Lecture-Free Classroom: Fully Active Learning on Moodle

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***Abstract*—Contribution: This paper shows that today's learning technologies have the potential to make lectures unnecessary by supporting student's active learning in the classroom.**

Background: Despite worries about their pedagogical effectiveness, lectures remain the main instructional method in university classrooms. Introducing active learning into the classroom can be difficult due to class sizes and the challenge of providing appropriate scaffolding to individual students. This article shows that a thoughtful deployment of today's learning technology can help in structuring a whole course as set of activities, which can improve students' engagement in classroom.

Intended outcomes: With this full engagement in the classroom, students' affective and learning attitudes as well as their learning performance are expected to improve.

Application design: Moodle was used to design learning activities for second-year students taking a digital logic design course in an electrical and computer engineering program. Throughout the semester, the students used class time entirely to complete these activities and reflect on them. The instructor's role in the classroom was limited to interaction with individual students or teams to clarify any questions. He did not give any lectures during the term.

Findings: A total of 103 students took this course in Fall 2018 and Spring 2019. The students showed a strong acceptance of the presented instructional design. Their evaluation of individual learning activities was consistently positive and their performance in the final exam has improved considerably compared to previous offerings of the course.

***Index Terms*—Active learning; Moodle; Quizzes; Students' engagement; Students' perceptions**

I. Introduction

The community of engineering education is highly interested in active learning [1], [2]. In their seminal meta analysis of 255 studies, Freeman et al. showed that active learning is the "preferred, empirically validated teaching practice in regular classrooms" for undergraduate science, technology, engineering, and mathematics (STEM) courses [3]. On average, students attending classrooms with active learning components score by about 6% higher than students attending traditional lectures. Also, the latter were 1.5 times more likely to fail than students who participated in active learning [3].

On some level of abstraction, learning can be seen as a two-task process. The first task is the reception of new knowledge. The second task is the integration of this new knowledge with previous knowledge (schema theory [4]). While the first task can be more or less controlled in lectures (e.g., by following some principles of cognitive load theory [5]), the second task is largely out of instructor's control:

1) Depending on class setting, an instructor can be completely unaware of whether a student has the previous knowledge (old schema) at all.
2) Even if the student has the previous knowledge, the instructor will not be able to accurately predict how long a student needs to activate it (retrieval from long-term memory).
3) Even if the previous knowledge is activated, the instructor cannot know the level of its integrity (e.g. whether it is free of misconceptions).

The prevalence of lectures seems to create the illusion that an instructor could *synchronize* the reception and integration tasks in the minds of not only one student, but many. In contrast, active learning recognizes that this synchronization must be the learner's responsibility because the actual processing takes place in her or his mind: The learner must be in charge of controlling the speed at which new knowledge is received, so that this reception task can be aligned with the integration task.

How has active learning been implemented? Prince divided instructional methods that support active learning into four main classes [1]: collaborative learning, cooperative learning, problem-based learning, and the introduction of activities into traditional lecture. This paper relates to the last class and scales it up to the level of replacing traditional lectures entirely with activities in the classroom. Introducing activities into classroom poses a 4-fold challenge to the instructor:

1) Designing good activities [6], [7].
2) Engaging students to do these activities [2], [8].
3) Evaluating students' work and providing immediate feedback [9]–[11].
4) Soliciting students' reflections on their learning and experience [12], [13].

As cited, each of these tasks or goals has been addressed in individual research work. However, a lecture-free class hour should support all of these goals, so that every student can leave the classroom with some level of confidence that she or he has learned something. While designing and preparing thoughtful activities can and should take place before class time, the other three tasks should be done in class. With any class size above a few students, these goals most likely will not be achieved without the support of technology. Fortunately, today's learning technologies have the potential of supporting a lecture-free classroom.

