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Comparative Analysis of Electronics Circuit Simulation software (EDA tools) for E-learning and Assessment

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ABSTRACT

Assessment is one of the important processes in teaching-learning. Student's performance in formative assessment decides the feedback and successive learning experience to be provided, while summative assessment decides the student's learning on course completion. The assessment tools to be used in a course depend on the nature of the course and course outcomes. Course outcomes statements are prepared in the context of Bloom's Taxonomy. The quality of assessment influences the student's learning. Nowadays, a higher student-to-faculty ratio impacts the quality of assessment. Online learning management systems and assessment tools can effectively address the concern in quality teaching – learning, and assessment.

The course on analog electronics is a basic course offered in many electrical allied engineering programs. This course requires analog electronics circuit analysis and design. Circuit simulation tools are widely used in teaching and learning electronic circuits. However, the use of simulation tools in assessment is not widely in practice. This paper presents a survey of various electronic circuit simulation tools and a comparative analysis of their features for their suitability for analog circuit simulation and integration with online learning platforms.

Keywords — E-learning, online teaching, Assessment, electronics circuit simulation, bloom's taxonomy, online learning management system, EDA tools.

I. INTRODUCTION

Nowadays, a higher student-to-faculty ratio (SFR) is the main concern in the delivery of quality education. The imbalance between a large number of students and a limited number of faculty members can indeed create problems in teaching [1] and quality of assessment. The interaction between the mass of students and fewer teachers can significantly affect assessment and student outcomes. Assessing large populations of students poses a significant burden on teaching staff capacity, especially when strict deadlines for feedback exist [2]. Imbalances in student-to-faculty ratios can indeed lead to poor assessment practices in education. Additionally, the current educational system often fails to address the personal needs of individual students, leading to feelings of alienation and discontent [3]. Research suggests that assessment plays a crucial role in student learning [4], with frequent testing positively impacting student engagement and performance [5]. Furthermore, students' perceptions of assessment tasks and the classroom assessment practices of teachers can significantly impact students' academic self-efficacy beliefs [6].

Online assessment can play a vital role in quality teaching-learning and assessment. Nowadays, many Learning Management Systems (LMSs) are available which support various assessment tools and methods. However, online automated assessments of higher-order thinking skills are still a challenge. Particularly in engineering courses where design problems demand certain domain-specific drawings and diagrams. In such cases, designing assessment tools and evaluations is more challenging.

Many Massive Open Online Courses (MOOC) platforms are also available. In Massive Open Online Courses (MOOCs), assessing complex and open-ended student assignments remains challenging [7]. To address this burden, automated tools like formative e-assessments in virtual learning environments can help assess students effectively and provide feedback, reducing the workload on facilitators [8]. These tools streamline the assessment process and contribute to maintaining the sustainability of Massive Online Courses by improving learners' performance [9].

A student's learning can be further improved if one-on-one teaching experience is provided based on his skills and knowledge [10]. To provide such a learning experience, many projects have been developed, such as a Web-based Intelligent Tutoring System for the Course on Control System Design [11].

This next section presents a review of various online learning platforms, followed by a review of adaptive e-learning platforms such as Online Intelligent Tutoring Systems. Section III presents the specific requirements of high-order thinking skills related to design problems and its assessment for the course on Analog Circuit Design. Electronic Design Automation (EDA) tools are widely used in the design and simulation of electronic circuits. Section IV presents the survey of various EDA tools and their capabilities for integration with online learning systems.

II. ONLINE LEARNING PLATFORM

Online learning refers to instruction delivered electronically through various multimedia and Internet platforms. Online learning is one of the most important means of learning in all

areas and levels of education and training. An online learning platform is specialized software, sometimes referred to as a virtual learning environment or the Course Management System (CMS) [12]. This software should be capable of providing facilities for both the development and the delivery of e-learning services. Furthermore, online learning platforms break through time and space limitations, connecting students and teachers effectively, enriching the learning experience, and enhancing teaching efficiency.

