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Exploring the Efficacy of Simulation-Based Learning (SBL) for Enhancing Program Outcomes in Mechanical Engineering: A Case Study on Engineering Graphics

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***Abstract*—This research investigates the effectiveness of Simulation-Based Learning (SBL) in enhancing student comprehension of complex mechanical engineering concepts, such as fluid dynamics, thermodynamics, FEA, and mechanics. The integration of tools like MATLAB, SolidWorks, ANSYS Fluent, AutoCAD, FluidSim, BricsCAD, and GeoGebra allows students to simulate theoretical mechanics and engineering graphics, bridging the gap between theory and practice. Additionally, Machine Learning playgrounds offer hands-on AI experience. A key novelty is the development of an Automatic Engineering Drawing Sheet Evaluation Algorithm, utilizing Python-based image processing to automate the assessment of technical drawings, increasing efficiency and accuracy. GeoGebra further serves as a tool for assessing geometric transformations in engineering graphics. Integrating simulation tools into the first-year Engineering Graphics course has significantly enhanced Course Outcomes (CO) and Program Outcomes (PO), particularly PO5 (Modern Tool Usage), with a 94.29% improvement. Tools like AutoCAD and GeoGebra have enhanced student understanding of Orthographic Projections and Isometric Views, reflected in improved test scores and positive feedback. Case studies showcase how these tools align with various POs, highlighting the critical role of SBL in modern mechanical engineering education.**

***Keywords*—Simulation based learning, Modern tools usage, Program Outcomes, Attainment.**

***JEET Category*—Practice**

I. INTRODUCTION

Visual representation is integral to effective learning, particularly in mechanical engineering, where students must navigate complex and abstract concepts. Visual aids such as simulations and interactive models significantly enhance comprehension and retention, which is essential across a range of subjects including Engineering Graphics, Theory of Machines, Strength of Materials (SOM), Design of Machine Elements (DME), Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA), Material Science, Manufacturing Processes, and Mechatronics(Praveena et al., 2025),(P. R. Beldar et al., 2025).

Simulation refers to the use of advanced software tools to model real-world scenarios, providing students with an interactive platform to explore and understand theoretical concepts. In mechanical engineering, simulation tools like ANSYS Fluent, MATLAB, SolidWorks, and AutoCAD are pivotal for addressing the challenges associated with understanding complex systems. These tools facilitate detailed analysis and visualization of fluid dynamics, structural responses, and mechanical designs. For example, simulations in Material Science can model phase diagrams, helping students understand material behavior under various conditions, while Python coding is often employed to develop custom simulations and process data, offering a step-by-step approach to complex engineering problems(P. Beldar, Rakhade, et al., 2025).

The need for simulation software is particularly pronounced in subjects involving intricate processes and detailed analyses. Theory of Machines benefits from simulations that allow students to visualize the motion and interactions of mechanical components. CFD and FEA simulations help in analyzing the behavior of fluids and structural elements under different conditions, respectively. In Material Science, simulations of phase diagrams are crucial for predicting material properties and transformations, while in Manufacturing Processes, simulation tools model and optimize various manufacturing

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techniques, enhancing students' understanding of process parameters and design considerations(P. Beldar, Galande, et al., 2025),(Anees et al., 2025).

Mechatronics, a multidisciplinary field integrating mechanical engineering, electronics, computer science, and control engineering, also benefits from simulation-based learning. In mechatronics, simulations provide an interactive platform to design, test, and optimize complex systems involving sensors, actuators, and control systems. Tools like MATLAB/Simulink and LabVIEW offer environments to simulate the behavior of mechatronic systems, allowing students to model and analyze dynamic interactions between mechanical and electronic components. This integration helps students grasp the principles of automation and robotics, crucial for modern engineering applications(P. R. Beldar, 2025).

Simulation-Based Learning (SBL) offers numerous benefits for mechanical engineering students. It enhances engagement, improves problem-solving skills, and deepens understanding of theoretical concepts. By utilizing simulations, students gain practical experience in Manufacturing Processes and Mechatronics, where they can model and optimize manufacturing techniques and complex mechatronic systems. This hands-on approach not only improves their grasp of engineering principles but also prepares them for industry challenges(P. R. Beldar et al., 2025).

Recent studies highlight the significant impact of SBL on student performance, demonstrating improvements in learning outcomes and academic achievements. SBL fosters greater engagement, retention, and comprehension of challenging subjects such as DME, CFD, FEA, Material Science, and Mechatronics. Additionally, SBL aligns with Outcome-Based Education (OBE) by helping students achieve critical program outcomes, including modern tool usage, practical problem-solving, and the application of theoretical knowledge in real-world scenarios(P. Beldar, 2025),(Abburi et al., 2021).

This paper explores the efficacy of SBL in mechanical engineering, examining its role in enhancing learning across various subjects, including Mechatronics, and assessing its impact on student outcomes and program effectiveness.

A. Problem Statement:

In Batch 1 (Academic year 2019-20, 20-21, 21-22, 22-23), the analysis of Program Outcome (PO) attainment revealed that PO5, which focuses on modern tool usage, had an attainment level of 1.05. This indicates a significant deficiency in the students' ability to effectively utilize advanced engineering tools and technologies. PO5 is crucial as it involves the application of modern simulation tools and techniques to address complex engineering problems.

To address this shortfall and enhance the attainment of PO5, simulation-based learning methodologies are being introduced across relevant subjects. This approach aims to integrate advanced simulation tools and software into the curriculum, providing students with practical experience in using these tools. The objective is to improve proficiency in applying modern engineering technologies, thereby enhancing the ability to solve complex engineering problems.

B. Research Objective:

The primary goal is to address the low attainment level of PO5 by implementing simulation-based learning strategies. This intervention is expected to:

1. Enhance Tool Proficiency: By incorporating simulation tools into the learning process, students are anticipated to develop a better understanding of these tools' functionalities and applications.
2. Improve Problem-Solving Skills: Practical experience with simulation software will enable students to apply these tools more effectively to solve complex engineering problems.
3. Increase PO5 Attainment: The introduction of simulation-based learning aims to elevate the attainment level for PO5, ensuring that students meet the expected competency in modern tool usage.

This intervention is expected to significantly improve the attainment of PO5 and equip students with the skills necessary for effective use of advanced engineering tools in their future professional endeavors.

