# Converting an Undergrad-Lab to an Interactive E-Learning Experience That Enables Student Teamwork


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***Abstract*—This Innovative Practice Work in Progress Paper presents a comprehensive approach to convert an undergrad hands-on electronics lab to an e-learning experience. Special care was taken to make the format interactive as well as to encourage teamwork between students. The conversion was made to conform with the social distancing measures implemented as a response to the COVID-19 pandemic.**

**Instead of relying on pre-recorded lessons, the lab was offered through live video sessions. Multiple cameras were used to make it easy for students to follow the instructor performing the experiment. Students worked together in teams they had chosen at the beginning of the semester throughout the entire course, giving team members the opportunity to get to know each other or strengthen existing bonds. During the live sessions, the teams were repeatedly sent to breakout rooms to discuss and vote on questions related to the execution of the experiments and the measurement results. The votes, which were carried out using the Moodle learning management system (LMS), were then discussed in the plenary, and the course of the experiment was adjusted accordingly.**

**Using data of student participation from the LMS and the results of a detailed survey, the success of the implemented measures can be proven empirically. $88.2\,\%$ of students found that the interactive elements helped them to stay concentrated during the live sessions. $79.6\,\%$ agreed that the breakout rooms improved cooperation within their team and $72.8\,\%$ plan to stay in touch with their team members.**



***Index Terms*—COVID-19, distance learning, electronics lab, teamwork, undergrad education, video conference software.**


## I. Introduction

The rapid spread of the COVID-19 pandemic has forced countries around the globe to implement social distancing strategies. This has presented an immense challenge for universities as traditional in-classroom courses had to be adapted to alternative e-learning formats almost overnight. Not being able to study in groups and meet other people leads to feelings of isolation [1], [2] as well as stress and anxiety [3], [4] in students. It is especially troubling that already disadvantaged students are affected the most by the detrimental effects of distance learning [5], [6].

This work describes the conversion of a hands-on electronics lab taught at the undergraduate level to an e-learning experience. Special care was taken to maintain high student engagement in the course. An additional focus was the promotion of student teamwork to alleviate the effects of social isolation.

## II. Background

The electronics lab is mandatory for students in the second year of the Bachelor's program in electrical and biomedical engineering. It was previously taught as a hands-on lab and is attended by about 200 students every winter term. The learning goals as laid out in the module handbook for the Bachelor's program [7] are: *a*) Being able to simulate and conduct measurements in the lab on basic transistor circuits, simple integrated circuit, digital logic, opamps, and filters. *b*) Implement a state machine on a field-programmable gate array (FPGA) using the Verilog language and industry standard software tools. *c*) Break down complex electronic systems into basic circuits and analyze the operation of the building blocks.

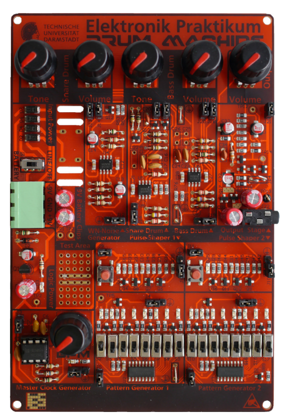


Fig. 1. Picture of the completed project PCB of the drum machine.

Four of the six labs are built upon a common project to achieve the third learning goal. Once completed, the assembled printed circuit board (PCB) (see Fig. 1) works as a drum computer with two voices. On the PCB students find the classic 555 timer IC used as a clock source, 74-series logic for the programmable sequencer, active filter, a discrete headphone amplifier and a few other circuits. The theory of operation of each circuit is introduced in the lecture notes and then verified through simulation in LTspice. Subsequently, students populate the respective area of the project PCB and finally verify its function using the supplied test gear.

## III. Related Works

Online education has been an ongoing trend for many years. However, the COVID-19 pandemic made it necessary to convert an unprecedented number of courses to e-learning as students were not able to attend courses on-campus due to social distancing measures. Some of these conversions have described in recent publications. However, only the ones focusing on lab activities will be discussed in the following.

