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Smartphone Apps for Learning Progress and Course Revision ⋆

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Abstract: Smartphones as our permanent companion seem to be an expedient choice for the implementation of e-learning tools in the form of smartphone apps due to their convenience and accessibility. We hence present two recently published smartphone apps that were developed for an introductory control course. The apps serve the purposes of (i) improving learning progress and (ii) revision of course content between lectures. In this paper, we explain how the apps align with our lecture *Introduction to Automatic Control*, put them into context of our e-learning strategy and describe our pursued goals. Moreover, a survey among third year control students is discussed, which supports the presented approach. Finally, we discuss and compare the mean (smartphone app) to other measures, considering both content and goals.

Keywords: Control education, educational games, e-learning.

1. INTRODUCTION

The integration of digital solutions in our everyday life has become self-evident. For decades now computers have been the main platform used at the workplace and over the last decade smartphones have become a perpetual companion to large parts of the society. Digital solutions are meant to facilitate life and improve the standard of living and appear in multiple sectors such as smart homes and smart factories, but as well in the education sector in the form of interactive e-learning tools. Along with digitalization in many fields, the number of smartphone apps that help us in everyday life is rising. Consequently, smartphones are a suitable platform for e-learning tools and the main focus of this paper.

Beside the choice of the e-learning platform there exist various approaches for overall e-learning strategies and concepts. Digital solutions can be established as self-contained classes, such as massive open online courses, but also as a supplement to classes that are well aligned with them. Here, integrating e-learning tools into the overall concept is key for their success. E-learning has advantages for both students, as it is accessible at any time and from any place which allows self-paced learning and high flexibility, and lecturers, as interactive tools may offer ways for clearer demonstration through the integration of animations or automatic generation of new examples. To make the most of these advantages, e-learning offers should have a clearly defined objective such that they are the solution to a problem rather than just exploit existing technology to full extent. It is essential to clarify who your target group is and what your objective is, e.g. motivation, routine, providing an outlook to the students. This requires careful analysis beforehand and a clear concept and strategy.

In recent years, many ways of supporting lectures through e-learning have been introduced. While educational videos are useful to compress information and stress important aspects, there are also approaches for interactive e-learning tools. Traditionally, tools have been developed for computers which is the preferred platform especially for more complex tasks with several figures potentially requiring a full screen. One of the most popular softwares in control systems education in this respect is Matlab that can effectively be used for e-learning tools (e.g. Dormido et al. (2005); Münz et al. (2010); Koch et al. (2020)). More recently, integrated development environments (IDEs) such as Sysquake and Easy Java Simulations gained more attention and have been successfully used to develop interactive control education tools (e.g. Guzmán et al. (2012); Díaz et al. (2019)). These IDEs come with the advantage that they are stand-alone applications and do not require software installations such as Matlab. Another example for smartphone apps in control education is an interactive textbook by Quanser called experience controls (Quanser (2019)). For a broader review of e-learning activities in control courses and more general interactive control design, the reader is referred to the survey paper by Díaz et al. (2019).

We developed two smartphone apps for our introductory class in automatic control, one providing mini quizzes that can be solved between lectures, for example on the train or bus. They give feedback to the students if they have understood the basic concepts of the previous lecture and help them keep track of the course. The other smartphone app is on the Nyquist criterion and meant for the students to gain practice by applying it to randomly generated examples. Both are available on the Apple App Store and Google Play Store and the respective links can be found on our website (Institute for Systems Theory and Automatic Control, University of Stuttgart (2019)).

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This paper is organized as follows. In Section 2, we briefly describe the course *Introduction to Automatic Control*. In Section 3, we outline our e-learning strategy explaining our goals and means. In Section 4, we then introduce our newly developed smartphone apps, one on the Nyquist criterion and one for revision of former lectures. In Section 5, we present survey results and finally, we draw conclusions in Section 6.