II. Literature Review

Simulation-based learning (SBL) has become a significant pedagogical approach in engineering education, offering numerous advantages in terms of enhancing student understanding and performance. Various studies highlight the effectiveness of SBL in different educational settings. Bishara, Xie, Liu, and Li review the state-of-the-art in machine learning-based multiscale modeling, simulation, and design of materials. Their comprehensive review underscores the evolving role of simulation tools in material science, which can be paralleled in engineering education to enhance conceptual understanding and practical skills (Bishara et al., 2023). Kouba et al. discuss the integration of machine learning with protein engineering, illustrating a growing trend towards incorporating advanced technologies in educational practices. Although their focus is on protein engineering, the principles of machine learning and simulation can be applied to other fields, emphasizing the relevance of such technologies in modern educational methodologies (Kouba et al., 2023). Rebello et al. provide guidelines for dynamic modeling in process engineering, discussing the transition from simple perceptron models to complex deep learning algorithms. Their work highlights the potential for simulation-based approaches to improve process modeling and prediction, which is applicable to various engineering disciplines (Rebello et al., 2022) . Aluga explores the application of ChatGPT in civil engineering, presenting a novel approach to integrating conversational AI with engineering education. This integration of AI and simulation tools can potentially enhance student engagement and learning outcomes (Aluga, 2023). Zaher, Hussain, and Altabbakh propose an active learning approach utilizing STEAMeD-based education, which emphasizes the integration of science, technology, engineering, arts, mathematics, and design in engineering programs. Their study indicates that active learning strategies, including simulation-based methods, can significantly improve educational outcomes (Zaher et al., 2023). Dahalan, Alias, and Shaharom conduct a systematic review of gamification and game-based learning in vocational education, demonstrating how these methods can be effectively applied to enhance learning experiences. The use of simulation games aligns with their findings, providing a dynamic and interactive learning environment (Dahalan et al., 2024). De Mesquita, Mariz, and Tomotani present a teaching case on discrete-event simulation, emphasizing its practical application in understanding complex manufacturing processes. This case study highlights the effectiveness of simulation tools in providing hands-on learning experiences (Mesquita et al., 2017). Deshpande and Huang review the role of simulation games in engineering education, noting their effectiveness in engaging students and improving learning outcomes. Their review supports the use of simulation-based learning to address the challenges in traditional engineering education methods (Deshpande & Huang, 2011). Negahban discusses the transition from physical experimentation to digital simulation environments, highlighting the benefits of immersive simulations in engineering education. This transition underscores the importance of integrating modern simulation tools to enhance educational practices (Negahban, 2024). Davidovitch, Parush, and Shtub examine simulation-based learning in engineering education, focusing on performance and project management. Their study demonstrates the effectiveness of simulation tools in improving project management skills among engineering students (Davidovitch et al., 2006). Koh et al. investigate the impact of 3D simulation-based learning on student motivation and performance in engineering. Their findings reveal significant improvements in both motivation and performance, supporting the integration of 3D simulation tools in educational settings (Kouba et al., 2023). Karadoğan and Karadoğan develop simulation-based learning modules for engineering dynamics, highlighting their effectiveness in enhancing students' understanding of complex concepts. Their work exemplifies the benefits of simulation tools in dynamic systems education (Karadoğan & Karadoğan, 2019). Kong explores active game-based learning in biomedical systems engineering, emphasizing the effectiveness of interactive simulations in teaching dynamics modeling. This study highlights the potential of game-based simulations to improve learning outcomes in specialized engineering fields (Kong, 2019). Nowparvar et al. assess simulation-based learning modules in engineering economy courses, demonstrating their impact on student performance and understanding. Their assessment provides valuable insights into the effectiveness of simulation tools in economic education (Nowparvar et al., 2022). Campos, Nogal, Caliz, and Juan examine simulation-based education models across European universities, showcasing the benefits of both online and on-campus simulations. Their study supports the use of simulation tools to enhance learning across diverse educational contexts (Campos et al., 2020). Davidovitch, Parush, and Shtub revisit simulation-based learning in engineering education, focusing on performance and transfer in project management. Their findings reinforce the positive impact of simulation tools on learning outcomes and skill transfer (Davidovitch et al., 2006) Hulme et al. incorporate modeling, simulation, and game-based learning in engineering dynamics education, highlighting improvements in vehicle design and driver safety. Their work illustrates the practical benefits of simulation tools in addressing real-world engineering challenges (Hulme et al., 2021) Suthar and Joshipura discuss the integration of simulation-based exercises in chemical engineering thermodynamics, demonstrating the effectiveness of simulations in enhancing conceptual understanding. Their study supports the broader application of simulation tools in engineering education (Suthar & Joshipura, 2023) Salazar-Peña et al. present a project-based learning approach for an online simulation engineering course, highlighting its effectiveness in various modeling applications. Their work underscores the potential of simulation-based project learning in enhancing educational experiences (Salazar-Peña et al., 2023). This review provides a comprehensive overview of the current research and applications of simulation-based learning across various engineering disciplines, emphasizing its effectiveness in improving student outcomes and engagement.

III. Methodology

To explore the efficacy of Simulation-Based Learning (SBL) in mechanical engineering, this study employs a multi-faceted approach involving both qualitative and quantitative methods. The methodology is designed to assess the impact of SBL on student learning across various subjects and to evaluate its alignment with Outcome-Based Education (OBE) standards(Abburi et al., 2021). Fig. 1 shows the methodology for this research.

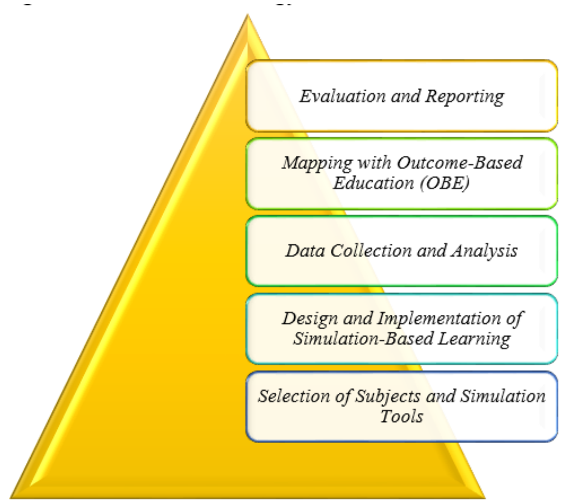

Fig. 1 Methodology

A. *Selection of Subjects and Simulation Tools*

- **Subjects Covered**: The study focuses on key mechanical engineering subjects, including **Engineering Graphics**, **Theory of Machines**, **Strength of Materials (SOM)**, **Design of Machine Elements (DME)**, **Computational Fluid Dynamics (CFD)**, **Finite Element Analysis (FEA)**, **Material Science** (including phase diagrams), **Manufacturing Processes**, and **Mechatronics**.

