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Students Perceptions on Teaching Design of Power Electronics Using Student-Response Systems: Thematic Content Analysis of Interviews

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ABSTRACT The paper presents an empirical study conducted in the context of an advanced power electronics design course in a technical university. In selected points of the lectures formative assessments were introduced and supported by the use of clickers. The purpose of the article is to examine students' perceptions of the effectiveness of clickers use. Individual, semi-structured student interviews conducted which were analysed using thematic content analysis. The findings reveal that the perceptions of the students with respect to the use of clickers were associated to: sustain student attention during the lecture, the provision of confirmatory and elaborative instructional feedback, the anonymity of the students' answers, asking questions appropriate for this teaching/learning method, students' motivation, students own suggestions for improvement, and the perceived existence of game-like elements. While in general the findings confirm the previous literature, there are a few points which are unique for this study, such as the relative importance of enhancing the students' attention compared to other studies, as well as the importance of using appropriate questions from the subject-matter. Besides, the drawbacks of previous research on clickers are not in line with the perceived ones in the present study. The paper is concluded with providing research and practical implications. The former touch upon the potential of this study on informing the research on didactics in the field of electrical engineering in Higher Education, whereas the latter pertains to its contribution with respect to learning design in similar learning contexts.

INDEX TERMS Power electronics education, power engineering education, electrical engineering education, engineering education, educational technology.

I. INTRODUCTION

In the context of higher education, parameters that touch upon students' characteristics (particularly, student engagement and motivation) coupled with learning design parameters (e.g., proper instructional feedback that accounts for the actual student needs) have received increased attention during the last decades from the educational community. This is mainly due to the fact that research suggests they are linked to high quality learning and deep student understanding [1], [2]. Furthermore, aligning the learning objectives, with the teaching methods and the student assessment is widely acknowledged in higher education [3]. At the same time, learning technologies have become a central component of higher education in recent years affecting all aspects of student experience [4]. These learning technologies have different affordances and limitations. This situation portrays a wide range of opportunities associated with a space of course design choices on behalf of the university tutor. In relation to that, it has been suggested [5] that in order to effectively integrate learning technologies in their teaching contexts, tutors should take into consideration a number of parameters, such as the characteristics of the students, the wider context, the affordances and the limitations of the learning technology used and the characteristics of the subject matter (e.g., structure, concepts). Next follows an example that touches upon engineering higher education.

Power Electronics courses are essential components of every higher-education study program in electric power engineering [6], [7]. Based on the learning objectives of the

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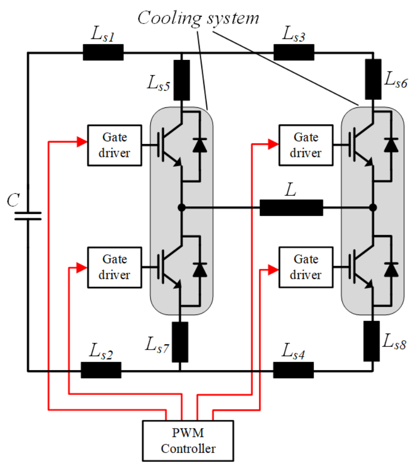

FIGURE 1. **Schematic diagram of a typical full-bridge power converter.**

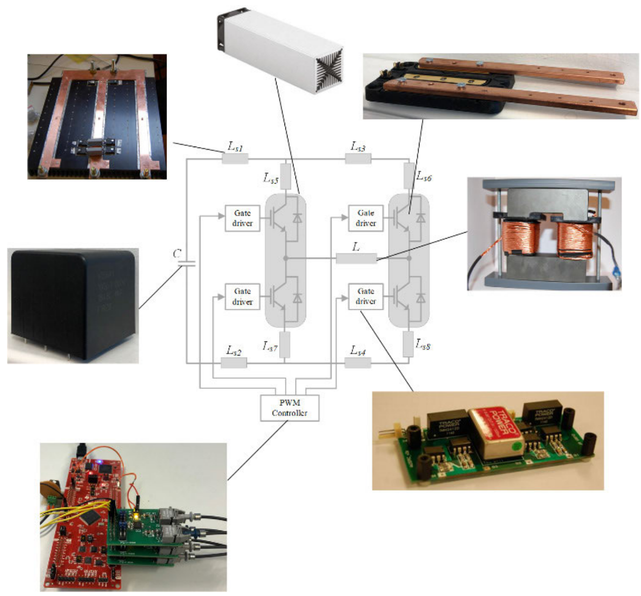

FIGURE 2. **Schematic diagram of a typical full-bridge power converter showing practical implementations of various system components.**

study program, as well as the educational level of the targeted students' groups, power electronics courses can be either designed as basic courses or having an advanced curriculum. The curriculum of an advanced power electronics course is developed beyond the fundamental concepts, such as the basic diode and thyristor converters, DC/DC converters and pulse-width modulation (PWM) inverters, contained in a basic course. An example of an advanced power electronics course is the design of power converters course. More specifically, physical design of power electronics converters including electrical, thermal and electromagnetic design aspects, as well as design of their vital auxiliary subsystems are integrated components of an advanced power electronics course [8], [9]. Students that choose this advanced course are required to have completed a basic course in power electronics. In such basic course, the learning objectives include analysis of the operating and control principles of power converters, as well as the presentation and analysis of converters' components. However, design aspects are not part of the learning objectives in a basic power electronics course. These aspects are taught in the advanced power electronics course that focuses on the electrical and thermal design aspects of power converters.

A typical schematic diagram of a full-bridge converter is shown in Fig. 1. The operating principles and modelling of such power converter are among the thematic areas of a basic power electronics course. For this analysis the power semiconductor devices are assumed to be ideal, the passive components lossless and the stray inductances negligible. However, the practical implementation of this converter requires various design considerations, not only related to the practical design and application of the components and parameters neglected above, but also to other components of the system. Among others, such components are gate drivers, PWM controller, cooling system, as well as a sophisticated bus-bar system design for minimizing stray inductances, as shown in Fig. 2.