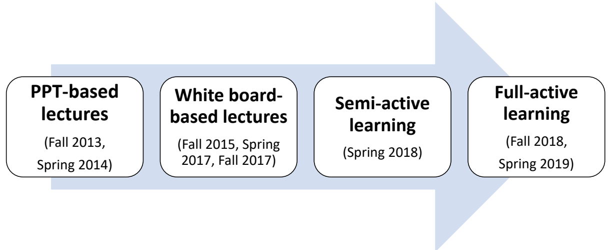

Fig. 1. From power-point slides to fully active learning

II. Background: DLD at Khalifa University

Digital logic design (DLD) is a course that deals with the foundations of computer hardware. This course is usually offered to first or second year undergraduate students. This poses some difficulties for students because high schools typically do not provide sufficient background in this area [14]–[16]. DLD is rich with concepts and methods and treats a wide range of topics in depth. Teaching and learning DLD has been addressed frequently in educational research. Treated aspects include using programmable logic to enhance students' learning [17], [18], using commercial and proprietary simulators for teaching and learning DLD [19]–[21], project-based learning [22], [23], e-learning solutions [21], [24], as well as misconceptions and cognitive aspects [25], [26].

DLD at Khalifa University is a four-credit hour core course for second-year electrical and computer engineering students. The course has a lecture and a lab component. In the lab, students perform eight experiments and one project using Transistor-Transistor Logic chips (TTL) or Field-Programmable Gate Arrays (FPGAs) starting from verilog code. The instructional approach described here relates the lecture component only.

Over the last five years, the author (referred to as *the instructor* in the paper) has taught DLD eight times. His teaching method has evolved in this period as illustrated in Fig. 1. Although the power-point slides used in the first two offerings were full of animations, e.g., to fill in a truth table line by line, the instructor realized that students' responses to white board explanations are much better. Therefore, he started to reduce the power-point presentations and to provide more and more white board explanations.

Although the lectures had some level of interaction, e.g., in form of question and answer, the level of students' engagement was low. In Spring 2018, the instructor tried to engage students by offering video-based activities in classroom from time to time. He used Moodle to add links to YouTube videos and developed related quizzes. Students brought their laptops and headphones to watch these videos and take the quizzes. While this method was attractive to many students, the instructor faced considerable difficulties in finding good videos that could be aligned with the course learning objectives [27]. He started to replace the video-based activities with lesson-based activities in the form described in Section III-A. In Fall 2018, the instructor refined and expanded this method to cover all learning objectives in the course. The classroom became a mature, lecture-free, fully active learning environment. In Spring 2019, some learning activities were improved and access control was implemented so that students could not open an activity before completing all related previous activities.

Fig. 2. Organizing class hours into activities (screen shot from the course page on Moodle)

III. Typical Operation of a Class Hour

In the first meeting, the students were made aware of the instructional approach. They were asked to bring their laptops to every class. A typical class hour runs as follows: students enter the classroom, log into Moodle, scroll to the day's activities, and start working on them. For assurance, the instructor writes the names of these activities on the white board. After this, the instructor role is limited to observing students and clarifying individual questions. Typically, students complete three activities in classroom: Learning activity or learning quiz (LQ), learning survey (LS), and review quiz (RQ). Fig. 2 shows an example of how class hours are organized on Moodle.

A. Learning Quiz (LQ)

Technically, a learning activity is implemented using the Moodle quiz format with multiple questions on separate pages. This allows students to check the answer of each question and read its feedback before moving to the next question. Pedagogically, a learning activity addresses one learning objective and appears as a multi-page interactive lesson. A learning objective in this context refers to what students should learn in one class hour or in a part of a class hour. Examples of learning objectives are: using Boolean algebra to minimize logical functions, the carry-lookahead adder and the synchronous counter. Each page has a concise introduction followed by one or more embedded questions. Since Moodle inevitably shows quiz terminology, the concept *Learning Quiz (LQ)* was used to refer to a learning activity. Learning quizzes and review