- **Simulation Tools**: The study uses a range of modern simulation tools:
  - **ANSYS Fluent** and **MATLAB** for CFD and FEA simulations.
  - **SolidWorks** and **AutoCAD** for Engineering Graphics and DME.
  - **GeoGebra** for visualizing Theory of Machines and Strength of Machines.
  - **Python** for coding simulations and data processing.
  - **LabVIEW** and **MATLAB/Simulink** for Mechatronics simulations.
  - **ML Playgrounds for Machine Learning**

*B. **Design and Implementation of Simulation-Based Learning***

- **Curriculum Integration**: Develop and integrate SBL modules into the curriculum for the selected subjects. Each module includes:
  - **Interactive Simulations**: Interactive tools for visualizing and experimenting with concepts.
  - **Hands-On Exercises**: Practical exercises to reinforce theoretical learning through simulations.
  - **Coding Assignments**: Python coding tasks to develop custom simulations for specific engineering problems.
- **Virtual Labs**: Implement virtual labs to simulate real-world experiments and processes, providing students with a risk-free environment to explore mechanical engineering concepts.

*C. **Data Collection and Analysis***

- **Student Performance Data**: Collect quantitative data on student performance before and after the implementation of SBL. This includes:
  - **Grades and Test Scores**: Compare performance in traditional vs. simulation-based assessments.
  - **Engagement Metrics**: Measure student engagement through participation rates and completion of simulation tasks.
- **Feedback Collection**: Use Natural Language Processing (NLP) to analyze student feedback on the effectiveness of SBL. Feedback is collected through:
  - **Surveys**: Structured surveys to gauge students' perceptions of the simulation tools and their impact on learning.
  - **Oral Viva**: In-depth oral vivawith a sample of students to gain qualitative insights into their experiences.
- **Analysis Techniques**:
  - **Statistical Analysis**: Perform statistical tests to determine the significance of improvements in learning outcomes and engagement.
  - **NLP Analysis**: Analyze feedback data to identify common themes, sentiment, and suggestions for improvement.

*D. **Mapping with Outcome-Based Education (OBE)***

- **Program Outcomes Mapping**: Align the SBL modules with specific program outcomes such as problem-solving skills, modern tool usage, and practical knowledge. This involves:
  - **Identifying Relevant POs**: Determine which program outcomes are addressed by each simulation module.
  - **Assessment of Achievement**: Evaluate how effectively the SBL modules contribute to achieving these outcomes based on student performance and feedback.

*E. **Evaluation and Reporting***

- **Comparative Analysis**: Compare the effectiveness of SBL with traditional teaching methods using performance data and feedback.
- **Impact Assessment**: Assess the impact of SBL on student understanding and application of complex mechanical engineering concepts.
- **Recommendations**: Provide recommendations for enhancing the integration of SBL in mechanical engineering education based on findings.

By following this methodology, the study aims to provide a comprehensive evaluation of SBL's efficacy in mechanical engineering, highlighting its benefits and alignment with educational outcomes.

IV. Simulation Based Learning

Simulation-Based Learning (SBL) is an educational approach that employs simulation tools to replicate real-world scenarios and complex systems, providing students with interactive and immersive learning experiences. SBL bridges the gap between theoretical knowledge and practical application, allowing students to engage with and understand complex concepts through hands-on experimentation and visualization.

*A. **How Simulation-Based Learning (SBL) Maps to Program Outcomes***

*1) **Engineering Knowledge***

SBL Application: Simulations in subjects like **Mechanical Design** or **Fluid Dynamics** enable students to apply mathematical, scientific, and engineering principles to solve complex problems. For example, using **ANSYS Fluent** for fluid simulations helps students apply their knowledge of thermodynamics and fluid mechanics to real-world scenarios.
Mapping: SBL enhances the application of fundamental engineering knowledge in practical contexts, directly contributing to the ability to solve complex engineering problems.

*2) **Problem Analysis***

SBL Application: Tools like **MATLAB** or **SolidWorks** allow students to analyze complex engineering problems by modeling and simulating various scenarios. For instance, students can use **FEA** simulations to analyze stress distributions and identify potential issues in design.
Mapping: SBL aids in identifying, formulating, and analyzing problems by providing detailed, visual, and quantitative analysis, leading to well-informed conclusions.

3) Design/Development of Solutions

SBL Application: Simulation tools support the design and development of engineering solutions. For example, **SolidWorks** and **AutoCAD** allow students to design and test mechanical components virtually, considering factors like safety, functionality, and environmental impact. **Mapping**: SBL assists in designing solutions that meet specified needs while considering various constraints and impacts, ensuring comprehensive solution development.

4) Conduct Investigations of Complex Problems

SBL Application: Using simulations to conduct virtual experiments and analyze data helps students investigate complex problems. Tools like **LabVIEW** and **MATLAB/Simulink** facilitate experimental design and data analysis.
Mapping: SBL supports the use of research-based methods for investigating problems, enabling students to derive valid conclusions from simulated experiments.

5) Modern Tool Usage

SBL Application: Students use state-of-the-art simulation tools such as **ANSYS Fluent**, **MATLAB**, and **GeoGebra** to model and solve engineering problems. These tools provide insights into modern engineering practices and their limitations. **Mapping**: SBL develops proficiency in modern tools and techniques, helping students understand their applications and limitations in engineering activities.

6) The Engineer and Society

SBL Application: Simulations can include societal and environmental considerations, such as optimizing designs for sustainability or analyzing the social impact of engineering solutions.
Mapping: SBL enables students to assess the broader implications of engineering solutions, incorporating contextual knowledge into their work.

7) Environment and Sustainability

SBL Application: Simulations in **Material Science** and **Manufacturing Processes** can model the environmental impact of different materials and processes, promoting sustainable practices. **Mapping**: SBL helps students understand and address environmental and sustainability issues by simulating the impact of engineering solutions on society and the environment

8) Ethics

SBL Application: Ethical considerations can be integrated into simulations by examining the consequences of engineering decisions, such as safety and regulatory compliance. **Mapping**: SBL promotes ethical thinking by allowing students to explore the ethical dimensions of engineering solutions and their societal impacts.

