or Octave code, respectively, can be executed online for computations and simulations. All offers are accessible 24/7 via web browser without any dependency on additional software. Beside for integration in classroom teaching, the platform can be individually used by students for targeted learning and filling of knowledge gaps. As e-learning platforms are highly accepted by students and have a positive influence on the students' performance, we expect to enhance our teaching with the new platform providing practical and theoretical offers tightly linked together.


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## 1. Introduction

The American Engineers' Council for Professional Development had once defined "engineering" as *The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, …* (Engineers' Council for Professional Development, 1947). In spite of this orientation to applications today's engineering programs still concentrate on teaching of theoretical and methodological aspects of engineering very often neglecting their application to real-world problems. On the contrary experts on engineering education have emphasized that efficient learning environments should have real-world relevance and encourage meaningful reflection on authentic tasks (Herrington, Reeves, & Oliver, 2014). The implementation of this demand contrasts with the requirement of thorough mathematical knowledge to solve engineering problems (Firouzian et al., 2014). Therefore practice most effectively enhances permanent and applicable knowledge if the underlying theoretical fundamentals are priorly known and comprehended.

In undergraduate engineering degree programs mathematics and technical courses are typically taught in parallel. Starting with fundamentals, the respective contents are developed over the semesters independently or build up on other courses of the same program. On the level of master's programs it should be easier to incorporate practical aspects: sound engineering qualifications and advanced mathematical knowledge as basis for further technical concepts should be existing. Nevertheless, master's students are often no longer able to apply mathematical fundamentals acquired in the first semesters of undergraduate programs (Rojko, Jezernik, & Španer, 2003). If international students are present the problem becomes even bigger: due to differences in undergraduate degree programs, the gap between expected and prevalent mathematical knowledge gets wider. Hence, the heterogeneity of the students' knowledge exacerbates the theoretical classroom teaching as well as the usage of laboratories for practical experiences.

## 2. Teaching robotics

In robotics courses the need for hands-on approaches is obvious. Many practice-oriented teaching approaches follow the learning-by-doing principle. Rubenstein, Cimino, Nagpal, and Werfel (2015) provide personal robots to the students for introductory programming and robotics teaching. This allows for individual implementation and testing of algorithms both at university and at home. But since only simple low-cost robots are affordable for students, possible applications are limited to basic functionality. For further applications, more complex robotic manipulators (Gutiérrez, Reséndiz, Santibáñez, & Bobadilla, 2014) or entire robots (Weinert & Pensky, 2012) are required, which leads to high financial demands and restricts the usage geographically to the university or laboratory, respectively. To face the access problem, real experimental setups often are accessible via internet and can be controlled remotely through an interface. These remote laboratories (Prada, Fuertes, Alonso, García, & Domínguez, 2015) offer practice independent of time and place, assuming a computer running the required software. The drawback of remote laboratories is, however, that the number of concurrent users is limited to the number of available real setups (usually one). Thus their usage is not really time-independent, but dependent on the number of possible users, their usage frequency and the average time of occupancy. Dogmus, Erdem, and Patoglu (2015) have presented an interactive virtual tool usable without real hardware to configure and simulate robot applications. Users do not need to know about the implementation and mathematical details, but can concentrate on the actual functionality and its outputs. Drawback of such approaches is the necessity of installing the software on a computer, which increases the inhibition threshold of students to use the offer. Some virtual labs even require industrial or commercial software packages (Gonzales, Mahulea, & Kloetzer, 2015) limiting the usage to computers in the university or involving a great deal of expense.

All these practice-oriented approaches focus on the engineering part and provide practical experience, but neglect the underlying mathematics and physics. Therefore, many universities provide extracurricular mathematical bridging courses, what involves a high workload for students as well as for teachers. One approach that addresses the mathematical fundamentals integrated in an engineering course is presented by Rojko et al. (2003). The authors provide a web page with additional material to the related undergraduate robotics course including explanations of