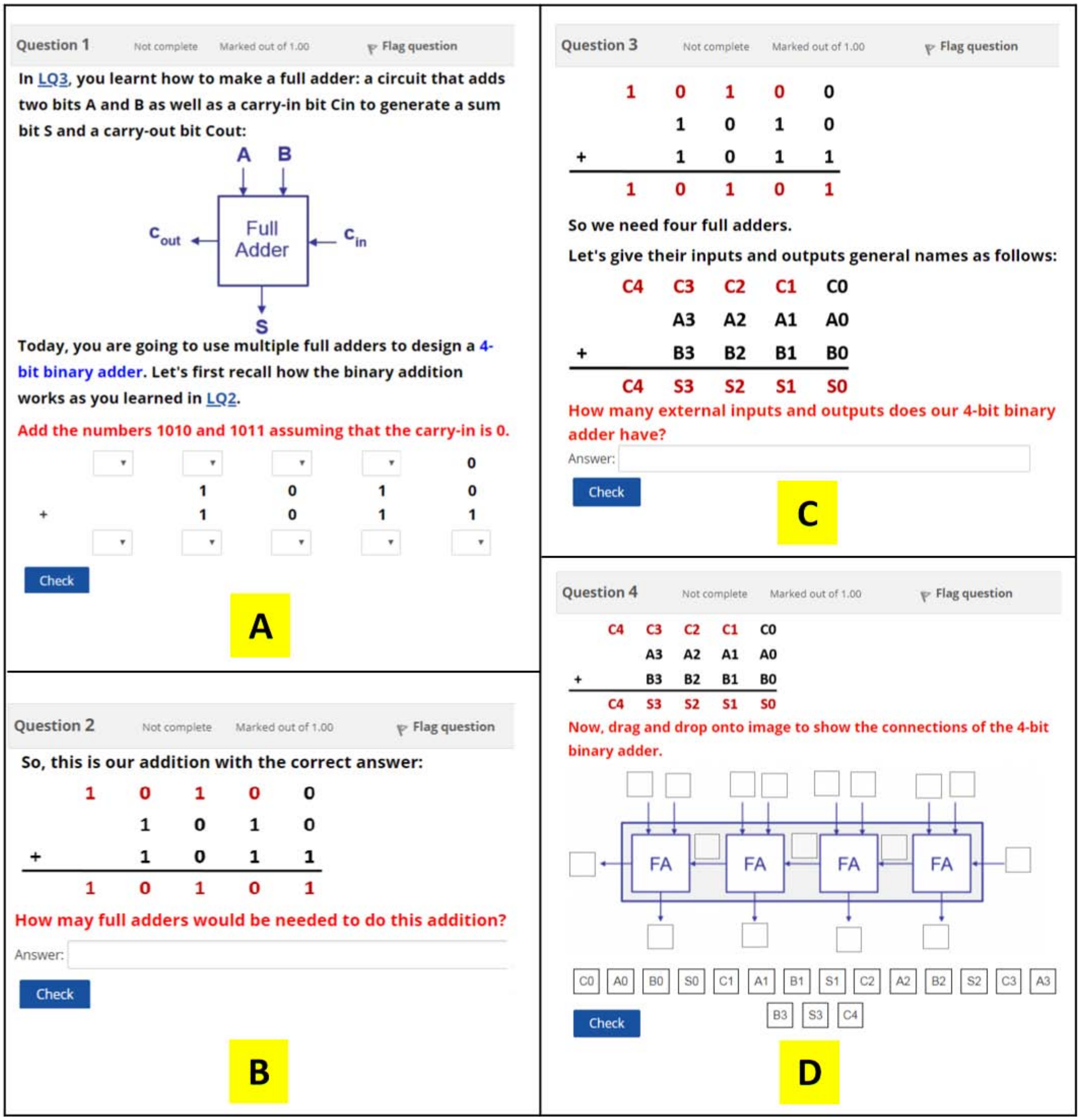

Fig. 3. LQ example: Form Full Adder 4-bit Binary Adder

quizzes are assessed for the purpose of feedback but aren't actually scored for a grade.

In the following, a learning quiz called "From Full Adder to 4-bit Binary Adder" is described. This activity has four questions only. Other learning quizzes can have up to 20 questions.