2. INTRODUCTION TO AUTOMATIC CONTROL

Introduction to Automatic Control is an introductory course on automatic control taught at the undergraduate level at the University of Stuttgart. The class covers the basics of analysis and control of linear time-invariant systems in the time and frequency domain, e.g. closed-loop systems, stability and robustness margins, loopshaping, pole placement, and controllability and observability. About 100-150 third year students with different backgrounds and career programs, being engineering cybernetics, mechanical engineering, mechatronics etc., take this class every year. For all of them it is the first class on automatic control. While for some students it is the only class in control, for others it is the first class in their specialization field. Our goal is to educate all students with different backgrounds as well as possible.

Therefore, the lecture and all lecture materials are clearly structured and categorized either as basic knowledge or advanced knowledge. The list of contents, all exercises and the exam questions are clearly marked as either one or the other. It is hence made transparent to the students what is expected for passing the exam and what is expected for higher grades. In this paper, we will describe how our e-learning tools support our lecture further.

3. E-LEARNING OBJECTIVES AND STRATEGY

At the Institute of Systems Theory and Automatic Control at the University of Stuttgart, we offer diverse e-learning tools. Mostly, they are supplementary to the course *Introduction to Automatic Control*. More specifically, we can divide the various tools into the following categories: educational games (Münz et al. (2008)), MATLAB apps (Koch et al. (2020)), and smartphone apps that were finalized and published only recently and are the focus of this paper. Judiciously, the objectives and target groups of the tools differ from one tool to another. Yet, everyone of these tools was developed for a thoroughly analyzed reason and they all serve a certain purpose. In this section, we elaborate on our motivation, objectives and the underlying strategy that led to the aforementioned e-learning tools. Moreover, we explain how the tools complement our introductory course on automatic control.

Lectures are at the core of the educational framework. This is where information is delivered and explained in detail and where everything is put into context. However, if the newly learned information is not revised and practiced appropriately, it is difficult to grasp for the students and they are likely to forget the theoretical concepts. This is not desired as the lecture builds on that knowledge and adds on it every week. For that reason, it is important to support the students in their studies of the course and to offer well-organized supplements to the lecture such that they can apply the learned methods themselves. Of course, tutorials, exercise sessions, and projects are helpful in this respect but for some methods interactive e-learning tools might be even more suitable. Interaction with other students and instructed tutors engages discussion and builds an important part in the learning process whereas e-learning is a powerful aid for certain other problems, e.g. when it is beneficial to generate a large number of random examples or for simple revision questions. This was realized in our smartphone apps. Altogether, the lecture, the exercise sessions, laboratories, projects and finally e-learning make the module *Introduction to Automatic Control* diverse, insightful, and complete. Hence e-learning is part of a wider effort of the whole course wherein the single parts of the module have to harmonize and build on each other and are tightly intertwined.

3.1 Objectives of e-Learning Tools

There can be multiple reasons and approaches for e-learning tools that have to be clearly defined before the development of the respective tool. We embrace a student-centered approach, i.e. that we take the students' direct and indirect feedback seriously, pair it with our experience and knowledge of the course material and from there develop ideas on e-learning. Direct sources for feedback are evaluations of the lecture and the students' comments, whereas indirect feedback comes from the assessment of exercises and exams as well as directly from the students' questions in exercise sessions and during the lecture. From these sources, lecturers can draw conclusions and analyze carefully what problems and difficulties the students have in their class. Looking at the students' performance, is a by far more expressive feedback than the judgment of the lecturer on the material they cover. While it is the first time the student is in contact with the new material, the lecturer is a specialist in their field and most likely has a different sense of what is most difficult. Once this analysis of problems has been performed, one logical goal of an e-learning tool can be to have an additional offer on the most problematic topics of the lecture.

Hence, our e-learning tools were developed to help students exactly where difficulties are. Material that is in general well understood needs no additional e-learning. Given the recent advances in technology, it is recommended to exploit this technology for the implementation of e-learning tools such that they run smoothly and that its use is intuitive and easy. However, e-learning tools should not be implemented without careful analysis. Otherwise, they become obsolete even though technologically impressive and nice to look at. In our opinion, e-learning tools should only be developed if they serve a purpose.