The multidisciplinary nature of power electronics (Fig. 3) imposes crucial challenges in their teaching [10]–[13]. Considering the diversity in the students' educational backgrounds, the required multi-domain knowledge might impact their understanding. Additionally, the ability of students to combine and critically process knowledge from various fields of electrical engineering during the power electronics classes might also vary. Students attending advanced power electronics courses might a) have graduated from different bachelor programs and at different universities, b) possess different levels of critical thinking, and c) follow different specializations within the same 5-year study program. This can result in different student perceptions regarding concepts from other relevant disciplines and their applicability in power electronics [10]–[13]. Thus, the overall student understanding can be limited by these barriers making it difficult to achieve the learning outcomes. In such environments of complex learning, it is likely that the motivation of students will drop and, in turn, that they will be distracted. These challenges become more crucial in advanced courses, for example an advanced (e.g., master-level) power converters design course. The curriculum of this course requires a deep understanding of basic concepts in power electronics and fundamental knowledge of several disciplines -not necessarily limited to electrical engineering- which are mentioned in Section 3.2.

It is, therefore, necessary to develop learning activities with a specific focus on monitoring and advancing students' understanding, while increasing student engagement and motivation during the lectures. Monitoring students' understanding allows the teacher to keep track of it in real time; and, hence, to adapt the instruction (e.g., the pace of the lecture) and to recap key elements from previous lectures or other fields in class.

The relationship between student engagement and student learning has been investigated by several researchers. For

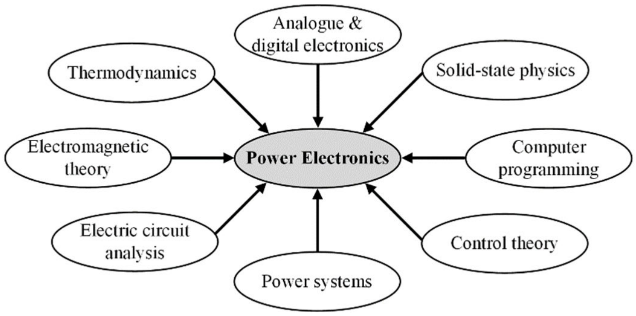

FIGURE 3. **Block diagram showing the multidisciplinary nature of power electronics.**

instance, the authors of [14] examined in a large survey the extent to which student engagement is associated to academic performance and found out that many measures of student engagement were linked positively with desirable learning outcomes, such as critical thinking and grades. Similarly, there are studies that positively link student motivation with achievement of learning outcomes, see for example [15]. Other research works suggest that students who are engaged through interactive learning environments learn more, retain more information, enjoy learning [16], [17], and dedicate their attention to the learning process [18] more than students who are not interactively engaged.

Finally, on behalf of the tutor the importance of keeping track of and visualise in simple ways the ongoing student understanding via formative assessments is important since it can help him/her to give proper instructional feedback; for example to address students' misconceptions as they emerge and so on. The emergence of Learning Analytics, a new field of educational technology, is built on that premise: the analysis of data collected from the interaction of users with Information and Communication Technologies holds the potential of advancing our understanding of the teaching-learning process [19]. Also, it seems that on behalf of the students, formative assessment and ongoing feedback is appreciated, since they perceive quality ongoing feedback in formative assessment "*as part of a dialogic guidance process rather than a summative event*" ([20], p. 671). In its simplest form, feedback can be confirmatory i.e. containing information on which is the correct answer in a question, an exercise or a problem. A more advanced option is elaborative feedback which provides justification on why a specific answer is the correct one; and why other possible answers were (partially or totally) incorrect.

Traditional learning activities in power electronics include, (but not limited to) physical lectures, weekly assignments, semester-based projects, and laboratory exercises [21], [22], [23], [24]. However, traditional lectures with minimum student interaction do not tackle the challenge of engaging students directly, monitoring class dynamics, assessing understanding in real time and providing immediate feedback. This is, mainly, due to the lack of bidirectional interaction between the teacher and the students. This is nicely illustrated by Prince [25] who posits that "*active learning is often contrasted to the traditional lecture where students passively receive information from the instructor*" (p. 223). The conceptual link between active learning, student interaction and immediate feedback involves the idea that active leaning entails the process of having students engaged in some activity that forces them to reflect upon ideas and how they are using those ideas [26] and the fact that providing immediate feedback to the students could promote students' reflection. Developing a course curriculum targeting enhanced students' engagement. requires a shift away from the lecture-based delivery model to a more interactive and student-centred teaching model. A conventional, teacher-centred course might involve the transmission of concepts required for the syllabus, or the transmission of knowledge from the lecturer, with few opportunities for students' interaction and little regard for students' existing knowledge of a topic. In addition to this, the lectures present and analyse the fundamental knowledge that is crucial for students to complete other course activities (e.g., lab exercises).

One way to tackle these challenges while promoting student engagement is by utilizing Student Response Systems (SRS) as a tool for allowing students to actively participate in the lecture. The main question is: what are the views of the students when it comes to utilising SRS in their course with respect to several aspects of active learning? In particular, with respect to the students' lived experiences on the use of clickers in this particular course of power electronics, classroom dynamics, engagement, motivation, and cognitive gains. This paper analyzes the students' perception and experiences when an SRS technology is used in a design of power electronic converters course at the Norwegian University of Science and Technology.

II. BACKGROUND

A. SRS BENEFITS AND CHALLENGES FOR HIGHER EDUCATION

SRS are electronic tools that allow tutors to ask questions during a lecture, collect students' responses, analyse and visually display the responses in real-time [27]–[29]. It has been suggested that the impact of clickers may differ depending on the educational context in which they are used [29], yet there exist generalised descriptions of benefits and drawbacks of SRS in several reviews. The literature review presented here is a synopsis of the current knowledge elicited by seven recent and relevant systematic reviews: [27]–[32].

Benefits of using SRS include increased levels of students' engagement ([28]–[30]) increased participation ([27], [32]) and attendance ([27]–[29], [32]) and improved interactivity ([28]–[30]), as well as higher levels of academic performance [27], [28], [31], [32], and increased student motivation to enhance their performance ([28], [29]) e.g.. by identifying areas of improvement [28]; also, they can be used as a means to improve the instructional feedback process [27], both for the student and for the tutor [28], [31].