9) Individual and Team Work

SBL Application: Collaborative simulation projects, such as team-based design challenges using **SolidWorks** or **MATLAB**, foster teamwork and leadership skills. **Mapping**: SBL supports effective teamwork and collaboration by involving students in group simulations and interdisciplinary projects.

10) Communication

SBL Application: Students use simulation results to create reports, presentations, and documentation. Tools like **MATLAB** and **GeoGebra** help in presenting complex data in an understandable format.

Mapping: SBL enhances communication skills by requiring students to effectively convey simulation findings and technical information.

11) Project Management and Finance

SBL Application: Managing simulation projects involves planning, resource allocation, and budget considerations. Tools like **Project Management Software** integrated with simulation tasks help students learn project management principles. **Mapping**: SBL provides experience in project management by involving students in managing simulation-based projects, including time and resource management.

12) Life-Long Learning

SBL Application: Simulation tools continuously evolve, requiring students to engage in ongoing learning and adaptation. Platforms like **Python** for coding and custom simulations promote continuous skill development. **Mapping**: SBL encourages life-long learning by exposing students to evolving technologies and promoting self-directed learning in the context of simulation tools.

Simulation-Based Learning effectively maps to the 12 program outcomes by providing practical, interactive experiences that align with key educational objectives. Through the use of modern simulation tools, students gain hands-on experience, develop problem-solving skills, and learn to apply theoretical knowledge in real-world contexts. This approach supports Outcome-Based Education by ensuring that students achieve the competencies required for professional success in engineering.

B. Case Studies

Table 1 depicts the use of simulation based learning for various mechanical engineering applications.

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TABLE I
USE OF SIMULATION BASED LEARNING

Case Study	Overview	Mapping to Program Outcomes
1. Simulation of Fluid Flow in Heat Exchangers	Use ANSYS Fluent to simulate fluid flow and heat transfer in heat exchangers. Design and optimize performance.	- PO 1: Apply knowledge of fluid dynamics and thermodynamics. - PO 2: Analyze issues such as pressure drop and efficiency. - PO 3: Design and refine heat exchanger configurations. - PO 4: Investigate design scenarios and data. - PO 5: Utilize ANSYS Fluent as a modern tool. - PO 7: Optimize for energy efficiency and sustainability.
2. Mechanical Design and Stress Analysis of an Automotive Component	Use SolidWorks for design and Finite Element Analysis (FEA) for stress analysis of an automotive component.	- PO 1: Apply mechanical principles and material science knowledge. - PO 2: Analyze stress concentrations and potential failures. - PO 3: Design and refine the component based on simulation results. - PO 4: Perform virtual testing and evaluate performance. - PO 5: Demonstrate proficiency with SolidWorks and FEA. - PO 6: Address safety and performance concerns related to automotive components.
3. Integration of Mechatronic Systems for Automated Manufacturing	Use MATLAB/Simulink and LabVIEW to simulate and control a mechatronic system for manufacturing automation.	- PO 1: Integrate knowledge of mechanical, electronics, and control systems. - PO 2: Analyze performance of control algorithms and system integration. - PO 3: Design control strategies and optimize the manufacturing process. - PO 4: Investigate system performance and reliability through simulation. - PO 5: Utilize MATLAB/Simulink and LabVIEW as modern tools. - PO 9: Promote teamwork and leadership in project tasks.
4. Simulation of Robotic Arm Kinematics and Dynamics	Use RoboAnalyzer to simulate and analyze robotic arm movements, kinematics, and dynamics. Design control algorithms and optimize arm configurations.	- PO 1: Apply knowledge of robotics, kinematics, and dynamics. - PO 2: Analyze robotic arm movements, control algorithms, and performance. - PO 3: Design and optimize robotic configurations and control strategies. - PO 4: Conduct virtual investigations into robotic system performance. - PO 5: Utilize RoboAnalyzer as a modern tool for simulation. - PO 9: Foster individual and team-based projects on robotic systems and control.
5. Simulation of Material Science Phase Diagrams	Use Python for coding and MATLAB for visualizing phase diagrams of various alloys and materials. Analyze material properties and phase transitions.	- PO 1: Apply knowledge of material science and phase transitions. - PO 2: Analyze phase diagrams and material properties. - PO 3: Design and optimize material compositions based on simulation results. - PO 4: Conduct investigations into material behaviors under different conditions. - PO 5: Utilize Python and MATLAB as modern tools. - PO 7: Address sustainability by analyzing material properties for efficient use.
6. Simulation of Manufacturing Processes	Use GeoGebra, Fusion 360, and MasterCam to simulate and optimize various manufacturing processes, including casting, machining, and welding.	- PO 1: Apply knowledge of manufacturing processes and materials. - PO 2: Analyze process efficiency and effectiveness through simulations. - PO 3: Design and optimize manufacturing processes based on simulation results. - PO 4: Investigate process parameters and their impact on quality. - PO 5: Demonstrate proficiency with GeoGebra, Fusion 360, and AutoCAD. - PO 9: Collaborate on process optimization projects and simulations.
7. Simulation of Robotics in Automated Systems	Use RoboAnalyzer and Geogebra to simulate and analyze various robotic systems used in automation. Focus on kinematics, dynamics, and control strategies.	- PO 1: Integrate knowledge of robotics and automation systems. - PO 2: Analyze robotic system performance and control strategies. - PO 3: Design and optimize robotic systems for automation applications. - PO 4: Conduct virtual investigations into robotic system performance. - PO 5: Utilize RoboAnalyzer as a modern tool for simulation. - PO 9: Engage in team-based projects involving robotic systems and automation.
8. Simulation of Mechanical Systems and Controls	Use Fluidsim and MATLAB/Simulink to simulate mechanical systems, including controls and automation. Evaluate system performance and control algorithms.	- PO 1: Apply mechanical engineering principles and control theory. - PO 2: Analyze performance of mechanical systems and control algorithms. - PO 3: Design and optimize mechanical systems and controls based on simulation results. - PO 4: Conduct virtual investigations into system dynamics and performance. - PO 5: Utilize RoboAnalyzer and MATLAB/Simulink as modern tools. - PO 9: Promote teamwork in mechanical systems and controls projects.
9. Machine Learning for Predictive Analysis	Use ML Playground to experiment with and deploy machine learning models for predictive analysis. Analyze engineering data for component reliability and process optimization.	- PO 1: Apply knowledge of machine learning algorithms to engineering problems. - PO 2: Analyze predictive models and evaluate their performance. - PO 3: Design and optimize models for specific engineering applications. - PO 4: Conduct investigations into data-driven insights and predictions. - PO 5: Utilize ML Playground as a modern tool for machine learning.