One of these purposes can be the motivation of the students in order to generate more interest in the course. E-learning tools can potentially be designed as games. In the case of the lecture *Introduction to Automatic Control* this was done by Münz et al. (2008) in the form of motivational games. Here, students have to control the movement of submarines, spaceships and airplanes by following a predefined trajectory. The horizontal speed is constant and the vertical speed can be adjusted with the mouse. Here, the underlying model of the vertical position is a double integrator. The dynamics are hence unstable which makes this problem a difficult control task. After steering the object themselves, the students can design controllers for the same problem and will see that the controllers do a much better job. We hope that this game gets them fascinated by automatic control and motivates them to learn more about it.

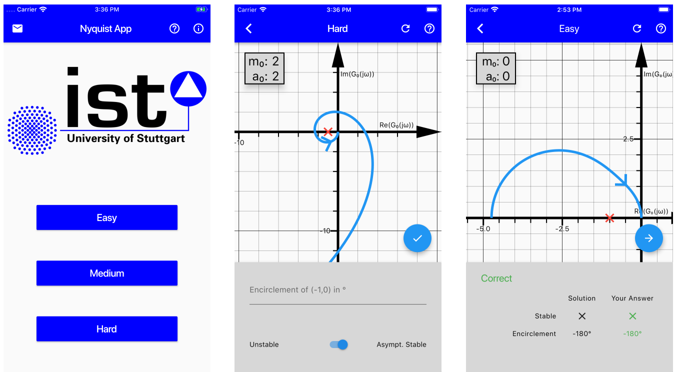
In addition to that, our recently developed quiz app is a fun and motivational mean that is supposed to motivate the students as well as support them in keeping track of the course throughout the semester. Our highly appealing smartphone app provides mini quizzes with short questions on the previous lecture. This way, the students have an accessible mean, their smartphone, and an expenditure of time of less than five minutes, but will get feedback if they need to revise the lecture in more depth. Experience shows that it takes too long for some students to unpack the lecture notes and revise them between lectures and that, in general, they take only little time to rework or prepare lectures. But using an app on the phone hardly has any overhead.

Another goal can be routine and support in the learning progress. This can be achieved by designing interactive tools that generate infinitely many examples of a certain task. While in lectures, there is no time to give a large number of examples, e-learning programs can be used to randomly generate examples. Students can use the tools to train their skills on as many exemplary tasks as individually necessary and get instant feedback on their solutions. This helps the students to apply the theoretical concepts on examples and develop a routine which reinforces their knowledge of the theory. Our MATLAB apps (Koch et al. (2020)) as well the second smartphone app presented in this paper serve this purpose. The MATLAB apps are on the topics of the Nyquist criterion, stability and robustness margins in the frequency domain, controller design via loopshaping, and controllability and observability. The students had difficulties with all of these tasks in the past which is the reason why we developed the apps. Our smartphone app also covers the Nyquist criterion. It essentially contains the same tasks but is more accessible than the MATLAB app and has a more modern interface and additional features like zoom.

3.2 Target Groups

Among the definition of the goal of an e-learning tool, it should also be clarified who to address with it. Here, again various approaches can be taken. Two obvious target groups are either (i) the students that have difficulties understanding the basic concepts or (ii) students that wish to fully understand the entire material and are interested in topics that go beyond what is covered in class. So for the first group e-learning is meant to help the students catch up with their peers and practice concepts by application or visualization. For the second group additional challenges can be created through e-learning such that they do not lose interest and expand their knowledge further.

The mini quiz app only covers questions on basic knowledge. They are supposed to be manageable without further efforts for everyone in the class who has followed the previous lecture. Our smartphone app on the Nyquist criterion is meant for the same target group. It is considered basic knowledge that the students are expected to apply effortlessly.