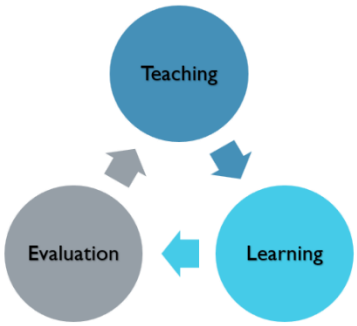

Figure-1 Education Process

In the last few decades, attempts have been made to develop adaptive online learning platforms that offer personalized one-to-one teaching and learning. These types of platforms provide very effective learning [11] [13]. Online platforms offering personalized learning experiences have significantly benefited one-to-one learning scenarios.

Teaching-learning-evaluation (figure-1) is a crucial process in education that involves assessing learning goals, providing feedback for improvement, and ensuring accountability. Educators must be competent to conduct effective evaluations, considering cognitive and non-cognitive aspects. Proper evaluation enhances teaching quality, motivates students, and determines the success of the learning process. Evaluation helps educators understand student progress, the effectiveness of teaching methods, and the overall quality of education, highlighting the importance of continuous assessment for educational enhancement [14]. Most Institutions use Learning Management Systems (LMS) platforms to facilitate online learning [15]. These systems organize content, assignments, and assessments. Assessment is pivotal in Learning Management Systems (LMS), contributing to effective learning experiences.

The CMS is usually a distributed online system connected to the Internet through the e-Learning web portal. Throughout history, some educational institutions have started the process of creating of enterprise open-source applications such as course management systems and electronic bulletin (e-bulletin) boards. These are some of the initiatives taken by higher institutions to move away from proprietary software towards open source. These platforms are normally located on a computer on the Internet and are typically accessed using a Web browser. Many educational organizations already have the infrastructure to support online tests and have also started experimenting with such tools in their teaching and learning activities. Many online tools support managing online assessments [16].

Various noteworthy systems have been developed to address the problems of automatic evaluation of question papers or assignments. The automatic evaluation systems being developed nowadays have a web interface so that the system can be accessed universally through any platform. Blackboard [17], WebCT [18], Moodle [19] etc., are different types of LMS. They all have many features that are easy to use and can be extended with even more functionality. Through web interfaces, they provide support for a wide collection of activities, including forums, assignments, and quizzes, and effective strategies for class management, such as grade books or student annotations. MOODLE is an open-source LMS. There are third-party modules and plugins available so that you can add special functionality that is not part of the standard core code. In all the above LMSs mentioned, the assessment of higher-order thinking skills remains the challenge.

III. ITS AND COURSE ASSESSMENT

Intelligent tutoring systems (ITS) have revolutionized course assessment by providing personalized and adaptive learning paths based on continuous feedback and assessment [20]. These systems aim to model the domain being taught and the student's mastery level, offering a more efficient and effective learning experience. By combining ITS with technologies like Markov decision processes (MDP) and query equivalence solvers, educational platforms like ViSQL have emerged, offering comprehensive teaching, tutoring, and assessment functionalities within a single system [21] . Such systems not only guide students efficiently towards higher intelligence levels but also enable the evaluation of learner performance parameters in real-time, enhancing the overall learning experience and assessment process [22].

Bhatt C. B. and Rao N. J. [10] have developed an Intelligent Tutoring System for the course on Control System Design. It is a web-based tool that provides individualized support to learners. An intelligent tutoring system should test the student's skill and knowledge in a given learning context, as defined by a set of learning objectives, and guide him through appropriate learning experiences. The system defines the learning objectives using Bloom's Taxonomy and Categories of Engineering Knowledge. The learning resources in the system are stored along with the metadata prepared in the context of Bloom 's-Vincenti Taxonomy proposed by the authors [13]. It captures the present state of the student's knowledge, which is then used to guide him. The tutoring module consists of ontology about the facts of the instruction material and a rule base based on the categories of engineering knowledge (Vincenti) and cognitive skills (Bloom's Taxonomy). The proposed way of knowledge representation supports scalability and reusability [10]. The authors have recommended pursuing further research in design assessment tools on automated assessment of higher-ordered thinking skills in engineering courses, where a solution to design problems involves mathematical equations, computer programs, and various types of diagrams.