Additional reported benefits include the possibility to answer questions anonymously ([29]–[31]) and to compare answers to peers, creating a safe environment for the students where their performance is not publicly judged, something that can be highly appreciated by them ([29], [30]) and that can have a positive impact on their self-esteem [31]. Drawbacks of SRS include additional time for answering technical questions and solving technical challenges, providing training, and distributing the remote controls [30]; high associated costs ([28], [29]) of obtaining and maintaining the equipment [28]; and blind guessing on behalf of the students due to anonymous voting [27], [28].

These studies also provided fruitful recommendations on future relevant research questions on the topic. For example, [31] suggests that rather than asking whether the effectiveness of clickers comes from the pedagogical method being used or by the clickers themselves, one should be asking "*how a specific instructional method might be enhanced by the use of clickers*" ([31], p. 14). In relation to that, the types of questions used in conjunction with SRS is also an important factor [30], [32]. For instance, these can be questions that are related to the key-concepts of the class [32] and contain a correct and partially correct answers [30]. Other suggestions for future research on SRS include the evaluation of long-term learning outcomes ([29], [31]) by using delayed post-tests, the use of mobile devices and smartphones not only as learning tools but also as a means to help addressing technological limitations [28].

Regarding students' perceptions in higher education on the use of SRS, a recent exploratory study [33] focused on perceived benefits, drawbacks and satisfaction by interviewing the participant students. The results indicate that the main perceived benefits are: anonymity, knowledge acquisition, interactivity, immediate feedback, usefulness, ease of use, and motivation to participate. On the contrary, perceived weaknesses are: nonparticipation, distraction, software reliability, and motivation to cheat. In addition, students of the research study provided suggestions for improvement while urging other instructors to adopt this technology in their courses. In another study, the authors of [34] developed a standardised instrument for assessing student perceptions of classroom response systems. The development of the instrument was evaluated through focus groups, one-on-one student interviews and a factor analysis of the survey responses. The items in the proposed questionnaire involve parameters like: wasted time, recommended use, motivation, interaction, instant feedback, instructor used results, increased participation, concentration, attention, and anonymity of answers. Finally, another interesting and relevant study [35], examined students' experience using a game-based student response system in an Information Systems course at a university in New Zealand. The authors conducted semi-structured interviews to learn about the perceived influence of SRS on classroom dynamics, motivation and students' learning process. The findings revealed that the integration of the SRS had a positive perceived influence reported on classroom dynamics, engagement, motivation and improved learning experience.

B. SRS USAGE IN ENGINEERING EDUCATION

The authors were not able to identify articles on the use of SRS in the topic of power electronics; thus, this section is presenting research works that are close to the topic as stake. In particular, this section will first showcase how university education was supported in case studies that provide different insights with respect to the use of SRS in electrical engineering topics.

With respect to electrical engineering education, the authors [36] present a proposal on how SRS can support power systems education originally established by a Consortium of Universities for Sustainable Power (CUSP^{TM}) Curriculum. Power electronics would be a part of this curriculum, according to the authors who suggest a blended learning proposal through a strategy that has three components: pre-, in- and after-class phase. In this strategy, SRS can help the teacher during class to get student feedback, to determine the level of student understanding, and to take appropriate corrective action on behalf of the educator(s). Although the approach suggested seems promising, the authors do not present enough evidence with respect to the (perceived) effectiveness of the use of SRS.

In another case study, the authors of [37] applied a quasi-experimental research design to observe the impact of implementing SRS in an electronic devices course towards students' engagement in class. The SRS questions were targeting students' conceptual understanding of topics in the course. Students used SRS to answer multiple choice tests at each topic. Students' achievements were also compared between the target group and the control group using a standard test. In addition, students' perceptions regarding their engagement were measured using an attitude survey. The findings indicated that the implementation of SRS had a significant and positive impact on students' engagement. However, improvement in academic achievement was not statistically significant in the target group when compared to the control group.

The work of Shen & Chen (2019) [38] is a case-based study that discusses the use of SRS to enhance student engagement and learning experience, and to improve academic performance. The context of the case study was a medium size classroom for a freshman-level electrical engineering course. A survey was administered to gather insight on students' feelings and thoughts towards the use of SRS. Besides, the correlation between students' engagement and their academic performance was investigated to assess the effectiveness of SRS. The study shows that students thought that learning using SRS was engaging and that they were learning better. The positive correlation between student engagement and corresponding academic performance can further validate these findings, according to the authors.

Finally, the case study of Sasidhar & Sahoo, (2018) [39] focused on a blended learning approach for an introductory power systems course. The approach included short educational videos, in-class quizzes using a gamified SRS (namely Kahoot!) answered by the students individually and online graded quizzes. The effectiveness of the approach was evaluated. Student feedback was positive for both the videos and the in-class Kahoot! quizzes. In particular, regarding the integration of the SRS in the learning process, students felt that it helped them to better understand the concepts presented during lectures and to reflect on the quality of their learning.

III. CONTEXT

A. CURRICULUM DESIGN FOR AN ADVANCED POWER ELECTRONICS COURSE

In order to create a suitable curriculum and to design appropriate learning activities that promote student engagement, mapping learning outcomes was a first step that the tutor of the power electronics course took into consideration [25]. This mapping process was supported by the use of a well-established taxonomy of learning objectives, namely the revised Bloom's taxonomy [40]. This exercise also allowed the course designer to well-limit the scope of the course, and to identify required previous knowledge, not only from the specific study program, but also from other relevant disciplines. This is a crucial design component for power electronics courses due to their multi-disciplinary nature, since the field combines various disciplines, such as electric circuit analysis, power systems, solid-state physics, electromagnetism, thermodynamics, analogue and digital electronics, control theory, as well as computer programming and modelling (Fig. 3).

The curriculum of a basic power electronics course aims at facilitating understanding, application and to some extent, analysis of fundamental converter topologies along with their basic operating principles at steady state operation. These correspond to the second, third and fourth levels of learning outcomes as described by the Revised Bloom's taxonomy (Fig. 4). According to university pedagogy research, to achieve higher order learning outcomes, the students are called to adopt a deep approach to learning, that requires them to be engaged and motivated to relate and connect the different knowledge components, as opposed to a surface approach in which they merely memorize and reproduce information [41]. Such a deep learning approach could also involve monitoring the development of student understanding [41].