1. Reactivating previous knowledge and defining the new learning objective (Fig. 3-A). The first page reviews the full adder as a hardware component and defines the new learning objective: designing a binary adder starting from the full adder. First, the school method of binary addition is reviewed as an activity. For this, the question type "Selecting Missing Words from Dropdown Menu" was used. The menu includes "0" and "1" in this case and the addition operation is organized as 4x6 table for better layout. Underlined text has embedded links to previous learning activities so students have access to previously covered material. In their first attempt, the students answered this question with an average grade of 89.2%. This high performance is most likely because

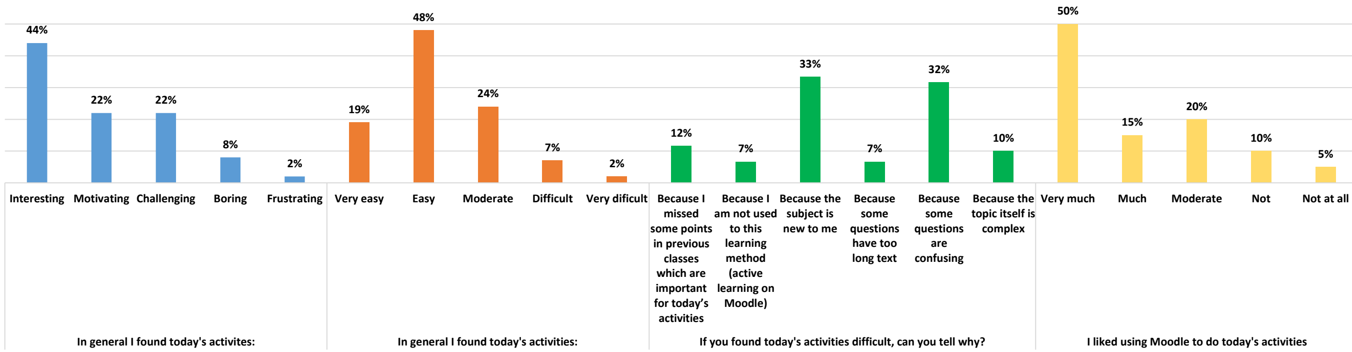

Fig. 4. Students' responses to the learning survey related to the case study-learning activity

the students had already learned how binary addition works in a previous activity. Note that only the results of the first attempt are given here. Many students reattempt learning quizzes for self-study. Their performance in the further attempts is usually better.

2. Creating connections between previous knowledge (Fig. 3-B). On the first page of the learning activity, the students have recalled the full adder and reactivated the method of binary addition. On the this page, the students are prompted to create a link between both by finding out how many full adders are required to perform the binary addition. For this, the question type "Numerical" is used, with 4 as the expected answer. For experts, this question may appear trivial. For students, however, using the full adder to build a binary adder is their first contact with modular design and the mapping of arithmetic operations to hardware primitives. In their first attempt, only 47% of the students answered this question correctly. 24% of them entered 5 as answer, probably because they thought an additional full adder would be required for the last stage. 20% of the students gave other answers and 9% did not answer this question at all.

3. Identifying the boundary of the new schema (Fig. 3-C). The feedback of the previous question explains why four full adders are required. The next step is to learn how these four full adders should be connected to make the binary adder. For this, the students first need to identify the interface of the binary adder, i.e., its external signals and differentiate these from the internal signals used to connect the full adders. This page first formalizes this problem by replacing the binary values by signal names. Then, the students are asked to find the number of external signals. The expected answer is 14 (C0, A0, A1, A2, A3, B0, B1, B2, B3, S0, S1, S2, S3, and C4) or 13 (because C0 could be assumed 0). Surprisingly, only 17% of the students entered one of these numbers. The remaining students gave different values between 2 and 22. Admittedly, this low ratio of correct answers should be attributed to lack of clarity in the problem statement itself. For example, the question "How many external inputs and outputs does our 4-bit binary adder have?" does not clearly state that the total number is required. In the responses to the related learning survey, students confirmed that "some questions are confusing", see Section III-B.

4. Completing the new schema (Fig. 3-D). On this page, the students should complete the design of the adder based on the knowledge gained in the previous two questions and using the given scaffolding. In particular, the full adders were connected and the students were asked to assign names to signals. For this, the question type "Drag and Drop Onto Image" was used. In their first attempt, many students answered this question accurately and the average grade was 80.4%.

B. Learning Survey

The purpose of the learning survey is to solicit students' reflection on the learning activity. The questions of the learning survey were designed at the beginning of the term and were used unchanged throughout the whole term. This helped students get used to the structure and content of the learning survey and to complete it quickly. The learning survey has six questions. Four of these questions are multiple choice questions as summarized in Fig. 4, which also includes students' responses to the learning activity on the binary adder. Note that in the first and third question, the student can select one or more choices. In contrast, in the second and forth question, only one choice is allowed. In addition to these selection questions, there are two free-text questions where students can summarize the most difficult points or the most interesting points they found in the learning activity.

