DOI: doi.org/10.58797/cser.020303

Improving Vocational Education with a STEM Approach to Op-Amp Circuit Theory and Practice

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Abstract

This study examines the use of the STEM (Science, Technology, Engineering, and Mathematics) approach in the instruction of operational amplifier (Op-Amp) circuit concepts to students of vocational education. With simulations and exercises done virtually, this study aims to enhance theoretical and practical capabilities of students in the learning of Op-Amp circuits, focusing on inverting amplifiers, non-inverting amplifiers, and summing amplifiers. The study produced STEM-based teaching materials in PowerPoint presentation form, including descriptions of theory, practice examples, sample problems, and quizzes. Findings indicate that incorporating a STEM approach encourages greater student interaction, critical thinking, and problem-solving capacity. Moreover, the online simulations offer an open platform for students to experiment and learn by hand in circuit design and analysis. According to the research, the application of STEM-based education practices has a great capability in improving vocational learning outcomes, particularly in the context of technical disciplines such as electronics.

Keywords: STEM, technology-based learning, vocational education

Received: 8 December 2024
Revised: 22 December 2024
Accepted: 22 December 2024
Published: 30 December 2024
Assigned: 30 December 2024

Current Steam and Education Research
e-ISSN: 3025-8529

INTRODUCTION

The rapid development of technology today requires adjustments in various fields, including education (Esteve et al., 2022). In the era of the industrial revolution 4.0, student competence is not only measured by theoretical understanding, but also by their applicative, innovation and collaboration skills (Kim et al., 2022). In the context of learning in Vocational Schools, the STEM (Science, Technology, Engineering, and Mathematics) approach can be the key to creating learning that is relevant to the needs of the industrial world (Mathieson et al., 2023). This approach can be integrated in the form of PowerPoint learning media. Learning media is anything that can channel messages, stimulate thoughts, feelings, and willingness of learners so as to encourage the creation of learning processes in learners (Jamali et al., 2022). This approach encourages students to integrate knowledge across disciplines in solving real problems, so that their critical and creative skills develop. One of the materials relevant to technological developments is the operational amplifier (op-amp) circuit. That is because Operational Amplifier or op-amp is one of the popular analog components used in various electronic circuit applications (Zhou, 2020). Until now, there has been no article analyzing the amplifier circuit with the Op-Amp LM741 configuration using Multisim software, which can be a STEM-based learning material for vocational students

In the recent years, there has also been greater emphasis on embedding the STEM approach into vocational study (Deepthi & Exley, 2023). This was carried out in a bid to put students better in line for responding to shifting requirements of the employment market by setting them upon firm bases regarding technical know-how and real-world skills (Xu et al., 2022). Technical students, especially those studying technical subjects like electronics, have certain difficulties in studying complex topics like operational amplifier (Op-Amp) circuits (Montoya et al., 2022). These circuits, being a component of electronic devices, not only require that students understand theoretical concepts but also gain practical experience for implementing these concepts in real-world applications.

The STEM approach favors the learning process more integrated and practical. As an illustration, while studying about Op-Amp circuits, the students can benefit from using virtual simulations that can emulate real conditions (Falloon, 2020). These help the students prototype circuit designs, debug, and understand how the Op-Amps operate without any physical hardware constraint (Park et al., 2020). Additionally, STEM-focused teaching materials, such as interactive PowerPoint presentations that include theory, applications, example problems, and quizzes, provide an interdisciplinary approach to learning that suits various learning styles (Abouhashem et al., 2021).

Another essential advantage of applying a STEM-based approach is the potential to increase student engagement (Mulvey et al., 2023). By incorporating theory with hands-on, technology-driven exercises, students are more likely to stay interested and develop a deeper understanding of the material (Niiranen, 2021). Use of simulations not only enhances the students' technical competency but also facilitates creativity, problem-solving, and analytical skills that are essential in future careers as technologists and engineers (Lee & Lee, 2022). Additionally, this process makes learning an individualized exercise, where students progress at their own pace and receive immediate feedback on their performance.

Operational Amplifier or better known as Op-Amp is one of the Linear IC forms that functions as an electric signal amplifier (Paul et al., 2021). Operational Amplifier is a component that has a function in the form of mathematical operations contained in electrical voltages, apart from addition there are also integrations and decreases as well as comparators or comparators (Hassanein et al., 2023). The structure of the Op-Amp consists of several diodes, transistors, capacitors and resistors that are integrated to produce gain at a wide frequency or also called an operational amplifier (Alisrobia et al, 2022). In its use Op-Amp is divided into two types, namely linear amplifiers and non-linear amplifiers. A linear amplifier is an amplifier that maintains the shape of the input signal, which includes this amplifier including a non-inverting amplifier, inverting amplifier, differential summers and instrumentation amplifiers (Corbacho et al., 2022).