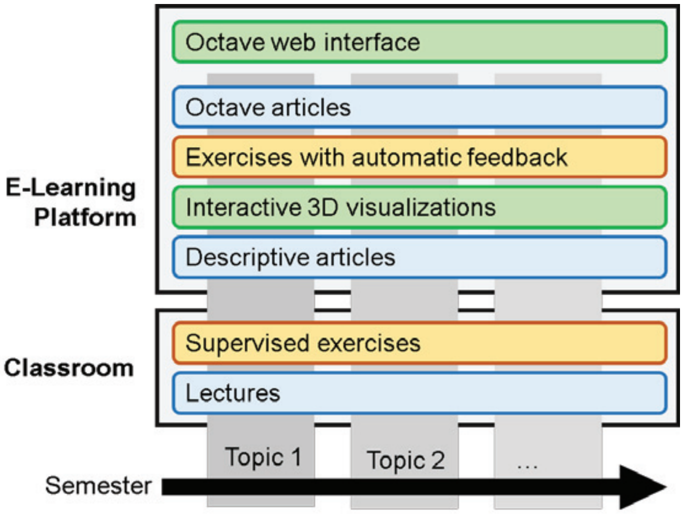


Fig. 1. Classroom teaching combined with topic-related e-learning and integrated practical use of knowledge.

mathematical and physical background knowledge. Recently, Rojko, Bauer, Prochazka, Pazdera, and Vitek (2015) presented a learning management system (LMS) with integrated remote and virtual experiments related to certain course contents.

In this paper we pursue a similar blended learning approach at Paderborn University, currently exemplarily for a *Robotics* course used also within international master's programs. The course consists of lectures and exercises. The content includes coordinate transformations using quaternions and direct and inverse kinematics. To address the mathematical problems of the students, our online learning platform similar to one presented by Hennig, Mertsching, and Hilkenmeier (2015) has been set up and extended by additional features. Our platform provides theoretical as well as software-related practical offers without depending on software except a common web browser. On the one hand, the platform is used for short digressions during classroom teaching to clarify complex statements. On the other hand it provides the possibility to individually learn and close knowledge gaps by purposefully using the offers related to problematic topics. Thus the platform supports balancing the heterogeneity of the students' theoretical knowledge while additionally allowing the students to directly make practical experiences using their knowledge through interactive web applications and tools.

## 3. Methodology

The online learning platform is based on the software *MediaWiki* (MediaWiki, 2016), which is also used for the well-known encyclopedia Wikipedia. The basic setup and its relation to the classroom teaching are shown in Fig. 1. Due to the heterogeneous backgrounds students demand help for different topics or individual aspects of topics. All the contents of the platform are thus subdivided into short chapters corresponding to the subtopics of the course contents. The individual consecutive chapters can be accessed in topical order through a navigation bar at the top of each article. Additionally articles building on one another are directly linked within the text, like it is known from Wikipedia. Fig. 2 exemplarily shows the top part of an article including the navigation bar and several links highlighted in blue leading to related articles and further offers within the platform. This structure supports the targeted use of certain topic-related offers based on the students' demands and prevents unnecessary processing of already known facts. Each chapter contains descriptive articles explaining the problematic topics with focus on the background mathematics and provides additional situated explanations and meaningful examples. Short exercises for each chapter can be processed online. Through immediate feedback showing and explaining the solutions, the students can directly check their knowledge (see Fig. 3). In the last semesters, it was observed that e. g. quaternions, which play an important


Fig. 2. Screenshot of the top part of an article with the navigation bar on top and links to related articles, exercises (green box) and the corresponding Octave and Matlab article (yellowish box).

role in robotics, are extremely difficult to understand. As quaternions are a four-dimensional number system including imaginary units, theoretical explanations are usually not sufficient to completely comprehend their functionality and meaning. Therefore interactive 3D visualizations based on WebGL and JavaScript similar to the ones presented by Hennig, Gaspers, and Mertsching (2013) are provided as applets allowing a broader understanding of the related technical facts. Fig. 4 shows such an applet visualizing the relationship of quaternions and the easier-to-understand yaw-pitch-roll angles to describe the rotation of an object. The students can use the applets to test different parameters or configurations, change the 3D viewpoint and so see the actual effect of their theoretical knowledge in practice.