In this paper, the integration of the SRS in teaching power electronics is targeting the Design of Power Electronic Converters course that is taught to the 5th year students at the Norwegian University of Science and Technology (NTNU) in Norway; it is an advanced power electronics course. The curriculum of this course contains eight thematic areas: 1) Power semiconductor devices, 2) Gate and base drivers, 3) Snubber circuits, 4) Thermal design of converters, 5) Packaging and reliability of power semiconductors, 6) Design of magnetic and passive components, 7) EMI in power converters, and 8) Guest lectures on Emerging research topics in power electronics. Each of the themes is taught using two teaching-learning approaches: lectures and tutorials (i.e. working with numerical problems).

A prerequisite for following an advanced power electronics course is the successful completion of the relevant basic course. The main pedagogical rationale is the levels of learning outcomes of the students as denoted in the Bloom's taxonomy (Fig. 4): the ones close to the bottom of the pyramid correspond to lower order thinking skills on behalf of the students compared the ones closer to the top which correspond to higher order thinking skills.

Regardless of the specific curriculum, the aim of an advanced power electronics course is to enable the students analyzing, evaluating and, as a top-goal, designing power electronics systems or their control systems and modulation schemes. In other words, an advanced course is a natural follow-up of a basic course. However, overlaps in curriculums through specific learning activities should also exist in order to make the transition between the two courses smooth. The pedagogical rationale is that there are many studies in educational research that have provided empirical evidence that the students' prior knowledge is vital on building students' new knowledge [42], since it is widely accepted that stimulating students' prior knowledge is an essential component of student-centered instruction [43], [44]. The overlap of targeted learning outcomes levels is shown in the red dashed-lined box in Fig. 4. For example, a simulation-based semester project in the frame of a basic course can aim to analyze and evaluate the electrical and thermal performance of a given power electronic converter. Another example is teaching about power semiconductor devices characteristics. In a basic course at bachelor level, a brief overview of the topic (usually organized as one of the first lectures at the beginning of the academic term) increases students' understanding. However, the presentation of their electrical characteristics and operation is made at circuit-level, avoiding the analysis of complex mechanisms of solid-state physics occurring in semiconductors' structures.

B. CHALLENGES ON CHOOSING PROPER LEARNING ACTIVITIES

The curriculum of the advanced design course is developed by integrating knowledge and skills from other disciplines and the combination of these disciplines imposes crucial challenges on the design of proper learning activities in order to maximize the learning outcome. The various disciplines that are involved in each thematic area of the course are summarized in Table 1. As shown in this table, there is a clear diversity in the various disciplines, which also necessitates the need for specific previous knowledge on behalf of the students. In particular, not only knowledge from the field of electrical engineering is needed, but also the students must be familiar with basic theories of thermodynamics, material science and solid-state physics.

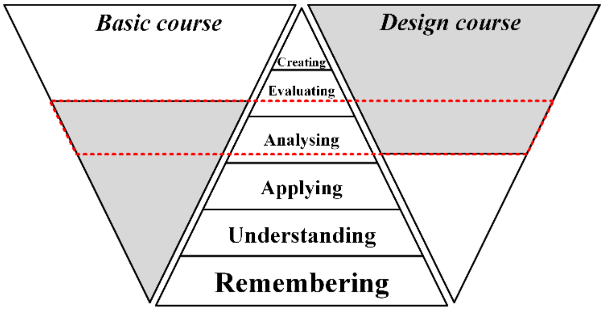

FIGURE 4. Learning outcomes levels of Bloom's taxonomy and mapping of course activities contained in a basic and an advanced design course in power electronics.

The nature and content of learning activities was not limited to the field of power electronics, but rather included aspects from the other discussed disciplines. However, this is done with the view of ensuring a good balance in the amount of activities containing information from thermodynamics, material science and solid-state physics. A good balance also allows to keep the course orientation on power converters design and not to divert towards other disciplines. In addition to this, monitoring the class dynamics in this course can become challenging with respect to the potentially limited previous knowledge from the other disciplines. The teacher of this case study was unable to know in advance the level of students' knowledge from the other disciplines, which could allow for real-time adaptation of the lecture pace, as well as for recognizing the needs for in-class student support well in advance.

C. DESIGN OF LEARNING ACTIVITIES BASED ON THE REVISED BLOOM'S TAXONOMY

In the course, the learning activities targeted the top three cognitive levels of the Revised Bloom's taxonomy. Apart from lecture classes and tutorial classes, a semester project on theoretical studies and practical design of a power converter was implemented in order to enable the students to master the top levels of the Revised Bloom taxonomy. The rationale is to allow the students to develop competences on power converters design, which will be useful for their professional careers, either in industry or in academia. However, the remaining challenge in such a course having the need for multidisciplinary knowledge, is the design of proper lectures and tutorial classes. This means not only creating informative and well-designed slides that will attract the students' attention, but also enhancing students' engagement in class.

Based on the existing literature, an SRS was considered the most appropriate educational technology for improving in-class engagement of students, as well as for real-time monitoring of students' understanding. An SRS allows the tutor to assess the students' understanding in real-time, which can be challenging in this particular course due to its multidisciplinary orientation. The tutor, knowing the student responses and their distribution using the SRS, can try to adapt the lecture pace, support students to destabilise their misconceptions or use back-up teaching material to explain complex concepts from other involved disciplines.

TABLE 1. List of disciplines involved in each thematic area of the "Design of Power Electronic Converters" course at NTNU.

Thematic areas of the course	Disciplines
Power semiconductor devices	Solid-state physics, material science
Gate and base drivers	Analogue electronics
Snubber circuits	Solid-state physics
Thermal design of converters	Thermodynamic theory
Packaging and reliability of power semiconductors	Material science, thermodynamic theory, basics of mechanical engineering
Design of magnetic and passive components	Electromagnetic theory
EMI in power converters	Electromagnetic theory, High-frequency engineering, digital signal processing
Guest lectures: *Emerging research topics in power electronics*	Several disciplines

IV. METHOD

A. DESIGN OF IN-CLASS ACTIVITIES USING SRS

Following up on the mapping of learning objectives, the tutor defined the purpose, the potential gains, and the expectations of using SRS-based learning activities in the class. This was done by also taking into consideration certain practical constraints or characteristics such as: the possible diversity in students' educational backgrounds, the course schedule, the frequency of the lectures, as well as the classroom setup.