IV. ANALOG CIRCUIT DESIGN COURSE

All the electrical allied engineering programs offer a course on Analog Circuit Design. In real life, most physical variables we observe and measure are continuous in amplitude and time.

These variables are converted to electrical signals, which are called analog electrical signals. Analog Circuits are used to perform various processes on analog electrical signals. The content of an analog circuit course typically includes fundamental transistor circuit analysis, operational amplifiers and their various circuit configurations, and a circuit's time response and frequency response.

Electronic circuit simulation is crucial in evaluating various aspects of electronic circuits. Studies have shown that utilizing computerized simulation with electronic circuits positively impacts students' motivation, achievement, and cognitive load [23]. During the Covid-19 pandemic, the shift to online learning necessitated the use of simulators to support virtual practicum activities related to basic electrical circuits [24].

Traditionally, electronic circuits were modeled and simulated using special-purpose electronic circuit simulators. Although several such simulation tools have been made available over the years, the one tool that is used widely is the "Simulation Program with Integrated Circuit Emphasis (SPICE)." It is widely used in open-source and commercial Electronic Design Simulation and Design Automation tools [25]. It was first released in 1972 by the University of California at Berkeley, followed by many further versions and add-on features. SPICE model has become a de facto standard in EDA tools.

V. ELECTRONIC DESIGN AUTOMATION (EDA) TOOLS

EDA tools are widely used in teaching and learning. Using EDA tools, students can actively engage in circuit design, receive automatic feedback, and improve their understanding of circuit components and connectivity. Reflection through SPICE simulation encourages self-regulatory behaviors and helps students recognize errors and strategize for future improvement. Overall, evaluation using circuit simulation tools not only boosts motivation and achievement but also reduces the cognitive load on students, making it a valuable tool for skill identification and development in electronics technology.

Though EDA tools can be effectively used in continuous evaluation and improvement of student skills, their use in student performance assessment is very rare. Even its use is mostly limited to offline teaching and learning. Nowadays, many EDA tools are available which can be used online. This section evaluates different EDA software programs based on their features useful for online teaching, learning, and assessment.

Open-source EDA tools have emerged as valuable alternatives for research and academic purposes due to their cost-effectiveness and transparency. Projects like OpenROAD, OpenLane, and the development of open-source EDA technologies are gaining traction [26].

EDA tools have different types of components like lumped components (resistors, capacitors, transformers, etc.), digital components (gates, flip-flops, multiplexer, de-multiplexer, etc.), sources (current source, voltage source, etc.), etc. Users place these components in the design area and connect them through wires in the schematic diagram. Each EDA tool has its file format to store the graphical schematic diagram. This file is called a netlist file. It contains the element type, an element's specification, and connectivity information between elements. A schematic file is processed by the netlist compiler to create a netlist file. The next step is verification of the design through simulation, which is the software equivalent of hardware prototyping.

SPICE (Simulation Program with Integrated Circuit Emphasis) simulation circuit follows language that describes device models and circuit data in text format and is called a netlist.

The most widely used simulation tools in electronics and electrical engineering are QUCS, Circuit Maker, and LT Spice. These software packages are essential components that help simulate and analyze electronic circuits before hardware implementation.

A brief feature discussion about the three widely used tools is given next, followed by a comparison of the important features useful in online platforms.

QUCS

QUCS (Quite Universal Circuit Simulator) [27] is an educational software program. It helps us to generate schematic diagrams and check their performance. It has a Graphical User Interface (GUI) based on Qt® by Trolltech. A Qucsator simulation engine is used to simulate circuit designs in QUCS. It has a wide range of component libraries, which include lumped components, sources, probes, transmission lines, nonlinear components, digital components, simulations, file components, diagrams, and paintings.

It supports circuit simulation types, such as DC analysis, AC analysis, S-parameter, Harmonic Balance analysis, S-parameter noise, AC noise, transient analysis, etc. SPICE netlists can be read and simulated by QUCS using the conversion program 'Qucsconv'. It uses FreeHDL and Icarus Verilog for VHDL and Verilog digital simulation.