Remotely accessible experiments have been shown to be one possible solution to enable students to take part in lab activities from afar [8], [9], [10]. Alternatively, a combination of video lectures, interactive simulations and online consultation hours has been demonstrated to yield good results [11].

This work differs from previous publications in its focus on enabling teamwork and increasing student engagement. It directly addresses the challenges caused by social isolation.

## IV. Methodology

For this work a hands-on lab was converted to an e-learning format. The design approach is laid out in this section. The presented course was held in the winter semester 2020/2021 and attended by about 200 students.

The main challenges this conversion would have to tackle were identified in a series of workshops hosted by the department of electrical engineering. In these meetings students and faculty discussed their experiences with e-learning so far and came up with recommendations for the upcoming winter term. Both students and faculty described feelings of isolation when being limited to asynchronous distance learning. Virtual meetings, whether they cover an entire lecture or are offered as regular office hours were suggested as a potential solution. Faculty offering live sessions over Zoom reported that these sessions suffered from reduced participation and high dropout rates. The planning of this lab went ahead based on these insights.

Faculty engagement has been proposed to be an important factor in promoting student engagement and success [12]. Several measures were implemented to demonstrate the teaching staff's engagement: a special e-mail address for course related questions was set up and all messages were answered promptly and using welcoming and supportive language; special attention was also paid to answering all questions in the online forum in a timely manner; questions of general interest were then added to an FAQ section on the course's homepage; finally, the results of the course evaluation were analyzed and discussed with students during a live session.

Keeping in mind the result of the e-learning workshops, it was decided early on to host the lab in the form of a series of virtual meetings using the Zoom video conferencing software. This is in accordance with the available research on this topic, where virtual meetings were associated with improving the quality of life for students compared to traditional, pre-recorded video lectures [13]. They also make it possible to gather immediate feedback from students through the Zoom chat feature. In the hands-on lab students had four hours during each session to complete the experiments. To make it easier for students to follow along, the duration of the virtual sessions was limited to three hours. This was further divided into chunks using the interactive elements described below and one break per session, in an attempt to improve learning success by matching the students' attention span [14]. Additionally, each session was recorded and made available afterwards, so students could re-watch when they felt it is necessary. The lab lasted from November 2020 to February 2021 and was comprised of six sessions taking $3\,\mathrm{h}$ each.

The Moodle LMS [15] has been used intensively for the course organization and management in the past. It was therefore the first choice for the implementation of the e-learning course. The available functions and processes are called activities in Moodle. The use of several of these activities will be presented in detail below.

### A. Video production

Video recording equipment has become an ubiquitous commodity, with even entry-level smartphones offering decent picture quality. The standards set by contemporary video productions are therefore high. Careful planning based on the available research on video lectures in academia is required to use the available resources gainfully.

Guo et. al. [16] have suggested that a more personal and enthusiastic off-the-cuff presentation style increases student engagement. They also recommend Khanh-style live drawing in place of a more traditional slideshow. This advice was implemented in the studio setup for the live sessions. The student lab where the course was traditionally held was selected as the filming location and multiple cameras were set up. The lab notes were shown using a document camera. This made interacting with the documents feel natural for the instructor, enabling them to point at important sections or to illustrate concepts using a quick drawing or calculation.

Having multiple cameras available made it possible to compose an image showing all areas of interest simultaneously. Fig. 2 presents an example of such a composition. Students can follow the measurement done on the circuit board to the left while being able to read values from the test equipment on the right at the same time. The excellent open-source project Open Broadcast Studio (OBS) [17] made it possible to do the video compositing in real-time.

As audio quality has been named as one of the most influential factors for the success of videos used in distance learning[18], [19], high-quality microphones and a professional audio interface were obtained for the studio setup.

### B. Teamwork and Interactive Elements

Students could choose teams on their own through the Moodle activity *group choice*. This was supposed to deepen

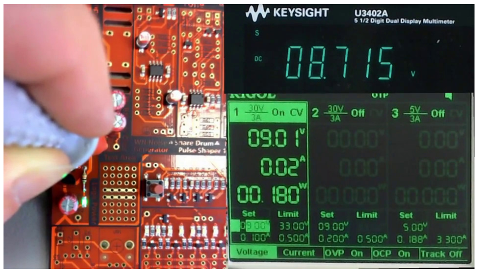


Fig. 2. Different camera angles make it easy to follow the presentation.