(a) Levels (b) Example task (c) Example answers

Fig. 1. Nyquist App.

4. SMARTPHONE APPS

Over the last decade smartphones have become an everyday gadget that most people cannot do without. Being available at all times and perpetual access to the internet has become an indispensable need for the majority of the members of our society. By now, looking up the weather, the use of dictionaries, buying tickets for public transportation is all facilitated via apps. Following this trend, we introduced smartphone apps that accompany our lecture *Introduction to Automatic Control*.

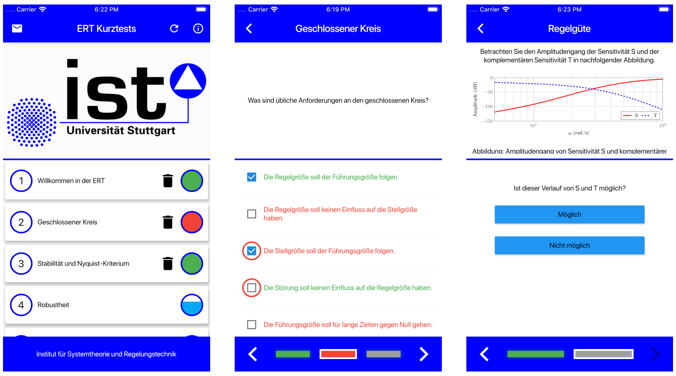
4.1 Smartphone Apps for learning progress

The main advantage of smartphone apps is that they can be used anywhere and at any time as long as you carry your smartphone with you. Therefore, they are a suitable mean for practicing concepts of the lecture and hence for learning progress and routine. The apps can generate numerous random examples and the student is encouraged to practice over and over.

4.2 Example: The Nyquist App

The goal of our Nyquist app is that the students learn how to apply the Nyquist criterion. The students are to determine from the frequency response and the location of the poles of the open loop whether the closed-loop system is stable. The app contains three difficulty levels *Easy*, *Medium*, and *Hard* and supports English and German language. Since its release on May 6, 2019 it was downloaded 706 times from the Google Play Store and 487 times from the Apple App Store.

The Nyquist criterion says that the closed-loop is asymptotically stable if and only if the encirclements Φ of the open loop G_0 around the critical point $(-1, 0)$ satisfy the following condition $\Delta\Phi(G_0(j\omega)) = m_0\pi + a_0\pi/2$, where m_0 denotes the number of poles in the open right half plane and a_0 denotes the number of poles on the imaginary axis. The Nyquist app randomly generates transfer functions of the open loop plant G_0 whose Nyquist plot is drawn from



(a) Overview (b) MC question (c) Binary question

Fig. 2. Mini Quiz App.

$\omega = 0$ to $\omega = \infty$ together with the critical point $(-1, 0)$. The number of poles in the open right half plane and the number of poles on the imaginary axis are given. Using this information, the student has to identify the encirclements (in degrees) $\Delta\Phi(G_0(j\omega))$ of the critical point $(-1, 0)$ from $\omega = 0$ to $\omega = \infty$, and determine whether the closed loop is stable according to the Nyquist criterion.

The interface of the Nyquist app is shown in Fig. 1, where Fig. 1a shows the landing page where the student can choose between the three levels, Fig. 1b shows an exemplary Nyquist plot in the level *Hard* where the encirclements have to be entered and where there is a switch to indicate stability or instability, and Fig. 1c shows the instant feedback to the student's answer for the level *Easy*.