At the first use of SRS-based activities in class, the teacher explained to the students the purpose of introducing this educational technology in the course, the potential benefits for students, as well as the educational challenges that he was planning to tackle (mentioned in the previous section). The aim was to build rapport with the students and to enhance their commitment while participating in the SRS-based learning activities. In addition, various information on practicalities and logistics were also conveyed to the students at the beginning of the semester (Fall semester 2019).

A number of in-class SRS-based multiple-choice quizzes were designed, relevant to the theory and concepts that were presented during each of the lectures. The questions were designed with the intention of helping students to overcome the challenges while also triggering their subject-specific critical thinking. Thus, they are designed in a way that the post-analysis phase of each quiz enabled the teacher to explain each alternative answer in view of the course theory, which is not necessarily limited to the fundamentals of power electronics. This is the key point in the use of SRS-based quizzes, that is, to cater for the explanation of theories and concepts from the other disciplines during the post-analysis of students' answers. The post-analysis of quizzes was made smoother by preparing slides containing relevant information

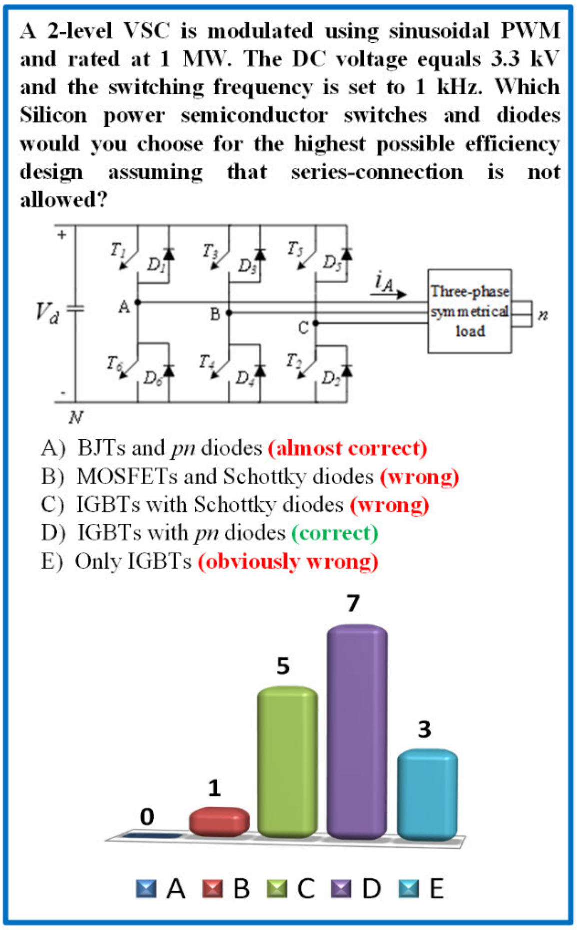

FIGURE 5. Example of an SRS quiz on power semiconductor devices theory presented in the class.

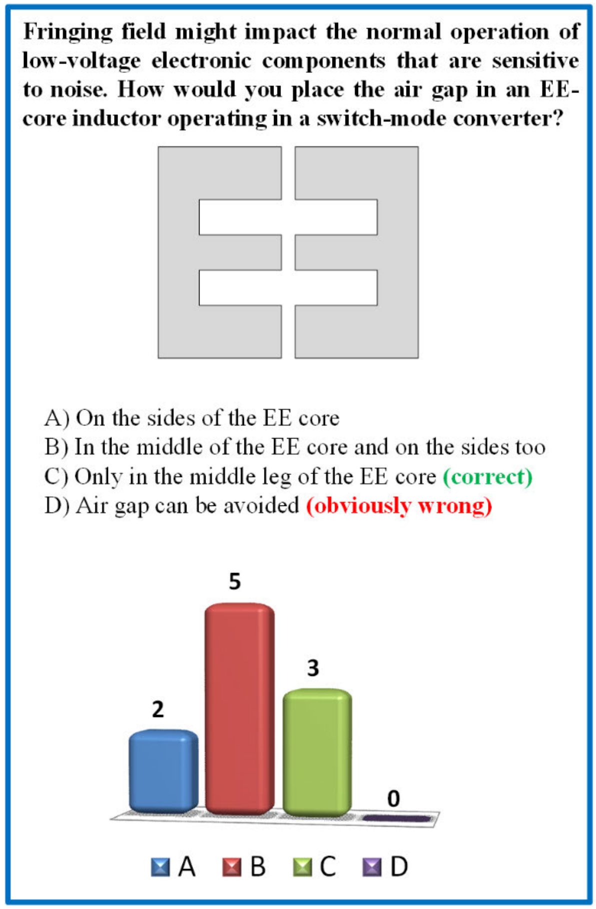

FIGURE 6. Example of an SRS quiz on design of passive components presented in the class.

and reveal them to the students when needed. However, this practice could impose a challenge: the answering patterns of the quizzes are unknown at the preparation phase by the course teacher. The student performance depended on the students' perception of the presented concepts, their understanding and their previous knowledge from the field of power electronics and from the other disciplines. Therefore, the teacher's role as a facilitator in the post-analysis and post-discussion of the answers necessitated ad-hoc adaptation of feedback to the answering patterns of the students. For example, if the majority of the students answered correctly, the post-analysis would start from explaining the most wrong alternative (i.e. the one that was obviously wrong) towards the correct one. On the other hand, if most of the students voted for an option that is neither the correct one nor the obviously wrong one, the post-analysis would usually start from the option that received most of the votes. These were two main approaches regarding instructional feedback provided as a result of the post-analysis of the quizzes i.e. the distribution of student answers across the four or five possible options which was automatically and instantly generated by the SRS system in-class after all students had answered the specific question.

Two further design and implementation aspects of the SRS-based quizzes are worth to be mentioned. The first one is related to the choice of the alternative answers, taking into account that the questions formation aimed at triggering an interesting post-discussion. In this line of thinking, the alternative answers were chosen in a way that there was always only one correct answer, one answer that was close to correct (e.g. it could have been related to some student misconception already known to the teacher from his previous teaching experience), one or two random wrong answers and one answer that was obviously wrong. Following this approach, the students were given the task to identify the correct and the almost-correct answers and, thus, to activate their critical thinking in order to answer correctly.