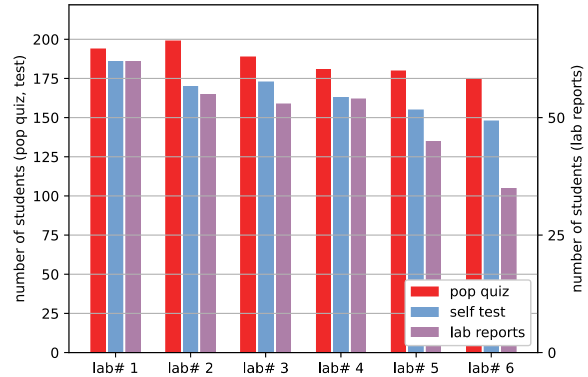


Fig. 3. Student participation in the different activities. Data was exported from Moodle.

the relationships in pre-existing peer-groups, as students could choose a group based on these networks. To make finding a group as straightforward as possible, a forum was created for this purpose. A collection of tools for communication with group members was also announced, including a forum where each group could communicate privately. The group choices were exported from Moodle and converted to a format suitable for Zoom. The resulting file was then used to create *breakout rooms* in Zoom, where teams could be sent to separate meetings during a live session to discuss among themselves.

For each lab session several polls were prepared, quizzing students on the concepts presented during the live session. These pop quizzes were used as interactive elements so students could in a way steer the flow of the experiment as well as provide them an opportunity to reflect on the content presented so far. They were integrated into the presentation so that they had to be answered before the instructor could continue the experiment, e.g. asking how the test gear had to be configured to achieve the desired result. The test design was based on the ConcepTest approach for live demonstrations as introduced in [20]. The Moodle activity *poll* was used to implement the pop quizzes. Before the poll was made available to the students the instructor presented the question and prompted them to discuss it with their team members before voting. Then they were sent to their separate breakout rooms as described above.

Students were also asked to hand in lab reports for two sessions each. Given a total of six lab sessions, the reports could be distributed evenly among each team of three. Students were encouraged to cooperate on the creation of these reports with their team members. The reports were collected and graded using the Moodle activity *assignment*.

One final element that was retained from previous years was a self-test after each lab. In this test students were given multiple choice questions to evaluate their understanding of the lab they had just attended. Students were encouraged to cooperate with their team members when answering these tests. This test was implemented using the Moodle activity *quiz*.

Bonus points for the final exam were offered as an incentive to students to participate in these activities as well as in the live sessions. To reward all students following along with the live sessions, they were rated based on whether a vote was cast rather than on the correct answers. However, attendance during the live sessions was not mandatory.

## V. Results

Participation in the offered activities was evaluated using the data recorded by the Moodle LMS. Additionally, the effect of the implemented measures on students was analyzed through an online questionnaire to which about 150 students responded.

### A. *Participation in the activities*

The participation of students in the activities described earlier was recorded through the Moodle LMS and could therefore be evaluated for this work. Dixson [21] has shown that this documented activity is indicative of student engagement in the course. The number of votes cast in the pop quizzes is of special interest, as these were only made available during the live sessions and can thus be seen as a proxy measure of student engagement during sessions. Fig. 3 shows the progression of the votes cast over the course of the semester. As there were multiple quizzes for each lab, the one with the most votes cast was plotted. It started out with a very high number of 194 votes for the first lab and decreased marginally to 175 for the last one.

The participation in the self-tests is also plotted in Fig. 3. As students were free to fill these out after the live sessions, the number of tests entered can be seen as a measure of student engagement outside of class. Again, numbers are very high for the first lab with 186 tests filed. However, this is followed by a steady decline to 148 tests for the last lab, corresponding to a 20 % decrease.