C. Review Quiz

After soliciting their perceptions, the goal of the review quiz is to assess students' learning. A review quiz has usually one or

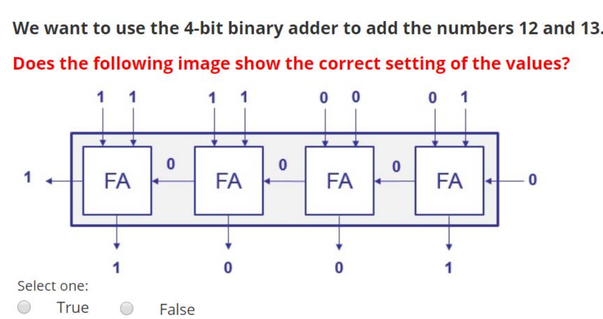

Fig. 5. Review quiz single question

two short questions which capture the essence of the learning objective. Fig. 5 shows the review quiz related to the binary adder. Note that the carry-out value of the third adder is flipped intentionally by the instructor. On average, the students took about 1 minute to analyze this circuit. 70 percent of them correctly identified that the value setting is mistaken.

IV. Course Structure and some Statistics

The course has 12 chapters, including an information chapter. The grid format was used for the course. This gives a clear overview of the course chapters and allows adding thumbnails related to the chapter topics. A chapter page is structured into four sections using Moodle labels:

1) **In-class activities.** This section is structured according to class dates as was illustrated in Fig. 2.
2) **Post-class activities**. This section includes practice exercises related to the chapter's learning objectives. Exercises are designed as Moodle quizzes with answers and feedback. Most students do these exercises at home after completing the learning activities in class. However, some students who complete the learning activities early can start with solving related practice exercises in class.
3) **Assessment.** This section includes graded assessment tools related to the chapter, if any.
4) **Resources.** This section includes legacy lecture notes (power point slides) and other resources.

The right half of Table I classifies the course activities into six categories from a pedagogical point of view. *Course questionnaires* were used to survey students about different aspects related to the course such as their preference for the date of an assessment quiz.

In the background of all quiz activities is a *Question Bank*, which contains all the questions of the course. Moodle provides an interface for adding, deleting, revising and categorizing questions. Upon creating an activity, e.g., a learning quiz, the instructor just needs to include questions from the question bank. To facilitate this, the question bank is structured into chapters and sections similarly to the course structure. At the end of Fall 2018, the question bank included 937 questions of 10 different types as detailed in the left half of Table I. Selecting the right question type for the learning objectives is a critical task. For example, the essay question type was used frequently to prompt students to think about possible solutions for challenging problems. The question following the essay question usually addresses the same point but is more specific and offers more scaffolding. Essay questions are weighted 0 in learning activities, so that the students can receive a grade after submitting the activity.

The question type "Boolean Function" is noteworthy because it was developed at Khalifa University specifically to support this course. Writing a Boolean function is a core step in the design and analysis of digital circuits. However, a Boolean function usually has many correct forms. For example, $F = AB+CD$, $F = BA+DC$ and $F = CD+AB$ are all correct forms of the same function.

TABLE I
Used question and activity types and their frequency

Question Type	Frequency	Activity Type	Frequency
Essay	40	Learning quiz	52
Short Answer	134	Review quiz	30
Numerical	27	Post-class exercise quiz	68
Select Missing Word	221	Assessment quiz incl. exams	7
Drag and Drop onto Image	21	Learning survey	30
Drag and Drop onto Text	4	Course questionnaire	8
Multiple Choice	96	**Total number of activities**	**195**
True False	34		
Cloze	150		
Boolean Function	210		
Total number of questions	**937**		

V. Evaluation

Moodle records several data such as the number of posts, views and student grades in the different activities. These can be used to understand students' learning and assess the instructional approach. For space reasons, only some key findings are presented here.