Figure 5 shows an example of a quiz that was presented in one of the last lectures on the thematic area ''Power Semiconductor Devices'' and aimed at students selecting proper semiconductor devices to design a voltage-source converter (VSC) with the highest efficiency. The five alternative answers were chosen based on the approach explained above and their classification is shown in red text.

Moreover, Fig. 5 shows the distribution of students' answers that was automatically created by the SRS system. In this question the majority of the students (7 out of 16)

Why simultaneous high voltage and high current must be avoided in power semiconductors?
A) High on-state resistance
B) High switching losses
C) Limited switching frequency
D) Gate drivers cannot sustain high-voltage stress

FIGURE 7. Example of an SRS quiz on snubber circuits that involves relevant and prerequisite knowledge.

Which of the following power semiconductor devices has a current-driven gate or base terminal?
A) IGBT
B) MOSFET
C) BJT
D) Schottky diode

FIGURE 8. Example of an SRS quiz on gate and base drivers that involves relevant and prerequisite knowledge.

answered correctly (option D), while 1, 5 and 3 students have voted for options B, C and E, respectively. Thus, the post-analysis of this quiz started by explaining the wrong answers in an ascending order in terms of votes received. Following this procedure, was it easier to justify the scientific rationale and develop the overall justification towards the correct answer.

A different design approach regarding the choice of the alternative answers is shown in Fig. 6. In this quiz, there is only one answer that is obviously wrong, and three potential answers that activate the students' critical and analytical thinking in order to answer correctly. This is due to the fact that -at a first sight- answers A, B and C seem to be all feasible and correct. However, in order to answer correctly, the students must combine their knowledge from electromagnetism and low-voltage analogue electronics with power electronics design. The voting pattern of the students reveals that the goal of this quiz has been accomplished and pave the way to carry a fruitful post-quiz analysis and discussion in the class.

The second aspect regarding the learning design of the SRS questions relates to the frequency of implementing the quizzes. During each lecture hour of the course, two rounds of one or two quizzes were performed. The frequency of the quizzes was chosen by taking into account that during a lecture that typically lasts a didactic period of 50 minutes, students attention begins to drop after 15 minutes of lecturing [45]. Therefore, during the lectures the students were asked to answer one or two SRS-based quizzes every approximately 15-20 minutes. Following this principle, the chances to enhance students' engagement in the course would increase and students would be more motivated to stay active in class.

SRS-based quizzes were also utilized as a link between two lectures in the same topic or between lectures on different topics in the course. The purpose of such type of quizzes was to recap the key knowledge from the previous lecture and put it into a perspective in the current lecture session. This approach has been applied in each lecture of the course. That is, the purpose of using SRS-based quizzes in this case was to implement diagnostic quizzes at the beginning of each lecture. Figures 7 and 8 show examples of SRS-based link quizzes.

In particular, the first example (Fig. 7) is a quiz at the start of the lecture on snubber circuits, while the second quiz example (Fig. 8) was used at the beginning of the lecture on gate and base drivers.

B. PARTICIPANTS

The educational endeavour described herein took place during the autumn semester 2019 at the Norwegian University of Science and Technology (NTNU). The language of the course was English, and all participant students were fluent in English. The class consisted of 16 students. All students that were enrolled in the course agreed to be interviewed. Two of them were females and the remaining ones were males. Two of them participated in the course as part of their 2-year international masters' program in Electric power engineering while the remaining ones were following the course as part of the 5-year integrated masters' program in the same topic. Most of the students were of Norwegian ethnicity and their average age was 23 years. Finally, most of them did not have previous experience with the use of SRS in their studies.

C. DATA COLLECTION

The study involves exploring the perceptions of students via semi-structured interviews; thus, a qualitative research approach was considered as the most appropriate option [46]. The main type of data collected was qualitative student interview data. Semi-structured interviews allow for considerable freedom in the sequencing of questions and in the amount of time and attention given to each topic [46]. Data was collected in the form of audio recordings (one interview recording per student). The interviews were semi-structured, following a specific interview protocol. They were conducted in English, in a room at the university premises, near the end of the academic semester. According to the interview protocol, the dimensions of the questions of the semi-structured interviews were in line with what is suggested in [35] who also conducted semi-structured interviews on student perceptions on an SRS approach. Consequently, the questions comprising the interview protocol revolved around students' perceptions on: students' experiences, classroom dynamics, engagement, motivation, learning, and proposals for alternative uses of SRS. An example question: on the influence of SRS on classroom dynamics: "*How do you feel about the changes in the interaction between students and the lecturer (or among you and your peers) brought about by the use of SRS, if any?*" In addition, the interview protocol contained prompt questions that were used whenever needed.

The specific SRS technology that was used in this course is a commercial SRS comprising of response pads and receivers. Each of these response pads had a unique identification number, which allowed to keep track of the answers by a specific user. Therefore, each student was assigned a unique ID number in order to secure students' anonymity in line with the new EU GDPR (General Protection Privacy Regulations). Although the distribution of students' answers across the questions and the options given in each of the SRS questions were gathered to facilitate the learning design of the course (as described above), they are not treated/used as research data herein. In effect, that mapping allowed for the removal of all student names from all research data gathered.

Before the interviews, all participant students completed a written consent form and the interviewer asked oral permission to record the interview. Furthermore, the consent form was accompanied by a short information sheet briefly mentioning: the purpose of research, the research responsible, data storage issues, and data access issues. At the beginning of the interviews a small introductory phase took place aiming to: introduce the interviewer to the interviewee, inform the interviewee on the purpose of the interview, make them aware about their rights according to the new EU GDRP restrictions; and inform them about the interviewer bias effect and the social desirability effect [47] in order to raise awareness to the students about them and their potential negative impact on interview-based research results. This action was taking as a measure to protect the research validity. Another relevant measure that was taking on behalf of the interviewer was paying attention to the absence of leading questions [48] that would in some extent guide the students' answers in order to enhance the interviews' reliability. In addition, the interview process was in line with the guidelines mentioned in [49] on the behaviour rules that the interviewer must adhere to during the interview. Each interview lasted approximately 15 minutes on average.