An inverting amplifier circuit using an op amp is an amplifier circuit by reversing the phase value with a very low input impedance (Kazama et al., 2021). An inverting amplifier uses negative feedback to invert and amplify a voltage. If the input signal is fed to the Op-Amp. through the inverting input terminal, then the output in addition to amplified voltage will also be 180^0 phase different from the input. Conversely, if fed through the non-inverting input terminal, the input voltage is amplified without a phase difference between the output and the input (Gintings et al, 2019). This is because, Non Inverting Amplifier is a signal amplifier with the basic characteristics of the amplified output signal having the same phase as the input signal (Tamrakar et al., 2022).

The operational amplifier (Op-Amp) is packaged in an integrated circuit (IC). Most Op-Amp has a simple frequency response. One popular type of operational amplifier (Op-Amp) is the LM741. IC 741 is an operational amplifier packaged in the form of a dual in-line package (DIP). Op-Amp functions as an active amplifier that allows the creation of various kinds of electronic circuits. Op amps are widely applied to electrical analog circuits such as voltage amplifiers, summation of two voltage sources, amplifying the difference between two voltages and others.

METHOD

The approach used is a STEM approach by designing an amplifier circuit with an Op-Amp LM741 configuration and other components, then capturing the screen for analysis. This analysis is done virtually. The software used is Multisim by utilizing components that are provided free of charge. The first step in this approach is to understand the basic principles of op-amp operation. Basically, Op-Amp is a high-powered operational amplifier with two inputs and one output (Merdeka et. al, 2022). In this research, the types of Op-Amp circuits discussed consist of inverting, non-inverting, and summing amplifier circuits.

The second stage is to design the Op-Amp amplifier circuit by utilizing Multisim software. The initial stage is to open the software. After opening the software, the next step is the treatment of making inverting voltage amplifier and non-inverting voltage amplifier circuits using resistor components, Op-Amp devices, ground, oscilloscope, and signal generator. The circuit is shown in Figure 1 and 2.

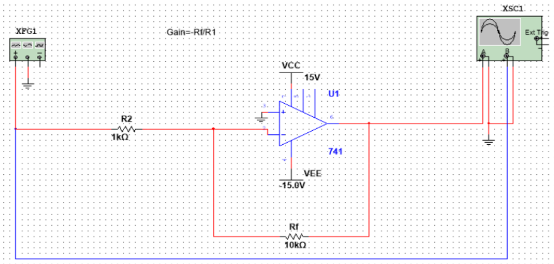

Figure 1. Inverting Voltage Amplifier circuit

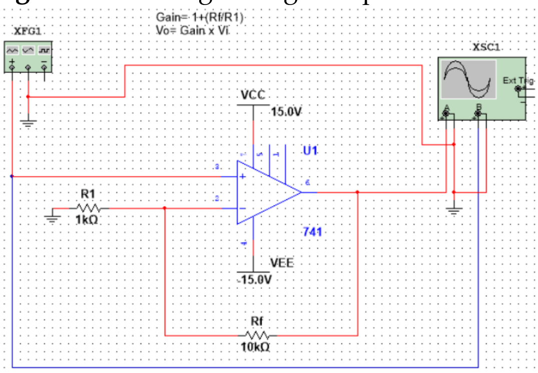

Figure 2. Inverting Voltage Circuit

While the summing amplifier circuit uses resistor components, Op-Amp LM741 device, ground, AC voltage source, oscilloscope, and multimeter. The circuit is made as shown in Figure 3.

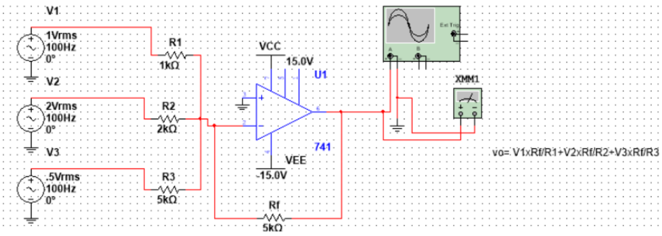

Figure 3. Summing Amplifier Circuit

The next step is to analyze the circuit by collecting the calculation results of the gain and output voltage (V_{out}) of the circuits that have been made. The gain of the op-amp circuit can be expressed by

In the inverting circuit with:

$$R2 = 1\ k\Omega$$
$$Rf = 10\ k\Omega$$
$$Vin = 1\ V$$

Has the result of gain and output voltage

$$\text{Gain} = \left(\frac{R_f}{R_2}\right) = -\left(\frac{10000}{1000}\right) = -10$$

$$Vout = Gain \times Vin = -10 \times 1 = -10\,V$$

In the non-inverting circuit with:

$$R1 = 1k\Omega$$
$$Rf = 10k\Omega$$
$$Vin = 1\,V$$

Has the result of gain and output voltage

$$Gain = 1 + \left(\frac{R_f}{R_1}\right) = 1 + \left(\frac{10000}{1000}\right) = 11$$