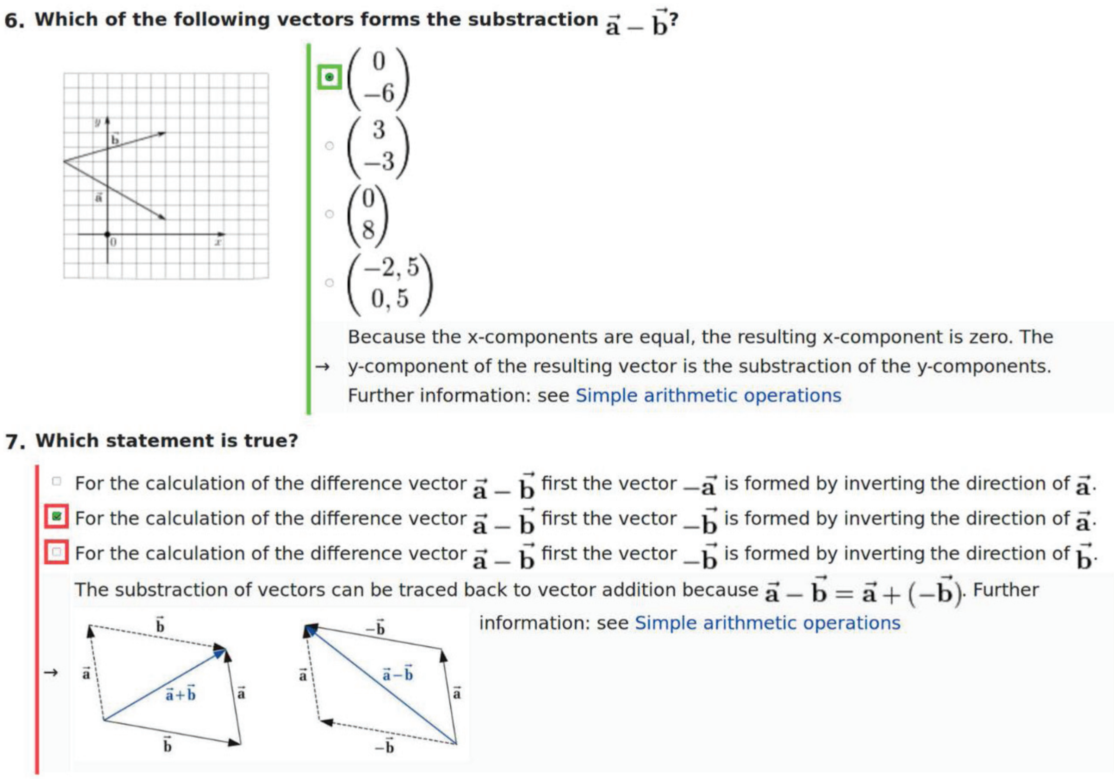


Fig. 3. Screenshot exemplarily showing an example of exercises solved online on the platform with immediate feedback explaining the correct solutions and linking to the related articles.

To gain practical experience we use the open-source Robotics Toolbox for Matlab (Corke, 2011) which allows the computation and visualization of transformations, kinematics and many other aspects. To allow for unlimited access, the freely available software Octave (Eaton, 2016) is used that provides almost the same functionality as the commercial Matlab software and supports the relevant parts of the Robotics Toolbox with little restrictions on the visualization. The toolbox functions for Matlab or Octave applicable for certain topics are explained in additional articles that are directly linked in the related theoretical articles (see yellowish box in Fig. 2). A particularity of our approach is the web-based execution of Octave code on the platform without the necessity of installing any software or plugins on the user's device. Through a framework (Octave Web Interface, 2016) integrated on the platform, the students can enter code and execute it on the server. The results are then displayed within the framework. As exemplarily shown in Fig. 5, serial link manipulators can be simulated with Matlab (left) and the Octave interface can be used to compute forward kinematics (right). Each Octave article comes with a navigation bar linking to the web interface, general Octave instructions, other Octave and related theoretical articles (see Fig. 6). Due to this well interconnected organization, the learned knowledge can easily be applied and tested through practical computations and simulations.

During classroom teaching, the multimedia offers of the platform are used to illustrate certain difficult facts and to present practical applications. Consequently students get familiar step by step with the applets and the Octave interface whereby the inhibition threshold to individually use the offers for learning decreases. Besides the links within the platform, all the offers are tightly linked with and can dynamically be invoked out of the course material (see Fig. 7). So each student can easily make use of the articles, visualizations and practical applications where needed. Hence using the wiki is not time consuming extra work, but targeted learning support. The whole platform including the Octave interface is accessible at any time and location-independent on any device like computers, notebooks, tablets and even smartphones without installing any software except a common web browser.