D. DATA ANALYSIS

The students' answers to the interviews were transcribed and on average, the transcribed interviews were 3,5 pages long each. To protect student anonymity, each student name was mapped against a unique identifier, ranging from P1 to P16. The transcribed interviews were qualitatively analysed using Thematic content analysis [50] which entailed a process with these main steps: the authors familiarised themselves with the interview data by reading all transcripts twice. Then, each author assigned preliminary codes to their data in order to describe the content. The preliminary codes corresponded to the interview protocol themes. Then, they searched for patterns or themes in the codes across the different interviews. Following, the authors got together in order to review their themes, by comparing and contrasting findings and reaching consensus. For example, they search for the codes related to students' experiences. By searching across the different interviews, it emerged that students' experiences were focusing on student attention, focus and concentration. These subthemes were grouped into one main overarching theme, under "student attention". Throughout this process two meetings took place between the authors who were otherwise working independently: a preliminary meeting (dealing with few interviews for pilot-testing) and a final one (reviewing themes). Finally, the authors defined and named the common themes, they defined the essence of what each theme is about and produced the final results (see next section).

V. RESULTS

A. STUDENT ATTENTION

This theme was mentioned from the students most frequently than any other theme, since it was mentioned by 12 students (P1, P2, P3, P4, P7, P9, P11, P12, P13, P15, P16). It touches upon using the clickers to sustain student attention (P4), concentration and focus (P11) during the lectures. Typical excerpts on that theme from students' interviews are:

- *I think it made me more focused, more "awake" (P11)*
- *when he introduced these clickers and when he would get to one of these slides where there was a question, you kind wake up a little bit: you have to pay attention and think for yourself (P4)*

B. INSTRUCTIONAL FEEDBACK

The second most frequently mentioned theme is providing immediate and elaborative instructional feedback to the SRS questions, which was mentioned by 9 students (P3, P5, P6, P8, P10, P13, P14, P15, P16). That is, the provision of immediate instructional feedback that not only reveals which answer is the correct one, but also explains why that particular answer was correct and the other answers were wrong (P13). This theme also involved the possibility of creating a learning situation after a tutor is asking a question which is distinctively different compared to a traditional lecture (P10). Typical excerpts that exemplify students' thoughts on that:

- *then [name of the lecturer] would reveal our answers and would say which answer was right and which answers were wrong and why [...] This way with the clickers helped you in understanding why a specific answer was wrong or right* (P13)
- *You can see how the class has responded and then the teacher goes through all the answers and explained why is wrong or correct* (P10)

C. STUDENT ANSWERS' ANONYMITY

This theme is pointing out that students could use the clickers in order to answer anonymously the questions presented to them during the lectures and that this was something that they appreciated. This was mentioned by 6 students (P2, P4, P7, P9, P12, P14) and typical interview excerpts include:

- *Anonymity helps students to feel more comfortable when answering questions and might choose the wrong answer* (P7)
- *But there is a very important difference if only you know that you answered wrong or if everyone is knowing* (P12)

D. ASKING APPROPRIATE QUESTIONS

This theme refers to the nature of the questions asked using clickers as well as to what constitutes an appropriate question to be used in tandem with an SRS. This was mentioned by 7 students (P1, P3, P5, P8, P10, P15, P16) and touches upon questions' attributes, such as: small (P16), relevant (P8), specific (P3), important for the course (P8, P16). Typical excerpts are:

- *having these small questions with the clickers underlined what were the key take-away's from the lecture or from the course* (P16)
- *also it [each of the questions] highlights important things. Because I assume that the questions are related to those things that he [the lecturer] wants us [the students] to know* (P8)
- *it is a kind of solving numerical problems which was very useful for me and the clickers was a nice way of implementing these problems* (P3)

E. STUDENTS' MOTIVATION

This theme is about the two sides of the same coin: students' motivation (P6) and demotivation coming from frustration (P5). The former revolves around them feeling activated via the use of clickers and the latter is about answering wrong and the feeling of frustration associated to it. This theme emerged in the interviews of 6 students (P1, P5, P6, P8, P11, P12). Typical excerpts include:

- *it can be frustrating if you see that your answers are wrong compared to the others* (P5)
- *try to get the correct answer, that was really motivating* (P6)

F. SUGGESTIONS BY THE STUDENTS

This theme involves suggestions given by the students on how the use of clickers could be implemented in the lectures. They can be categorised in three main groups: a) practical considerations such as the use of own mobile phones (P1, P5, P7, P10, P14), b) the activation of some learner tracking that would enable students to see their history (i.e progress across the different lectures of the course) and reflect (P9, P12, P16), and c) timed questions and the difficulty to adjust the timing of the questions, i.e. how much time is given to the students to answer each question. provided their suggestions (P4, P8, P13). Below are three excerpts, one from each category respectively:

- *...because people usually have their phones and it is pretty fast* (P8)
- *...to be able to see your own progress during the semester* (P13)
- *I think that this is difficult to adjust [the time to answer the questions], because some people are really fast* (P4)

G. GAME-LIKE ELEMENTS

This theme refers to the fact that a small number of students (5 students: P1, P3, P6, P11, P12) considered the learning situation like a game, at some extent. The main game-like element of the learning situation introduced by using the clickers according to these students was competition (P12) and social comparison (P6) among the students. Typical excerpts from students' interviews:

- *by introducing the clickers and together with my competitive nature it made me pay a more attention compared to what would probably do and raised my engagement level, because it is also fun* (P12)
- *especially since I knew that I would also get responses from the other students in the class and I wanted to be better than them* (P6)

VI. DISCUSSION AND CONCLUSION

The aim of the study was to understand students' perceptions on introducing an SRS in a power electronics course with a series of questions in selected points of lessons throughout the course. The introduction of SRS was intended to promote deep learning on behalf of the students via supporting student engagement, motivation and monitoring student progress.

Previous research on SRS has showed that they can be used as a mean for allowing students to actively participate in a university lecture, since their use can extend beyond the conventional type of a lecture by allowing for enhanced opportunities for formative student assessment and ongoing instructional feedback. More specifically, they can improve classroom dynamics (e.g., the possibility to answer questions anonymously, and to compare answers to peers, creating a safe environment for the students where their performance is not publicly judged, improved instructional feedback process), student engagement (e.g., enhanced focus and attention, increased participation and attendance) and student learning (academic performance).