4.3 Smartphone Apps for revision

At university, full time students attend multiple classes throughout the week. Especially if a class is only given once a week, it may be hard to remember the last lecture's material at the beginning of the next lecture. This is where our mini quizzes come in. They are meant for the students to revise the previous lecture during the week, at their convenience and without a large expenditure of time. The mini quizzes very generally have the following different motivations:

- to encourage the students to pay more attention during the lecture
- to encourage the students to think about the control content outside the lecture room
- to increase the preparation time of the students for the next lecture
- to give the students some feedback about their understanding at a very high level of the last lecture

4.4 Example: The Mini Quiz App

We developed a mini quiz app called "ERT Kurztests" for the class *Introduction to Automatic Control* at the University of Stuttgart. This course is given in German which is why the mini quiz app is only available in German language. Since its release on October 17, 2018, it was downloaded 129 times from the Google Play Store and 112 times from the Apple App Store. After each lecture, a new mini quiz is uploaded to the app consisting of three to seven questions. In total, there are nine mini quizzes. The questions are designed for the students to answer them in less than five minutes and they receive instant feedback whether their answers are right or wrong. In the beginning of the following lecture, the answers to the previous mini quiz are discussed, building the basis for a short revision of last week's lecture.

The questions are designed to be easy to answer for students that attended the previous lecture and paid attention. If they are not able to answer the mini quiz questions they are advised to check their lecture notes and study the material in more detail to be able to follow the upcoming lecture. The mini quizzes only cover basic knowledge and are anything but self-contained but rather a supplement that serves as a reminder of the basic concepts. The app really only is an aid for students and may be used at a voluntary basis. The students' answers are not tracked nor analyzed, they only serve the purpose of providing feedback to the students.

The app was implemented on the basis of three different question types. The most common question type is a multiple choice question as shown in Fig. 2b, where multiple answers are provided to a question. Here, more than one answer may be correct. There also is the binary question type that is shown in Fig. 2c, where the student has to make a choice between two options, such as right/wrong, stable/unstable etc.. The binary question type allows for subquestions. By swiping to the right only the lower part of the question changes. There also is a drag and drop question, where symbols from a picture can be dragged and dropped into a list and thereby assigned to their corresponding name.

The footline, that can be seen in Figs. 2b and 2c, shows how many questions are left. After answering a question, the corresponding rectangle in the footline turns green if the student answered the question correctly or red if the student's answer was wrong. After finishing a mini quiz, a summary appears where the students see how many and which questions they have answered correctly. Going back to the landing page, the bubble next to the mini quiz that was just solved turns green if all answers were correct or red otherwise (cf. Fig. 2a). We believe that it is desirable for the students to turn all bubbles green - which means to get all answers right - so the colors serve as an incentive to retake the quiz and get all answers right the second time. The students can retake the quizzes as many times as they like.

4.5 Programming

Both the Nyquist and the mini quiz app were developed using Flutter. Flutter is an open source UI framework written for the programming language Dart that was published in December 2018 and is partly sponsored by Google. The main advantage of Flutter compared to technologies that are based on JavaScript and HTML is its noticeably better performance. Flutter apps are not executed in a browser, but directly in a natively realized virtual machine. Furthermore, no graphical OEM elements (native platform specific display elements) are used that are employed for instance in XAMARIN Forms. Instead, the entire user interface is described in Dart and rendered using the SKIA

Graphics Engine. This way, an identical presentation of the user interface is possible independent of the platform (iOS, Android, ...).

For the mini quiz app it was necessary to provide the mini quizzes on a server via http. This way the mini quiz questions can be inserted and changed flexibly at any time without the need of republishing the app. For this purpose, a short test model had to be developed that interprets the files available on the server correctly. Another difficulty was the representation of formulas and mathematical symbols. For this purpose, a language similar to LaTeXwas developed, that allows to include fractions, subscripts and superscripts of text.

5. SURVEY AND COMPARISON

5.1 Survey on mini quizzes

The mini quizzes are a long standing measure in the course *Introduction to Automatic Control* (cf. Schweickhardt et al. (2006)). Up to last year, the mini quizzes were given out on paper at the end of each lecture. In October 2019, we replaced the paper quizzes by the new format of a smartphone app. Hence, even though the app itself was only introduced recently, we have many years of experience with the mini quizzes. In this subsection, we provide the results of our yearly student evaluation of the lecture, focusing on the mini quizzes.