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- PO 12: Engage in life-long learning and adapt to technological advancements in machine learning.

1) Simulation of Fluid Flow in Heat Exchangers

Using ANSYS Fluent as shown in fig. 02, students simulate fluid flow and heat transfer in heat exchangers to optimize performance. This involves creating a detailed model, generating a computational mesh, and defining boundary conditions. Simulation results offer insights into temperature distribution, flow patterns, and pressure drops, which help refine design parameters to enhance efficiency and energy usage.

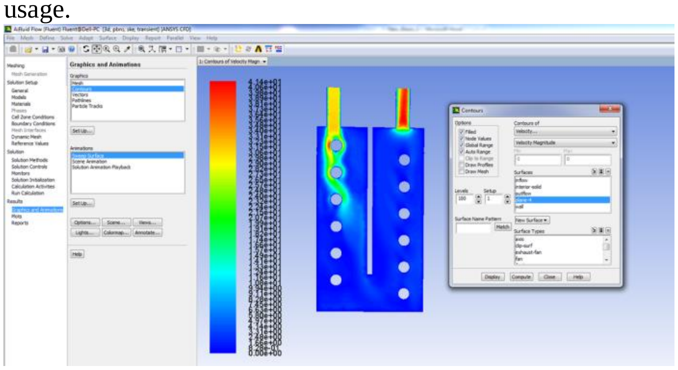
Fig. 2. Simulation of fluid flow in Heat Exchanger

2) Mechanical Design and Stress Analysis of an Automotive Component

SolidWorks is utilized for the design of automotive components, while Finite Element Analysis (FEA) assesses stress and deformation as shown in fig. 3. By modeling the component and applying load conditions, students analyze stress distributions and potential failure points, leading to design improvements for increased durability and performance.

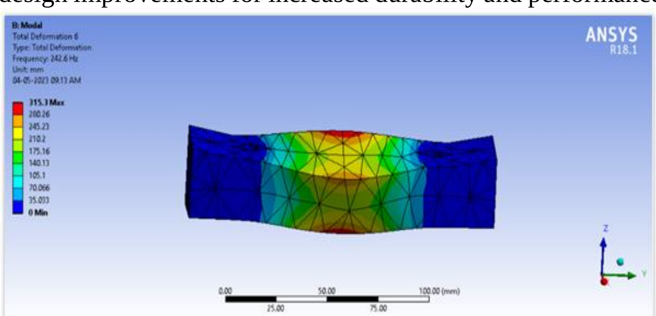

Fig. 3. Stress Analysis

Simulation websites like BeamGURU.com helps students for plotting Shear force diagram and Bending Moment Diagram as shown in fig. 4

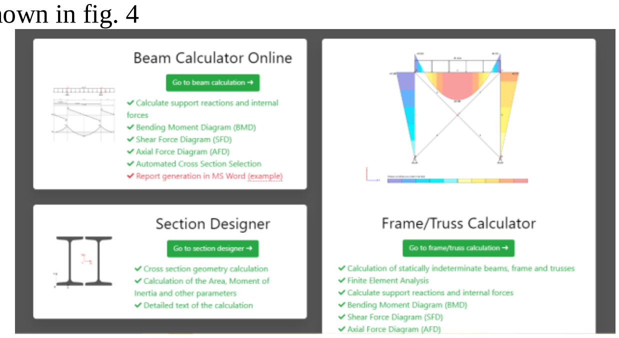

Fig. 4. Online simulation website- BeamGURU

3) Integration of Mechatronic Systems for Automated Manufacturing

MATLAB/Simulink, TinkerCAD for Arduino simulation and LabVIEW are used to simulate and control mechatronic systems in manufacturing automation. These tools assist in designing control algorithms, integrating sensors and actuators, and optimizing system performance for precise automation in manufacturing processes.

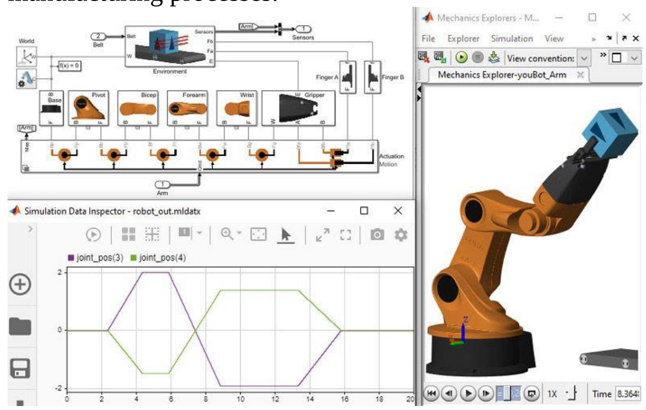
Fig. 5. MATLAB Simulink: Robot Simulation

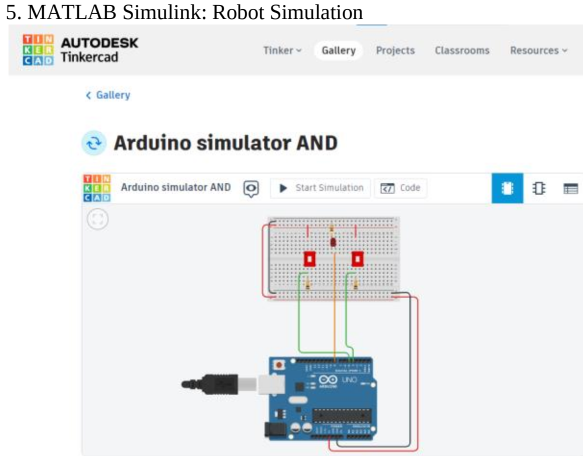

Fig. 6. Online Arduino simulator

Fig. 5 shows the MATLAB Robot Simulation adapted from MATLAB Simulink User Guide. MATLAB, MathWorks. Fig. 6 shows the Online Arduino Simulator, Adapted from Arduino Simulator Online.