A. Students' engagement

The presented instructional design leaves no option to students, but to work on Moodle. So, the number of viewing and posting activities is a reflection of the level of students' engagement with the course. Table II shows some figures which were calculated from the data generated in Moodle for Fall 2018. Recall that the quiz and the questionnaire were the only activity formats used in the course. So, a post means that the student has either submitted a quiz or a questionnaire. According to Table II, students have posted 33 time per week on average. From Table I and assuming a 15-week semester, the average number of activities per week can be determined: $195 \div 15 = 13$. Thus, every student has attempted every activity $33 \div 13 \simeq 2.5$ times on average.

B. Exam performance

Table III compares the last five final exams. The difficulty level of the exams was estimated based on the assessment of a panel of three experts who are or were involved in teaching DLD. The author was not in this panel. The experts gave each question a rate from 1 to 6, whereas 1 and 6 correspond to the least or most difficult, respectively. The exam difficulty level was determined by averaging the difficulty rates of its questions. Table III shows that the students performed better using the semi-active and fully active learning modes despite the fact that the difficulty level has increased in the Moodle exams. Compared to Spring 2017, for example, the final exam in Fall 2018 was 34.5% harder ($\frac{5.1-3.6}{(5.1+3.6)/2}$). Nevertheless, students performed 13.7% better ($\frac{78.2-68.2}{(78.2+68.2)/2}$).

TABLE II
Students Engagement

	Views	Posts
Total number of activities	208.566	29.503
Avg. No. of activities per week	13.035	1.844
Avg. No. of activities per student	3.742	527
Avg. No. of activities per student and week	233	**33**

TABLE III
COMPARING STUDENTS' PERFORMANCE IN FINAL EXAMS

	Spring'17	Fall'17	Spring'18	Fall'18	Spring'19
No. of students	43	60	47	56	47
Instructional method	Lectures	Lectures	Semi-active learning	Fully active learning	Fully active learning
Examination method	Paper	Paper	Moodle	Moodle	Moodle
Difficulty level	3.6	2.7	4.3	5.1	5.1
Average grade	68.2	70.5	81.7	78.2	81.0

An independent-samples t-test with a 95% confidence interval was conducted to compare students' performance in these two final exams. There was a significant difference in the scores for Spring 2017 ($M = 68.2$, $SD = 17.3$) and Fall 2018 ($M = 78.2$, $SD = 12.1$); $t = -3.07$, $p = 0.0014$.

C. Exam performance vs. overall engagement

Fig. 6 shows students' performance in the final exam as a function of the total number of posts for Fall 2018. The trend line indicates a general positive relationship. The diagram also highlights some outliers surrounded by a square or a circle.

D. Perceptions of Learning Activities

Fig. 7 summarizes students' responses to the first question in the learning survey for all learning activities both in Fall 2018 and Spring 2019. The results allow the following conclusions:

1) The low level of perceived boredom and the high level of perceived interest can be seen as positive indicator for the level of engagement.
2) Student perceptions are very sensitive to the design of learning activity: The refinements performed in Spring 2019 have improved student perceptions of interest and motivation considerably. Not only the mean value has increased but the standard deviation has decreased. On the other hand, the students in Spring 2019 have perceived the activities as less challenging, although no considerable change in the core questions has been made.