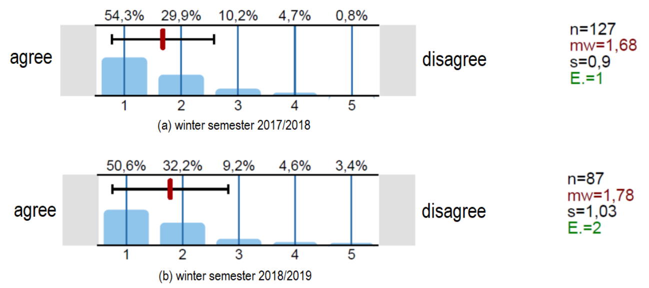


Fig. 3. Histogram of the student agreement with the following statement: *The distributed mini quizzes and their discussion at the beginning of each lecture help to understand the contents of the course.* The percentage above the histogram denotes the relative frequency of the response, the mean (mw) and standard deviation (s) are also plotted into the histogram. Further information given is the total number of answers (n) and abstentions (E).

The mini quizzes have always been very well received by the students. In Fig. 3, the result of the student evaluations of the last two years is presented. In both years almost half of the students fully agree that the mini quizzes and their discussion help them to understand and revise the content from the course. Furthermore, more than 75% of the students agree to this statement to a fairly large extent.

As this general concept has been a huge success, we were working on improving this measure even further resulting in the development of our mini quiz smartphone app. Given that the mini quizzes have successfully existed for many years, we are confident that the mini quiz app will be successful, as well. We even project it to be more successful due to the numerous advantages.

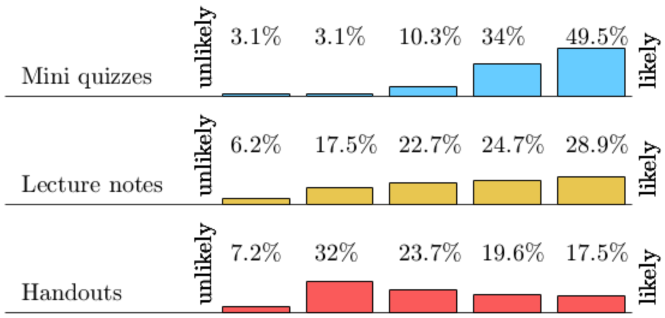


Fig. 4. Results on the question how likely students will look at the mini quizzes, their lecture notes or the provided handouts between lectures.

5.2 Survey on e-learning

At the Institute of Systems Theory and Control, we have implemented e-learning methods for many years now. Only recently, we expanded to the regime of smartphone apps by introducing an app on the Nyquist criterion and replacing our paper mini quizzes by a mini quiz app. The advantages connected to this change are manifold: Making it more flexible (time, place), and also more sustainable (no paper prints), immediate feedback, additional information, and a modern design. Except for the additional workload in programming and setting the app up, we do not see any disadvantage compared to the paper format. This is supported by the questionnaire-based survey presented in this subsection.

In a short survey consisting of seven questions, we asked the students of the class *Introduction to Automatic Control* about our e-learning offers, especially about our new smartphone apps. We asked them how likely they were to look at the mini quizzes, their lecture notes and the handouts offered on an online platform between lectures. Their responses are shown in Fig. 4. Out of 97 submissions, 48 students (49.5%) said it is very likely that they solve the mini quizzes between lectures, another 33% state it as likely while only 28.9% most likely regularly look at their lecture notes, and only 17.5% look at the handout provided on an online platform. We were aiming for a tool that almost everyone would use during the week as the overhead is minimal while there is a clear benefit to the students. This goal was clearly achieved.

We also asked the students where and when they take the mini quizzes. Results are shown in Figs. 5b and 5c. Half of the students (49.5%) solve the mini quizzes during the week (not the same day as the lecture), 30.9% on the same day as the lecture and the rest (19.6%) right before the next lecture. The place where they solve it differs, one part uses the app at university (33%), another part does so at home (37.1%), and yet another part on their commute (25.8%). This supports that the mini quizzes are solved anywhere and at any time.