4) Simulation of Robotic Arm Kinematics and Dynamics

RoboAnalyzer serves as an effective educational tool for teaching both the theory and mechanisms of machines, particularly in the context of robotics. By simulating robotic arm movements and analyzing their kinematic and dynamic properties, RoboAnalyzer enhances the understanding of theoretical concepts and practical applications. Here's how RoboAnalyzer can be used to teach these concepts effectively:

5) Teaching Theory and Mechanisms of Machines with RoboAnalyzer

1. Understanding Kinematic Chains: In the theory of machines, kinematic chains are fundamental in analyzing how different machine parts move relative to one another. RoboAnalyzer allows students to model and visualize kinematic chains of robotic arms, demonstrating concepts such as linkages, joints, and degrees of freedom.

Example: Students can simulate a robotic arm with multiple joints and links using RoboAnalyzer. By inputting various configurations and observing the resulting motion, they can understand how kinematic chains are formed and how they influence the arm's range of motion and end effector placement.

2. Exploring Forward and Inverse Kinematics: Forward kinematics involves calculating the position and orientation of the end effector based on given joint angles, while inverse kinematics determines the required joint angles to achieve a desired end effector position. RoboAnalyzer provides tools to input joint parameters and visualize both forward and inverse kinematics, enhancing theoretical understanding.

Example: In a lesson on forward kinematics, students can use RoboAnalyzer to input specific joint angles and observe the arm's end effector's path. Conversely, for inverse kinematics, students can set a target position and use RoboAnalyzer to compute the required joint angles to achieve that position.

3. Analyzing Dynamics and Forces: Understanding dynamics involves analyzing the forces and torques acting on machine components. RoboAnalyzer allows students to simulate dynamic conditions, examining how different loads and movements affect the robotic arm. This helps in understanding principles such as Newton's laws, torque, and dynamic stability.

Example: Students can simulate different loading conditions on the robotic arm and observe how the forces and torques change. This practical analysis helps in understanding the concepts of dynamic equilibrium and how different design choices impact machine performance.

4. Teaching Mechanisms and Control Systems: Mechanisms involve the study of motion transmission and transformation through various components. RoboAnalyzer helps in studying mechanisms like gears, levers, and linkages by allowing students to simulate how these components interact within the robotic arm. Additionally, students can design and test control algorithms to manage these mechanisms.

Example: During a lesson on gear mechanisms, students can use RoboAnalyzer to simulate different gear configurations and observe their impact on the arm's movement. They can also develop control algorithms, such as PID controllers, to fine-tune the robotic arm's performance and precision.

5. Configuring and Optimizing Designs: RoboAnalyzer provides tools for experimenting with different arm configurations, component sizes, and joint types. This helps students understand the impact of design choices on the functionality and efficiency of mechanical systems.

Example: While studying mechanical design principles, students can use RoboAnalyzer to test various arm lengths and joint arrangements. They can analyze how these changes affect the arm's operational range and payload capacity, which helps in understanding the trade-offs in machine design.

As shown in fig. 7, RoboAnalyzer effectively integrates theoretical concepts with practical simulation, offering a comprehensive approach to teaching the theory of machines and robotics. By visualizing kinematic chains, exploring kinematics, analyzing dynamics, and experimenting with mechanisms and control systems, students gain a deeper understanding of both the fundamental principles and practical applications of mechanical systems.

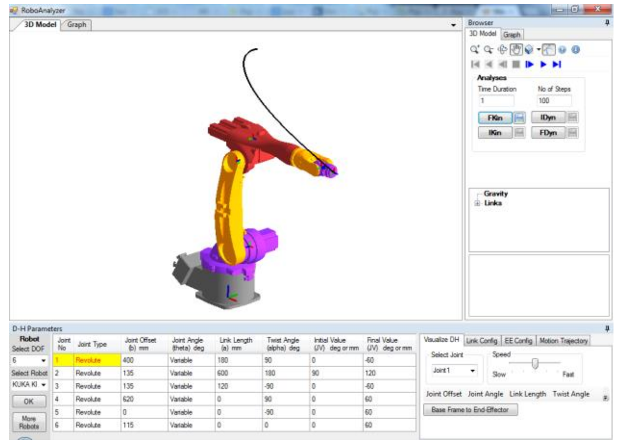

Fig. 7. Simulation with RoboAnalyzer

6) Simulation of Material Science Phase Diagrams

Python coding and MATLAB visualization tools are used to simulate and analyze phase diagrams of various alloys and materials. This helps in understanding phase transitions and material properties, aiding in material selection and processing. Data is collected from experimentation in industries from nearby areas. Fig. 8 explains the simulation of temperature vs. velocity for pin on disc setup using python.

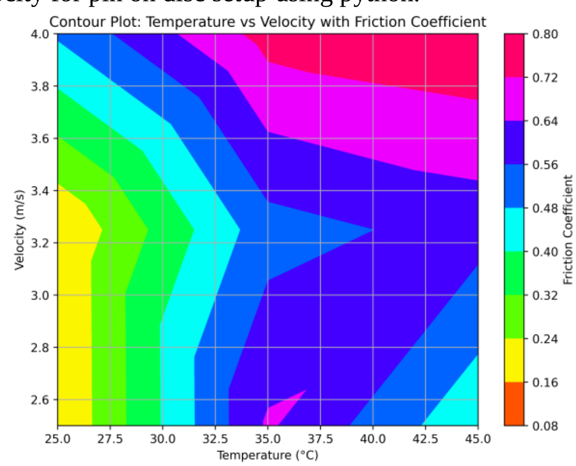

Fig. 8. Simulation of Pin on Disc test experiment

7) Simulation of Manufacturing Processes

GeoGebra, MasterCam, and Fusion 360 are used to simulate and optimize manufacturing processes such as casting, machining, and welding. Fusion 360 adds advanced capabilities for 3D modeling and simulation, providing a comprehensive platform for designing, simulating, and refining manufacturing processes to improve efficiency and quality. Fig. 9 shows the simulation of manufacturing process by MasterCam software.