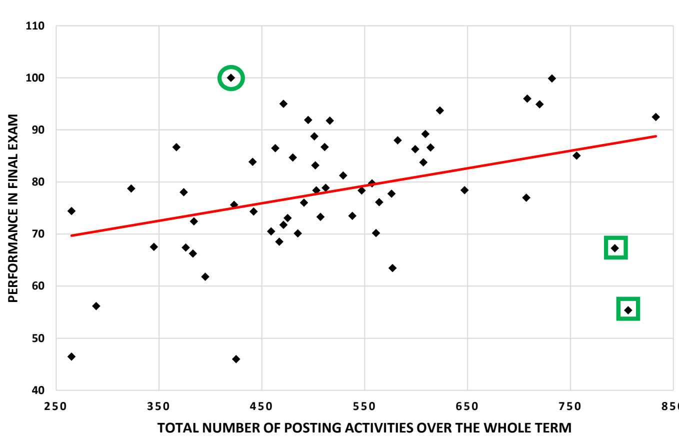

Fig. 6. Final exam performance vs. number of posting activities

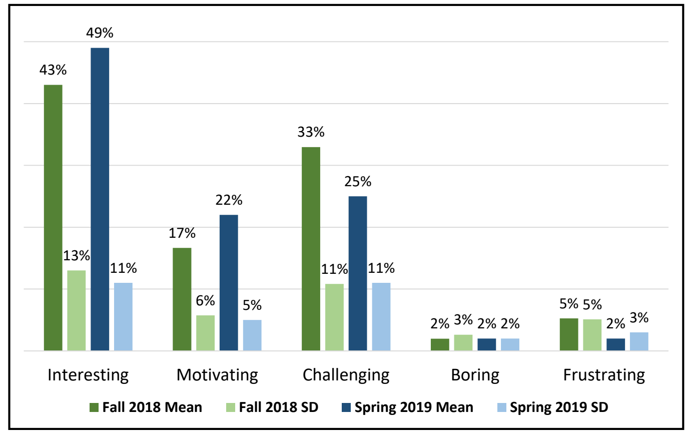

Fig. 7. Students perceptions of learning activities

E. Institutional Course Evaluation

At the end of each term, the University's Office of Institutional Research and Planning asks students to anonymously evaluate courses they are enrolled in. Fig. 8 shows students' responses to two overall questions which relate to their satisfaction with the DLD course content and delivery in the last four semesters for comparison. As can be seen, there has been a steady improvement in students' satisfaction since the introduction of active learning in Spring 2018.

VI. DISCUSSION

The general positive relationship between students' exam performance and the level of engagement according to Fig. 6 is encouraging, though not surprising. With active learning on Moodle, the role of engagement becomes evident. The outliers in squares show two students who worked hard but seem to have had major issues in the exam. On the other hand, one student shows perfect exam performance despite lower engagement level in terms of the number of posts (circled point). Based on the instructors' knowledge of this particular student, the student enjoyed higher cognitive abilities and relied more on conceptual understanding rather than repeated exercise.

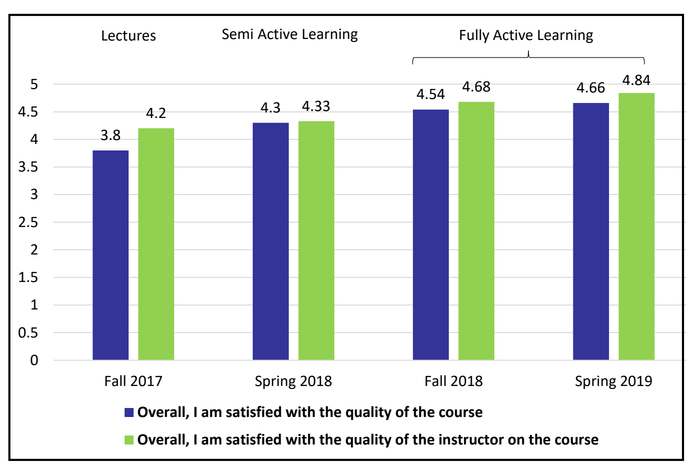

Fig. 8. Course evaluation by students in the last four terms

Table III shows that the semi-active and fully active learning methods are superior to traditional lecturing at the same university, for the same course, and by the same instructor. Why did experts find the Moodle final exams more difficult? This is simply because the active learning method has ”forced” the instructor to address complex topics with more care which allowed him to assess such topics in exams. For example, in previous offerings the carry lookahead adder (CLA adder) was treated in one lecture hour and the instructor had never felt that this topic is developed enough to be assessed on an exam. In Spring 2018, the instructor spent almost 12 hours on developing a thoughtful learning activity for the CLA adder with 15 questions. In Fall 2018, he spent 7 more hours on optimizing this activity. Students took on average 42.3 minutes to complete this activity with an average performance of 64.8% in the first attempt. Because students have had sufficient engagement with the CLA adder, the instructor has been able to include it on the final exams.

The last example shows that the presented design is highly time-consuming. Nevertheless, the author believes that this time investment is worth it because it has the following benefits for students:

1) Students are more engaged in the classroom.
2) Every student works at own pace (individual differences).
3) Every student gets immediate feedback and scaffolding.
4) Many students opt for team work on challenging activities (collaborative learning and peer instruction).
5) Students have a structured overview of their learning history (meta-cognition).