The number of lab reports handed in for grading was also evaluated. Each student was only supposed to create reports for two out of the six labs. Therefore, the maximum number of reports expected per lab is just a third of the number of students registered for the course. To make it easier for the reader to compare figures, the number of reports was plotted against a seconds y-axis located on the right side of the plot. The declining trend is even more distinct than with the other two activities. The number of reports was 62 for the first lab and went down to just 35 for the last one. This translates to

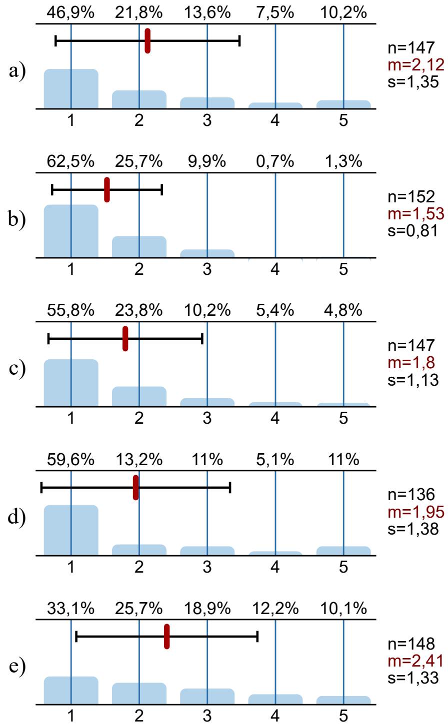


Fig. 4. Survey results for the questions exploring the effect of the implemented measures. Questions can be found in the text below. Mean (*m*) and standard devivation (*s*) are indicated through markers with error bars. *n* is the number of students having responded to the question. Scale ranges from 1.0 (strongly agree) to 5.0 (strongly disagree).

a 43.5 % decline. It can be reasoned that some students were satisfied with the number of bonus points they had achieved and therefore refrained from creating a second lab report.

### *B. Online survey*

An online survey was conducted at the end of the semester in early 2021 to evaluate the success of the implemented measures. Students were repeatedly reminded through friendly messages to fill out the questionnaire to increase the response rate. The turnout of more than 150 completed surveys shows that these efforts were successful. The results of the survey cover about two-thirds of students registered for the course and are statistically significant. In the survey 34.9 % of students identified as female and 65.1 % as male. No student identified themselves as gender non-binary. The majority of students (59.5 %) were in the third semester of their six semester Bachelor's program. 33.3 % stated they study in the electrical engineering program, 31.4 % in the medical engineering program and the remaining 35.3 % were spread among other programs offered by the department of electrical engineering.

Students assigned the lab an overall grade of 1.7 on average (scale from 1.0 to 5.0 with 1.0 being best), which is on par with the last two years where it was offered as a traditional hands-on lab (average grade for winter term 2018/19 was 1.57, for the winter term 2019/20 it was 1.78). 88.0 % of students found the e-learning format to be helpful or very helpful and 94.7 % were able to follow along the online course. 61.5 % of respondents agreed or strongly agreed that the course has encouraged them to keep exploring the topics presented. The questions added specifically to determine the effect of the measures implemented on teamwork and student engagement are listed below:

a) The live sessions made it easier to follow the course compared to a recorded lesson.
b) The interactive elements and breaks helped me to stay concentrated during the lab sessions.
c) The breakout sessions improved the cooperation in my team.
d) I plan to stay in contact with my team members even after the course has ended.
e) Using the supplied template I had no difficulties creating the lab report.

The results corresponding to these questions are presented in Fig. 4. Students strongly prefer live sessions over recordings. The majority finds interactive elements and short breaks helpful in maintaining attentiveness during these sessions. In the evaluation of the measures taken to improve teamwork, students agree that discussing during the breakout sessions improved cooperation among the team members. 72.8 % think they will even stay in touch with their team members after the course has ended, indicating the forming of friendships. Although the level of feelings of isolation was not measured directly these results hint at that students got to experience community in the course. Finally, as most students did not find it difficult to prepare the lab report using the supplied template the decline of handed in reports over the course of the semester is likely due to a decreasing interest in earning more bonus points.