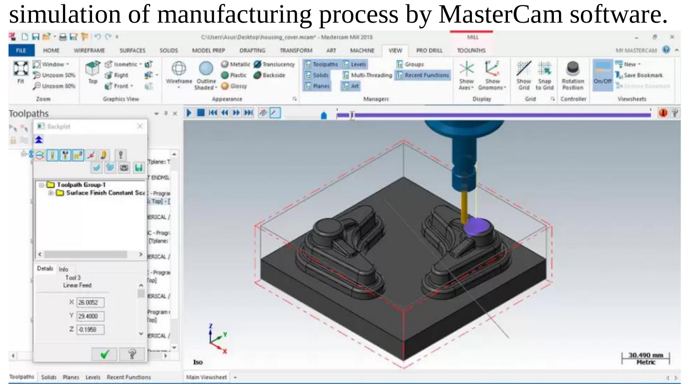

Fig. 9. Simulation of manufacturing process by MasterCam software

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8) Simulation of Robotics in Automated Systems

RoboAnalyzer and Geogrbra simulate robotic systems used in automation, focusing on kinematics, dynamics, and control strategies. This simulation helps analyze robotic performance and optimize control algorithms for effective automation across various applications. Fig.10 shows the Simulation of degree of freedom using Geogebra

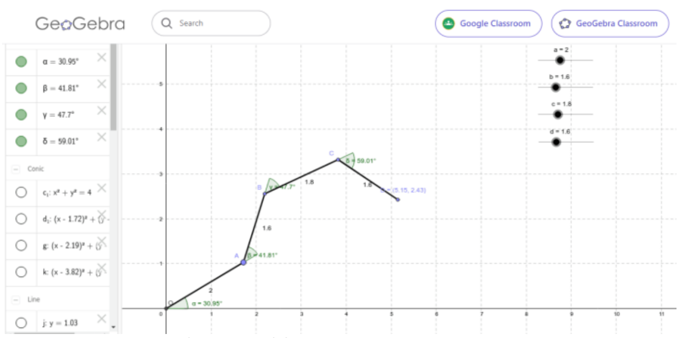
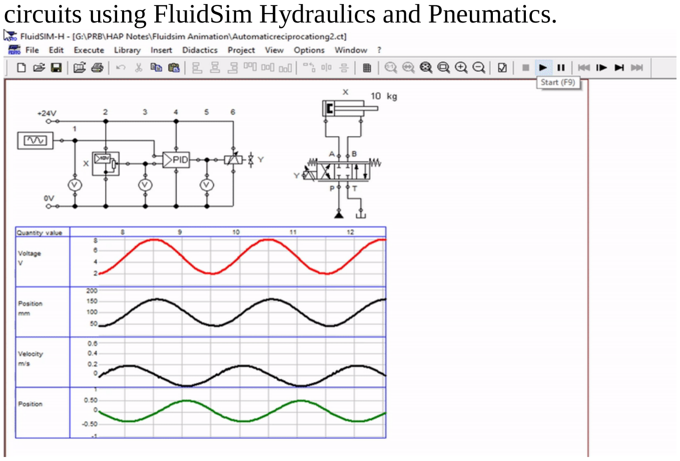


Fig. 10. Simulation of degree of freedom using Geogebra

9) Simulation of Mechanical Systems and Controls

FluidSim and MATLAB/Simulink are used to simulate mechanical systems, including their controls and automation. This approach provides detailed analysis of system performance, control algorithms, and operational efficiency, ensuring effective integration of mechanical and control systems. Fig. 11 a and b explains the simulation of industrial circuits using FluidSim Hydraulics and Pneumatics.



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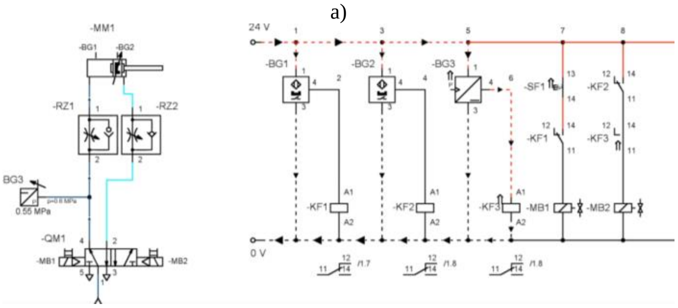

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Fig. 11 a) FluildSim Hydraulics, 11 b) FluidSim Pneumatics

10) Machine Learning Playground for Predictive Analysis

ML Playground as shown in fig. 12, is utilized for experimenting with and deploying machine learning models to predict various engineering outcomes. Students can use this platform to train and test models on datasets, perform feature selection, and evaluate model performance for predictive analysis in areas such as component reliability, process optimization, and fault detection.

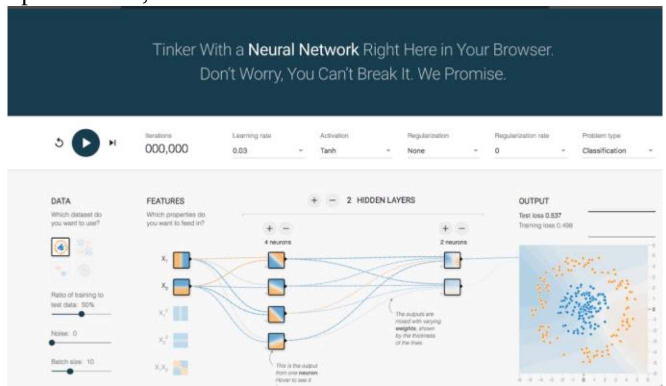


Fig. 12. ML Playground for simulation of Deep Learning

Incorporating simulation tools like AutoCAD and GeoGebra into Engineering Graphics can significantly enhance the alignment with Program Outcomes (POs). Here's how these tools can maximize CO-PO mapping for Engineering Graphics:

V. Results and Discussion

A. Case Study on Engineering Graphics

Course Outcomes (CO) for first year engineering graphics course is as follows-

1. **CO1**: Implement engineering drawing standards and conventions for consistent and precise technical documentation.
2. **CO2**: Apply geometric principles to solve problems related to shapes, projections, and transformations.
3. **CO3**: Produce accurate technical drawings including orthographic projections of lines, planes, and isometric views.
4. **CO4**: Evaluate and interpret technical drawings to ensure clarity and adherence to design specifications.

TABLE II
STRENGTH OF CO-PO MAPPING FOR ENGINEERING GRAPHICS

CO/PO	Program Outcomes											
	1	2	3	4	5	6	7	8	9	10	11	12
CO1	2											1
CO2	2											1
CO3	2											1
CO4	2	1										1
Average	2	1										1

TABLE III
ENHANCED CO-PO MAPPING WITH SIMULATION TOOLS

CO/PO	Program Outcomes											
	1	2	3	4	5	6	7	8	9	10	11	12
CO1	2				2				2	2		2
CO2	2				2				2	2		2
CO3	2				2			1	2	2		2
CO4	2	1			2			1	2	2	1	2
Average	2	1			2			1	2	2	1	2

CO3 (producing accurate technical drawings) and CO4 (evaluating and interpreting technical drawings) are mapped with PO8 (ethics) because adherence to drawing standards, conventions, and accuracy directly relates to professional ethics and responsibility in engineering practice. Any deviation or misrepresentation in technical documentation can lead to errors in design, manufacturing, or safety compliance. Hence, ensuring correctness and clarity in drawings reflects ethical responsibility, justifying the mapping of CO3 and CO4 with PO8.