The instructor and the institution benefit from this approach as well:

1) Moodle generates an enormous amount of data that can be used for learning analytics and course improvement.
2) The activities can be exported and reused.
3) Automatic grading saves time.
4) Instructors with chronic or acute dysphonic issues or even with naturally disadvantaged voice or body language can benefit from this approach.
5) Offering assessment tools on Moodle save a huge amount of time and money spent on printing and managing examination papers and answer booklets.

The presented design differs significantly from the flipped classroom model and from online learning [28], [29]. These models –despite their diverse implementation forms– generally aim to replace the classroom lecture with online resources such as prerecorded lectures or external multimedia content. The activities are used mostly to *reinforce* learning either in the classroom or online. In contrast, the presented approach replaces the lecture with activity. This means that students are engaged in constructive learning from the beginning. Reinforcement exercises are presented as post-class activities.

VII. Challenges and Limitations

Probably the biggest challenge of the presented design is the time demands on the instructor. For the DLD course, the estimated time needed for preparing one learning activity was around nine hours on average. In the first term of introducing this method, a considerable part of this time was spent on learning the capabilities and shortages of Moodle. However, most of the time was spent on the actual design of the learning activity which requires deep thinking to:

1) split the learning topic into appropriately sized segments of knowledge,
2) find an appropriate representation for each of these knowledge segments,
3) find the right points for engaging students and formulate related questions,
4) find the right question type for each question,
5) formulate the appropriate feedback for each question to help students understand their mistakes and continue the activity with as few difficulties as possible, and
6) implement, test, and refine the learning activity on Moodle.

Since Moodle allows users to export courses including activities and the question bank, the overall time demands decrease if the course is taught frequently. Also, the automatic grading of assessment quizzes and exams mitigates the time overhead.

Another challenge or limitation of this approach is the strong reliance on technology usage on the student side (students' computers), on the server side (Moodle), and for the communication in between (Internet). Moodle supports different user platforms including tablets and smart phones. In the presented course, some students used such mobile devices without noteworthy issues. Using small devices such as mobile phones could be uncomfortable when the questions have large or detailed images. Also, answering drag & drop questions using a touch screen can be challenging on the platform. As for the server side and the network, the system scalability should be considered when the number of students who use Moodle simultaneously increases. As for the presented course, the campus Moodle was used and the peak utilization was in the two-hour final exam of Fall 2018, where 57 students worked simultaneously. It should be noted that the IT department and the Center for Teaching and Learning, which is responsible for managing Moodle at our university, were informed about the exam time to be ready to respond just in case. The reliance on technology, however, has a positive side: it relaxes the dependency on the physical location for doing or re-doing the activities. If a student misses a class, he or she can do the activities from home or elsewhere. If a student forgets his or her computer or mobile device or if this device fails to work in class, the student can work with another student and later re-attempt the activity from his or her account. Engineering schools usually have computer labs and these could be used to support this type of learning if some students cannot afford a personal computer or mobile device.

Thoughtful design of a learning activity tends to lead to fewer questions from students while working on the activities, so larger courses can be better supported by one instructor. In the case of very big classes, the instructor may seek the support of one or more teaching assistants. In this case, the teaching assistant would study the activities in advance and help answer students' questions in the class. In the presented course, a teaching assistant has helped in preparing post-class exercises on Moodle and replaced the instructor in class several times without issues.

Finally, depending on the course taught, the proposed design can be limited by the available question types which support automatic grading. In the presented course, for example, Boolean functions are at the core of the design and analysis of digital circuits. As mentioned previously, a Boolean function usually has many correct forms which must all be accepted by the automatic grader. Neither built-in question types nor community plug-ins available on the Moodle website support automatic grading of Boolean expressions. This is why it was necessary to develop a plug-in for this question type by the author's team.

VIII. Conclusion

The paper showed that today's learning technology can be utilized to support fully active learning in and out of the classroom. The design of challenging, interesting, and motivating activities, which can replace the instructor's voice and maintain students' engagement, is not easy. It requires a high level of engagement and time on the instructor's side to understand the capabilities and constraints of available technologies and accommodate pedagogical concepts.

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