## VI. Conclusion

Overall, the conversion of this lab to an e-learning experience was deemed successful. The survey results indicate that students prefer the offered synchronous course style over prerecorded videos. This finding is supported by the high level of activity during these sessions as evidenced by the data retrieved from the Moodle learning management system.

Combining the breakout room feature of Zoom with groups chosen in Moodle made it possible to form teams that can collaborate across these platforms. According to the survey, students found this measure to support cooperation in their teams and most plan to stay in touch with their team members, indicating that the level of community progressed from mere acquaintances towards friendship [22].

Due to the COVID-19 pandemic, the majority of the students taking part in this lab had less than one semester to experience university lectures and labs in person. The results of the survey might therefore be biased, as students did not have a baseline to compare this lab to.

The results of this work will be used to continually improve the design of this course, especially in regards to the upcoming winter semester where COVID-19 related restrictions will still be in place.

## REFERENCES


[1] Emmanuel Aboagye, Joseph Anthony Yawson, and Kofi Nyantakyi Appiah, “COVID-19 and E-Learning: The Challenges of Students in Tertiary Institutions — Social Education Research,” *Social Education Research*, vol. Volume 2, no. Issue 1, pp. 1–8, Jun. 2020. [Online]. Available: http://ojs.wiserpub.com/index.php/SER/article/view/422

[2] J. C. Fruehwirth, S. Biswas, and K. M. Perreira, “The Covid-19 pandemic and mental health of first-year college students: Examining the effect of Covid-19 stressors using longitudinal data,” *PLOS ONE*, vol. 16, no. 3, p. e0247999, Mar. 2021. [Online]. Available: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0247999

[3] C. Son, S. Hegde, A. Smith, X. Wang, and F. Sasangohar, “Effects of COVID-19 on College Students’ Mental Health in the United States: Interview Survey Study,” *Journal of Medical Internet Research*, vol. 22, no. 9, p. e21279, Sep. 2020. [Online]. Available: https://www.jmir.org/2020/9/e21279

[4] C. K. Kaparounaki, M. E. Patsali, D.-P. V. Mousa, E. V. Papadopoulou, K. K. Papadopoulou, and K. N. Fountoulakis, “University students’ mental health amidst the COVID-19 quarantine in Greece,” *Psychiatry Research*, vol. 290, p. 113111, Aug. 2020. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7236729/

[5] E. Grewenig, P. Lergetporer, K. Werner, L. Woessmann, and L. Zierow, “COVID-19 and Educational Inequality: How School Closures Affect Low-and High-Achieving Students,” Collaborative Research Center Rationality & Competition, München, Discussion Paper 260, Oct. 2020.

[6] G. Di Pietro, F. Biagi, P. Costa, Z. Karpiński, and J. Mazza, *The Likely Impact of COVID-19 on Education: Reflections Based on the Existing Literature and Recent International Datasets.* Luxembourg: Publications Office of the European Union, 2020, vol. JRC121071. [Online]. Available: https://op.europa.eu/publication/manifestation_identifier/PUB_KJNA30275ENN

[7] Technische Universität Darmstadt, “Module Handbook for B.Sc. Electrical Engineering and Information Technology (PO 2014),” Mar. 2021. [Online]. Available: https://www.etit.tu-darmstadt.de/media/etit/01_bilder/2_studium/2__3_im_studium/2__3__1_studienplanung/modulhandbuecher_1/bsc_etit_modulhandbuecher_1/BSc_ETiT_2014_-_EN_module_manual.pdf

[8] I. M. Moreno-Garcia, M. C. Salado-Saavedra, and V. Pallares-Lopez, “Digitization of an Electronic Instrumentation Laboratory Practice: Measurement of an LDR with Arduino,” in *2021 IEEE Global Engineering Education Conference (EDUCON).* Vienna, Austria: IEEE, Apr. 2021, pp. 36–42. [Online]. Available: https://ieeexplore.ieee.org/document/9454108/

[9] B. P. Veettil, D. Payne, D. Bagnall, and E. Cetin, “Quantifying and Improving Student Engagement with Remotely Accessible Laboratory Project Hardware (RALPH),” in *2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE).* Takamatsu, Japan: IEEE, Dec. 2020, pp. 714–718. [Online]. Available: https://ieeexplore.ieee.org/document/9368478/