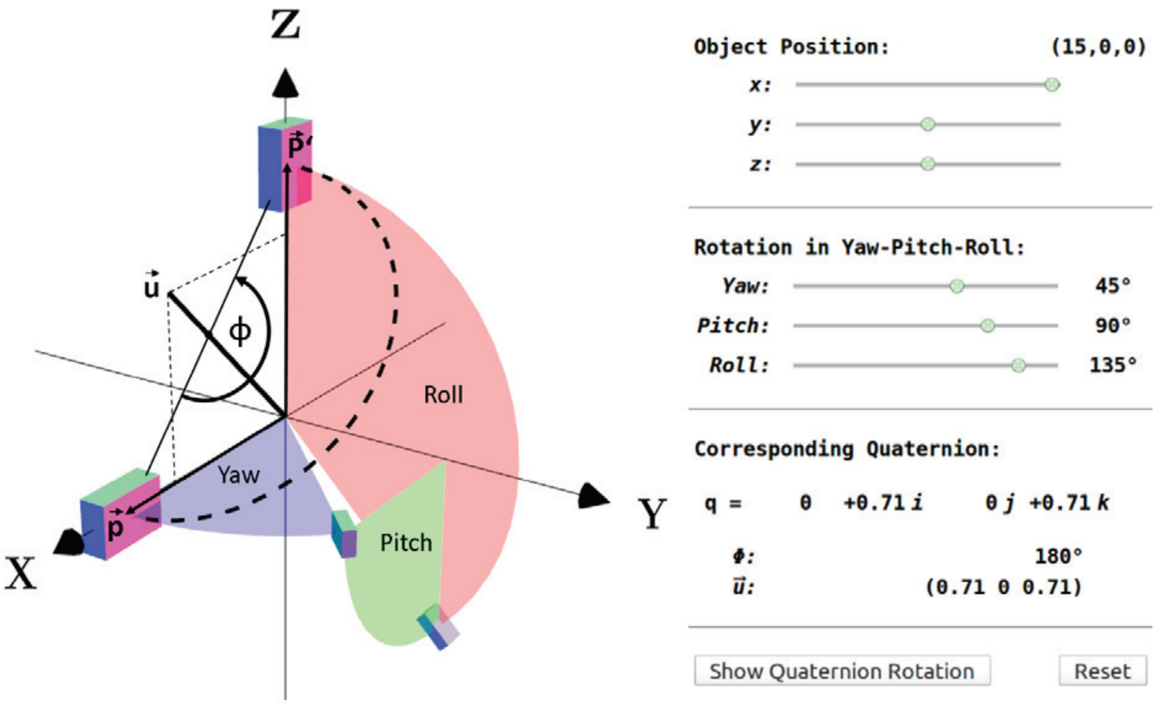


Fig. 4. Screenshot of an applet to visualize the relationship of yaw-pitch-roll angles and quaternions. Parameters are set through the interface on the right side. The successively applied yaw (blue), pitch (green) and roll (red) angles are displayed as parts of circles. The axis of the related quaternion is visualized as a black line marked with u. The dashed curved line corresponds to the trajectory of the object while it is rotated by the quaternion.