$Vout = Gain \times Vin = 11 \times 1 = 11\,V$

In the summing circuit with:

$$R1 = 1k\Omega$$
$$R2 = 2k\Omega$$
$$R3 = 5k\Omega$$
$$Rf = 5k\Omega$$
$$V1 = 1\,V$$
$$V2 = 2\,V$$
$$V3 = 0.5\,V$$

Has a gain result and output voltage

$$\text{Gain}=\frac{R_f}{R_1}+\frac{R_f}{R_2}+\frac{R_f}{R_3}=\frac{5000}{1000}+\frac{5000}{2000}+\frac{5000}{3000}= 5 + 2.5 + 1 = 8.5$$

$$\text{Vout}=V_1\left(\frac{R_F}{R_1}\right)+V_2\left(\frac{R_f}{R_2}\right)+V_3\left(\frac{R_f}{R_3}\right)= 1\left(\frac{5000}{1000}\right)+2\left(\frac{5000}{2000}\right)+3\left(\frac{5000}{3000}\right)\text{=5+5+0.5= 10.5 V}$$

RESULTS AND DISCUSSION

The teaching materials produced from this research are in the form of learning PowerPoints with a STEM approach. The PowerPoint was created using Canva which can be accessed through the web or application. This learning PowerPoint is used for material presentation in class. This learning PowerPoint was developed with basic operational amplifier circuit material. This learning PowerPoint is also equipped with competencies and learning objectives, theory about operational amplifiers and their applications which are equipped with sample circuit images and there are sample problems, discussions and calculations about the circuit. There are also assessments to train and test students' understanding. This PowerPoint can also be accessed via PC/Computer/Smartphone/Tablet offline if it has been downloaded. The following are the components of the Operational Amplifier teaching material PowerPoint with a STEM approach:

Figure 4. Learning Media

Table 1. Implementation of STEM in Basic Op-Amp Circuit Material

Science	Circuit concepts using Op-Amp
Technology	Use of Multisim software
Engineering	Circuit design
Math	Calculation of output voltage and gain

Traditional teaching methods that rely primarily on lectures, textbooks, and repetition are no longer as effective in addressing the diversity of learning needs of vocational education students. Vocational education is practical skills and application, but these methods tend to concentrate on theory that may not necessarily work in translating to the hands-on that students need. In areas like electronics, where abstract constructs like Op-Amp circuits are the topic of study, more than just reading definitions or formulas is required to learn. Students need room to learn from each other interactively, connecting theory to real-world applications to ingest the material comprehensively.

This lack of fit between traditional teaching methods and practical requirements of vocational education often leads to disinterest and short-term knowledge retention. Students will not enjoy the practicality of theoretical materials when they cannot make the direct connection between what is studied and application. This is most prevalent in courses such as electronics, where studying is so far from the process of execution. Without the process of application through experimentation and exposure to devices, the student might have no way of attaining problem-solving methods critical to the job in the future.

Also, the conventional system is not always flexible enough to cater to multiple learning styles and needs of students. In a vocation classroom, some might be visual learners, while others will be more apt to learn through experimentation or collaborative problem-solving. One model binds students from learning in a manner that best suits their respective strengths. Students who struggle with traditional methods can feel behind, leading to frustration and demotivation. For example, a student who learns by interacting with computer simulations may not be able to fully benefit from a lecture-based method that does not involve hands-on experimentation.

The application of STEM-based teaching methods offers a solution to these issues. By incorporating science, technology, engineering, and mathematics, STEM techniques accommodate a more hands-on and interdisciplinary way of learning. Virtual simulations, for instance, offer an immersive and interactive experience that is not possible with conventional techniques. Students are able to test Op-Amp circuits virtually, debugging issues and seeing complicated concepts visually in real-time. These materials not only address the different learning styles of students but also optimize engagement and support deeper understanding. By going beyond theoretical memorization, STEM-based methods allow students to apply knowledge in real-world settings, building the problem-solving and analytical skills required for professional achievement.

In conclusion, traditional teaching approaches in vocational studies are likely to ignore the hands-on, experiential aspect of the topics being taught. Students need more interactive, immersive, and personalized learning that bridges theory and practice. STEM-based approaches, through technology and hands-on applications, provide a superior way of teaching complex concepts like Op-Amp circuits. These approaches not only support multiple learning styles but also enhance student motivation, interest, and retention of key skills needed in the workplace.

CONCLUSION

STEM-based learning approach is effectively used on the concept of operational amplifier (Op-Amp) circuit for vocational students' learning. By using Multisim software, students can virtually learn circuit design and analysis, including inverting, non-inverting, and summing amplifier configurations. In addition to improving students' theoretical understanding of the basic principles of Op-Amp, this learning process can train practical skills such as circuit design, output voltage calculation and gain.

The development of STEM-based teaching materials in the form of PowerPoint presentations complements the learning process by providing theory, application, example problems, discussions, and assessments to measure student understanding. The integration of science, technology, engineering, and mathematics in the STEM approach helps improve students' analytical, creative, and innovative abilities in accordance with the demands of the industrial revolution 4.0.

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