[10] P. C. Nicolete, F. Herpich, E. T. d. O. Junior, L. M. R. Tarouco, and J. B. da Silva, “Analysis of student motivation in the use of a Physics Augmented Remote Lab during the Covid-19 pandemic,” in *2021 IEEE Global Engineering Education Conference (EDUCON).* Vienna, Austria: IEEE, Apr. 2021, pp. 1040–1047. [Online]. Available: https://ieeexplore.ieee.org/document/9454104/

[11] A. Gruenewald, C. Giesser, S. Buechner, C. Gibas, and R. Brueck, “Going Virtual: Teaching Practical Skills of Circuit Design and Programming for Heterogeneous Groups Online,” in *2021 IEEE Global Engineering Education Conference (EDUCON).* Vienna, Austria: IEEE, Apr. 2021, pp. 404–412. [Online]. Available: https://ieeexplore.ieee.org/document/9454125/

[12] H. L. Chen, L. R. Lattuca, and E. R. Hamilton, “Conceptualizing Engagement: Contributions of Faculty to Student Engagement in Engineering,” *Journal of Engineering Education*, vol. 97, no. 3, pp. 339–353, 2008. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/j.2168-9830.2008.tb00983.x

[13] P. G. d. B. Silva, C. A. L. de Oliveira, M. M. F. Borges, D. M. Moreira, P. N. B. Alencar, R. L. Avelar, R. M. R. B. Sousa, and F. B. Sousa, “Distance learning during social seclusion by COVID-19: Improving the quality of life of undergraduate dentistry students,” *European Journal of Dental Education*, vol. 25, no. 1, pp. 124–134, 2021. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/eje.12583

[14] M. Murphy, “Matching workplace training to adult attention span to improve learner reaction, learning score and retention,” *Journal of Instruction Delivery Systems*, vol. 22, no. 2, pp. 6–13, 2008. [Online]. Available: http://repository.usp.ac.fj/9029/

[15] Martin Dougiamas and The Moodle Developers, “Moodle - Open-Source Learning Platform.” [Online]. Available: https://moodle.org/

[16] P. J. Guo, J. Kim, and R. Rubin, “How video production affects student engagement: An empirical study of MOOC videos,” in *Proceedings of the First ACM Conference on Learning @ Scale Conference*, ser. L@S ’14. New York, NY, USA: Association for Computing Machinery, Mar. 2014, pp. 41–50. [Online]. Available: https://doi.org/10.1145/2556325.2566239

[17] The OBS Project Contributors, “Open Broadcasting Software.” [Online]. Available: https://obsproject.com/

[18] E. B. Gregori, J. Zhang, C. Galván-Fernández, and F. d. A. Fernández-Navarro, “Learner support in MOOCs: Identifying variables linked to completion,” *Computers & Education*, vol. 122, pp. 153–168, Jul. 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360131518300678

[19] A. M. F. Yousef, M. A. Chatti, U. Schroeder, and M. Wosnitza, “What Drives a Successful MOOC? An Empirical Examination of Criteria to Assure Design Quality of MOOCs,” in *2014 IEEE 14th International Conference on Advanced Learning Technologies*, Jul. 2014, pp. 44–48.

[20] E. Mazur, G. Kurz, and U. Harten, *Peer Instruction: interaktive Lehre praktisch umgesetzt*. Berlin; [Heidelberg]: Springer Spektrum, 2017.

[21] M. D. Dixson, “Measuring Student Engagement in the Online Course: The Online Student Engagement Scale (OSE),” *Online Learning*, vol. 19, no. 4, Jul. 2015. [Online]. Available: https://olj.onlinelearningconsortium.org/index.php/olj/article/view/561

[22] R. E. Brown, “THE PROCESS OF COMMUNITY-BUILDING IN DISTANCE LEARNING CLASSES,” *Online Learning*, vol. 5, no. 2, Mar. 2019. [Online]. Available: https://olj.onlinelearningconsortium.org/index.php/olj/article/view/1876