The curriculum of the power electronics course requires a deep understanding of basic concepts in power electronics and fundamental knowledge of several disciplines not necessarily limited to electrical engineering. Therefore, in the case study discussed here it was necessary to develop learning activities with a specific focus on monitoring and advancing students' understanding, while increasing student engagement and motivation during the lectures. Developing curriculum for a course in advanced power electronics that engages students requires a shift away from the lecture-based delivery model to a more interactive and student-centred teaching approach. Consequently, the motivation behind the use of SRS pertained to the fact that the pedagogical affordances of SRS mapped the pedagogical requirements of teaching advanced power electronics concepts.

The participant students were interviewed with respect to several parameters that were pinpointed as relevant by the previous literature on the integration of SRS in Higher Education settings (see Sections 2 and 5.2), namely: classroom dynamics, engagement, motivation and improved learning experience. In addition, parameters such as student satisfaction and motivation have been acknowledged by the educational research literature as important predictors of student learning. The results were analysed qualitatively using Thematic content analysis.

These themes, in descending order of occurrence in the students' answers, are: 1) student attention, 2) instructional feedback, 3) anonymity of students' answers in the quiz, 4) asking appropriate questions, 5) students' motivation, 6) suggestions by the students, and 7) perceived game-like character of the SRS activities. The seven themes could be broadly grouped into two main categories, those related to instructional design (instructional feedback, anonymity of student answers, appropriate questions, game-like character) and those related to the participant students themselves (student attention, student motivation, students' suggestions). It is not possible to conclude on the relative importance between these two categories for the research question at stake.

Succinctly, according to the majority of the students, the integration of SRS managed to sustain their attention levels throughout the lessons in which SRS was used. Also, many of them highlighted the importance of using the SRS activities as an opportunity of providing immediate and elaborative feedback. In addition, giving to the students the opportunity of answering the SRS questions anonymously was well-received by them. A considerable number of students thought that the SRS teaching method had a positive impact on their motivation, and a small number of them appreciated the element of competition and the social comparison element introduced by the SRS questions. Furthermore, students mentioned that small, relevant and specific questions are appropriate for use with SRS. The term ''small question'' refers to a question that does not contain a complex set of multiple sub-questions, that can be read quickly and touches upon a specific issue or topic that has been just presented in the class, and which is to be highlighted by the lecturer. Besides, the term ''relevant question'' refers to the focus of the questions on the on-going lecture with the aim to increase awareness among the students regarding important topics. The questions are not built upon theories and knowledge from other lectures in the course. Finally, a small number of students had suggestions on how they would prefer learning with SRS, such as the use of own mobile phones, and activating a mechanism that can show to the students their history of their performance and progress.

The opinions of the students concerning the perceived benefits of SRS confirm previous research on the actual pedagogical affordances of SRS: increased levels of students' engagement, participation, and motivation [28], [33] as well as improved instructional feedback [51]. Also, they confirm previous research related to interactive learning environments: that students engaged in such environments dedicate their attention [18].

On the other hand, herein the students also mentioned demotivating factors, something that has not received particular attention in the SRS literature so far, especially when it comes to drawbacks of SRS. Two demotivating factors emerged from the answers of the students: solving incorrectly problems as well as performing lower than peers, which shows that some of the students embarked in a logic of social comparison irrespective of the fact that the use of SRS did not encourage it as much as a gamified SRS. Yet, the participants did not emphasize known drawback of SRS from previous literature, such as: dealing with logistics and training [28], [52] and blind answer guessing due to anonymous voting [28], [53]. Consequently, the findings concerning perceived drawbacks of SRS are unexpected.

The participant students also appreciated the anonymity of the questions as well as the provision of immediate feedback and this is not surprising, since both are mentioned as benefits of SRS in the literature [29], [33]. Yet, regarding the provision of instructional feedback, the students emphasised herein that it was the combination of immediate and elaborative feedback that made the difference for them. That is, the fact that the tutor explained why a particular answer is correct and the remaining ones were wrong or partially correct.

The pedagogical affordance of SRS that was most commonly mentioned by the students is the enhanced student attention and concentration during the lectures, something that is not particularly highlighted in previous research findings, except for [34]; one study [33] mentions distraction as a possible drawback of SRS. A possible explanation could be that this is a contextual factor: that is, for this particular context (i.e. lecture-based, electrical engineering course, complex learning, interdisciplinary student knowledge) where the educational innovation took place, the fact the SRS teaching method enhanced students' attention and concentration was perceived as the most important factor by them.

A finding that was also mentioned in previous research on SRS in higher education is the perceived importance of using SRS along with subject-matter questions that are appropriate for that purpose. In particular, in both [39] and [37] the integration of SRS was orientated towards students' conceptual understanding. This finding, is line with the concept of TPCK (Technological-Pedagogical-Content-Knowledge), a theoretical framework that pinpoints to the importance of designing learning activities by effectively and purposefully aligning the educational technology used with the characteristics of the subject-matter being taught and the pedagogical method followed [54]. It clearly emerges from our study that this is something that students can realise and appreciate.

These findings can have research and practical implications. The former touch upon the potential of this study of informing the research on didactics in the field of electrical engineering in Higher Education. SRS are tools which can be used in numerous ways, but using them in ways that are well-received by the students is detrimental since the students' perceptions of the learning environment influences how a student learns [3], considering learning as a process that pertains to active engagement, motivation, and cognitive gains. Ensuing recommendations include the difference of integrating versus just using SRS: 1) it was used complementary to lecture-based teaching, 2) with questions in selected points of the learning content where it was mostly pedagogically meaningful, 3) with questions that were anonymous and 4) accompanied with immediate feedback that was not only confirmatory but also elaborative. In addition, the findings can be useful to course designers of similar learning contexts or to program designers of electrical engineering courses in Higher Education, since no prior empirical research study was found on using SRS in electrical engineering topics.

Limitations of our research include the small number of the participant students and their geographical distribution, i.e. the fact that all live in Trondheim, Norway. This, in turn might have a negative effect with respect to the generalisability of the results. Also, that although the interview protocol catered for reliability and validity, it is still not possible to exclude interview research effects such as interviewer bias. Future research plans include extending the research work with other similar topics in electrical engineering with a larger cohort of students as well as in similar topics.

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