Simulation data can be presented in various diagrams, including Smith-Chart, Cartesian, Tabular, Polar, Smith-Polar combination, 3D-Cartesian, Locus Curve, Timing Diagram, and Truth Table. It takes a netlist, checks it for errors, performs the required simulation actions, and produces a dataset. Many of the basic circuit components and simulation domains found in SPICE are also available in QUCS [28].

Circuit Maker

Circuit Maker [29] is a Microcode Engineering proprietary product protected by Copyright Law. Circuit Maker is a simulation program that, in most cases, produces results very similar to a real-life circuit. Circuit Maker allows the minimization of the breadboarding required to produce a functional circuit. However, it should not be used as a replacement for proper breadboarding. Using Circuit Maker's advanced schematic capabilities, one can design electronic circuits and output netlists for TraxMaker and other PCB design tools, and auto routers. It also enables the performance

of fast and accurate simulations of digital, analog, and mixed analog/digital circuits using Circuit Maker's Berkeley SPICE/XSpice-based simulator.

LT Spice

It is free simulation software which Linear Technology provides [30]. LTspice is also called SwitcherCAD by its manufacturer since they use it primarily to design Switch Mode Power Supplies (SMPS). A nice feature in LTspice is that several models may be added to any symbol. This means that there does not have to be a symbolic view for every model included in the library. This makes it very easy to add new device models to the component library and adjust model parameters if needed. The file structure for LTspice is very simple, which makes it easy to add any components to its library structure. All libraries are simple ASCII files, and the user only has to open the respective file in any editor and cut and paste the corresponding component of the spice model into this file. When this has been done, the new model should appear when the user tries to pick a new component again.

Comparison of EDA Software

The table-I presents a comparison of QUCS, CircuitMaker, and LTspice. The comparison is based on the library of components, open-source or proprietary tools, types of circuit analysis that can be done, and the workings of the simulation engine. It also presents the comparison of the ability of the tools to be integrated into the online platform.

TABLE I
COMPARISON OF EDA SOFTWARES

Parameter	QUCS (Quite Universal Circuit Simulator)	Circuit Maker	LT Spice
Power source AC, DC	Available	Available	Available
ALL Passive and active components	Available	Available	Available
All type of analog components (Op-Amp)	Available	Available	Available
Simulation Analysis AC, DC and Transient	Available	Available	Available
S- Parameter	Yes	No	No
Temperature	No	Yes	Yes
Noise	Yes	Yes	Yes
Harmonic Balance	Yes	No	No
Subcircuit	Yes	Yes	Yes
Runs on Windows?	Yes	Yes	Yes
Other Platforms?	Linux, Solaris, Mac	Linux, Mac	Linux
Open Source?	Yes	No	No
Spice Netlist Format	No (QUCS Netlist Format)	Yes	Yes
Is online version available	No- Offline Version 0.0.19	No- Offline Version 2.2.1	No- Offline Version 24.0.12
Can be integrated with LMS?	Yes	No	No

VI. CONCLUSIONS AND FUTURE WORKS

Over the last three decades the SPICE simulation circuit netlist language has become a standard for describing, interchanging and publishing semiconductor device models and circuit data. Therefore, EDA tool which follows SPICE model-based simulation, have wide range of basic components, allows to perform various required analysis to be carried out in a course, and also open source is the best option to be used in teaching-learning and assessment.

Qucs and SPICE differ significantly in circuit file netlist formats, which are very different. Qucs cannot directly simulate standard SPICE circuit netlists but requires them to be converted to their Qucs equivalent prior to simulation [27].

Circuit Maker is user-friendly software. It works on spice model. It is not an open-source tool and it can be difficult to integrate with LMS.

LT spice is also user-friendly software. Its format is quite similar to SPICE netlist file. Its netlist file format is quite simple and understandable. This is an important feature. But it does not allow digital simulation and it is free but not an open source so it cannot be useful for further integration in LMS.

As discussed above the three software are not suitable to integrate in LMS. It is necessary to develop one such tool for electronics circuit simulation which can be integrated with LMS and also used for assessment purpose.

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