According to Fig. 5a, most people solved the mini quiz once (44.3%), which makes sense as they get instant feedback and there is no need to retry. Yet, quite a few did it a second time (40.2%). 34% got all answers of the

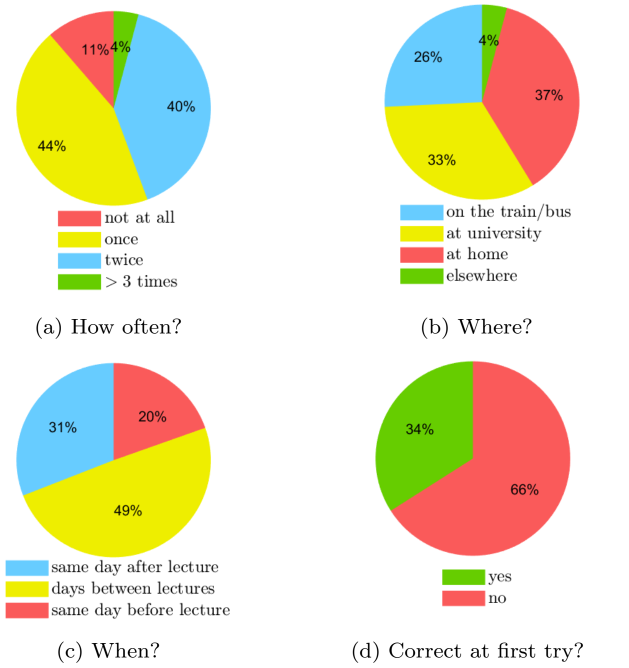


Fig. 5. Results on (a) how many times, (b) where, and (c) when the students solve the mini quizzes and (d) if they get the whole mini quiz right at their first try.

mini quiz right at the first try, as can be seen in Fig. 5d, so more than two thirds retook the mini quiz at least one more time in case they got it wrong. We tried to encourage this by introducing the colors green and red for feedback if the answers and quizzes were right or wrong. Only if all answers are correct, the feedback bubble of a quiz is shown in green.

The mini quizzes are also projected to the screen in the beginning of the lecture for two reasons. The first reason is that they serve as a basis for a summary of the previous lecture. The second reason is to remind the students of the app such that they use it every week. More than 75% of the students appreciate that the questions are explained in the beginning of the lecture.

The feedback we got so far is highly positive. The students complement the app and ask for more questions, for more explanations and apps with more difficult questions that help them prepare for exams and hope that we expand our catalogue of smartphone apps in the future.

5.3 Comparison

In comparison to other interactive tools the main advantage is the high accessibility of smartphone apps. However, the smaller screen compared to computer screens restricts the projects that can be implemented such that smartphone apps are applied to slightly different use cases than computer-based tools. One advantage of web apps is that they do not need additional software like MATLAB or the installation of a smatphone app as they run online on a website. However, many web apps are not optimized for a cell phone screen. Native apps, that are optimized for a specific platform or device, have better performance than general smartphone apps and web apps, that run on multiple systems.

6. CONCLUSIONS

We developed two smartphone apps for an introductory class on automatic control at the University of Stuttgart. We believe that due to their accessibility and convenience these apps will be helpful means to support students in following the lecture. It takes less than five minutes a week to go over the mini quizzes, so the effort is minimal, yet the app provides feedback whether the basic concepts of the previous lecture have been understood and the quiz structure makes it fun to use. The Nyquist app can be used to systematically train the application of the Nyquist criterion on randomly generated examples. We expect that the students embrace the apps and become more motivated and that the Nyquist app may also be useful for undergraduate control students at other universities.

To further improve the apps in the future, we will collect feedback from students on a regular basis to create updates that make the apps even more intuitive to use and expand the number of questions and explanations. Further future developments include the implementation of mini quizzes for other more advanced control lectures. For clear arrangement, the mini quizzes of the difference lectures will be collected in one joint smartphone app.

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