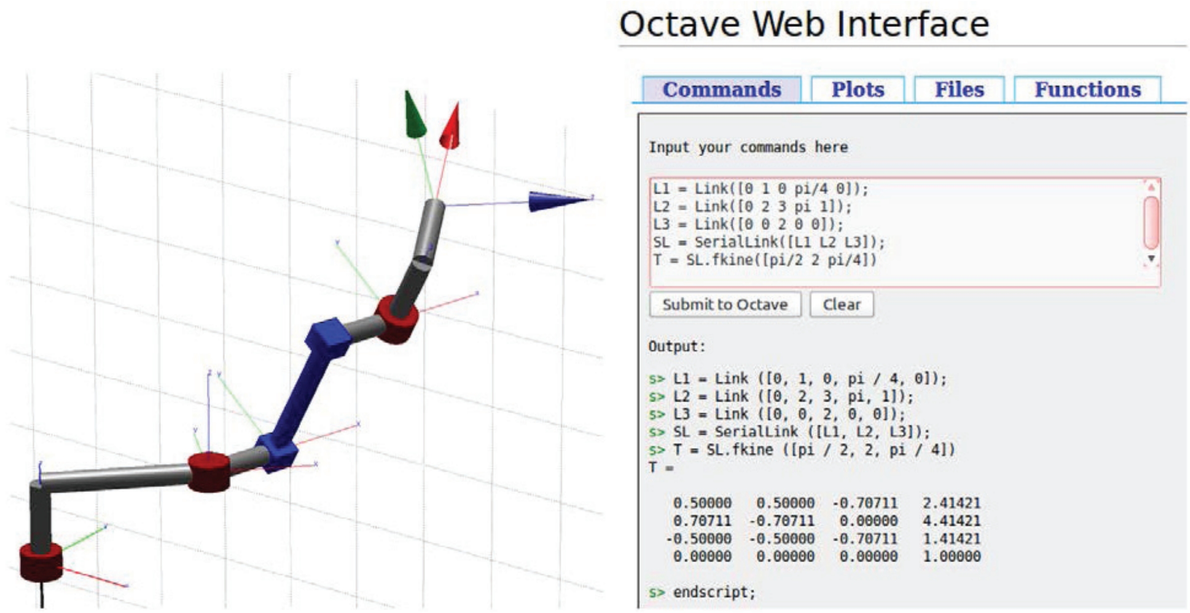


Fig. 5. Screenshots showing examples of the usage of the Robotics Toolbox in Octave and Matlab. Left: Simulation of a serial manipulator with Matlab. Right: Computation of forward kinematics using the Octave web interface.


Fig. 6. Navigation bar of an Octave article linking the web interface, instructions and other articles.

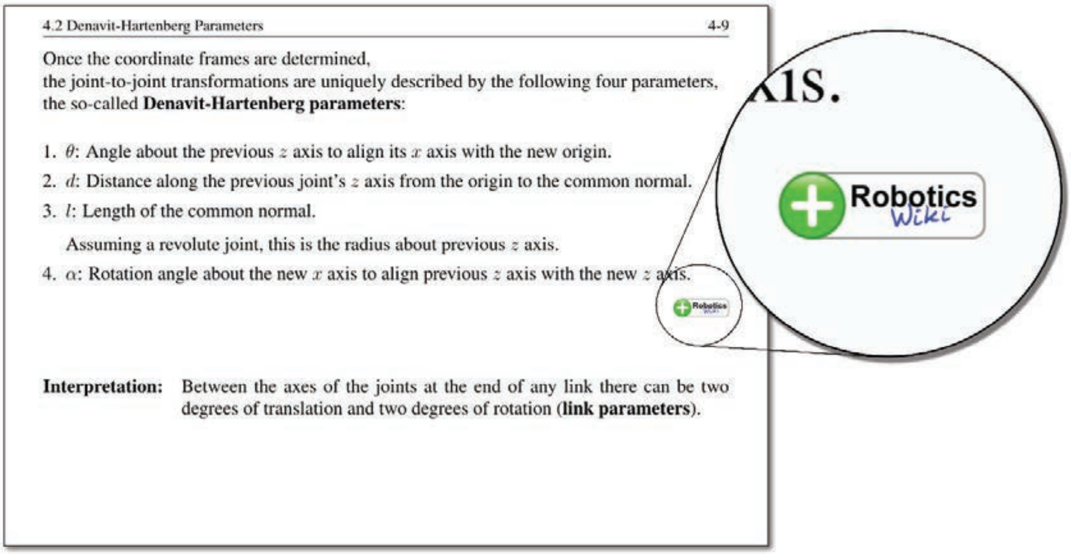


Fig. 7. Example slide of the lecture notes with interactive link to related article on learning platform.

## 4. Discussion

As the *Robotics* learning platform is still under development and only partially integrated in a first version in the teaching yet, its evaluation is continuing. It could already been shown within an undergraduate electrical engineering course that a wiki platform integrated in the teaching is highly accepted by students (Hennig et al., 2015). 60% of the course participants used the platform throughout the semester. The introduction of the e-learning offer had a positive influence on the students' performance as the failure rate of the final exam dropped from 38% in the previous semester to 24.2% without changing the requirements. It was also shown, that students who had problems but used the platform performed significantly better than the ones with problems not using the platform. We therefore expect a high acceptability of the presented approach and an increased effectiveness of our teaching. The theoretical learning of mathematical backgrounds tightly linked with multimedia applications and practical experiences deepens the students' knowledge and increases their motivation. Thus the overall performance will be enhanced and the students will be better prepared for their future work as engineers.

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