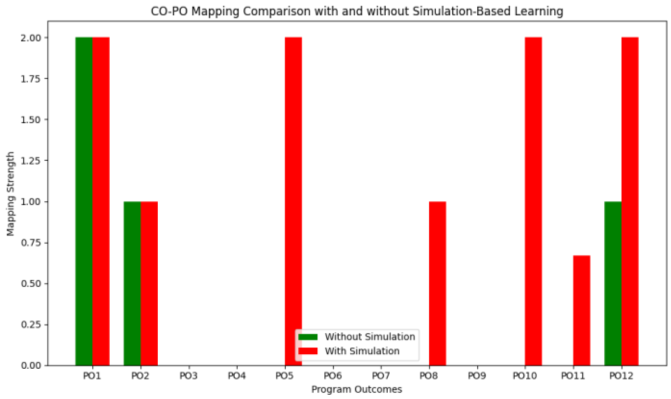


Fig. 13. Comparison of PO Mapping with and without simulation tools

CO1: Implement engineering drawing standards and conventions for consistent and precise technical documentation (using tools like BricsCAD)

Assignment Question: "Draw the floor plan of your home using BricsCAD, adhering to engineering drawing standards."

- PO1 (Engineering Knowledge): Students apply fundamental engineering principles to maintain drawing standards using BricsCAD.
- PO5 (Modern Tool Usage): BricsCAD enables precise documentation according to engineering standards.
- PO9 (Individual and Team Work), PO10 (Communication), PO12 (Life-long Learning): The open-ended nature of this assignment encourages collaboration, clear communication, and continuous learning as students explore technical tools.

CO2: Apply geometric principles to solve problems related to shapes, projections, and transformations (using tools like GeoGebra for 3D plotting and transformations)

Assignment Question: "Plot the locus of a line in 3D using GeoGebra and explore its transformation under different conditions."

- PO1 (Engineering Knowledge): Applying geometric principles using GeoGebra requires understanding mathematics and engineering.
- PO5 (Modern Tool Usage): GeoGebra helps visualize and manipulate complex geometric problems in 3D.
- PO9, PO10, PO12: The assignment fosters teamwork, enhances communication through shared problem-solving, and promotes lifelong learning with advanced tools.

CO3: Produce accurate technical drawings including orthographic projections of lines, planes, and isometric views (using tools like BricsCAD)

Assignment Question: "Use BricsCAD to generate orthographic projections of a mechanical component and produce an isometric view."

- PO1 (Engineering Knowledge): Producing orthographic projections and isometric views involves solid engineering knowledge.
- PO5 (Modern Tool Usage): BricsCAD's capabilities help students create accurate, technical drawings.
- PO9, PO10, PO12: This assignment enhances collaborative efforts in creating accurate designs and fosters the development of communication skills and lifelong learning in technical drawing software.

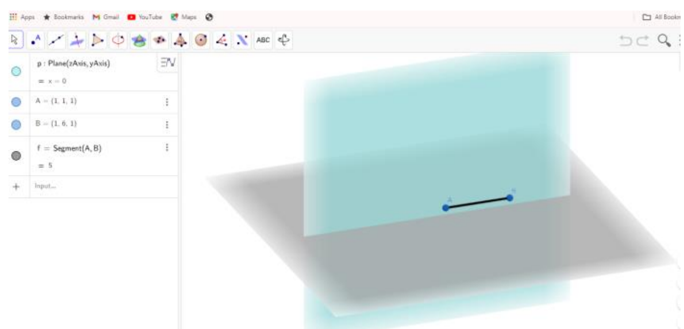
CO4: Evaluate and interpret technical drawings to ensure clarity and adherence to design specifications (using simulation tools for analysis and interpretation)

Assignment Question: "Evaluate a set of technical drawings created in BricsCAD for design adherence, clarity, and accuracy."

- PO1 (Engineering Knowledge), PO2 (Problem Analysis): Interpretation of technical drawings requires strong analytical and design skills.
- PO5 (Modern Tool Usage): BricsCAD enables precise evaluation and ensures that drawings meet design standards.
- PO9, PO10, PO11 (Project Management), PO12: Evaluating designs in teams enhances project management, communication, and lifelong learning while applying modern tools effectively.

By incorporating these assignments, students can directly map course outcomes (COs) to program outcomes (POs), ensuring that skills such as modern tool usage (PO5), teamwork (PO9), and lifelong learning (PO12) are effectively developed.

As shown in table 1, table 2 and fig. 13 we can discuss that



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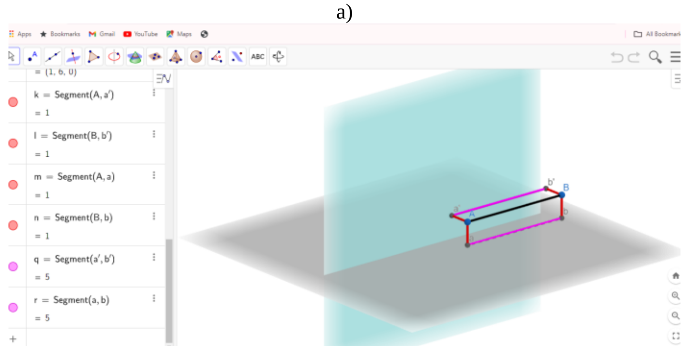

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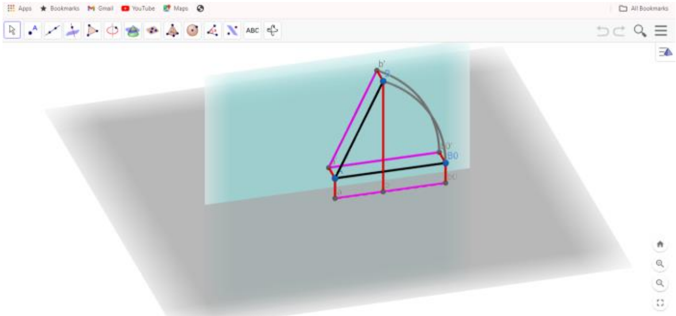

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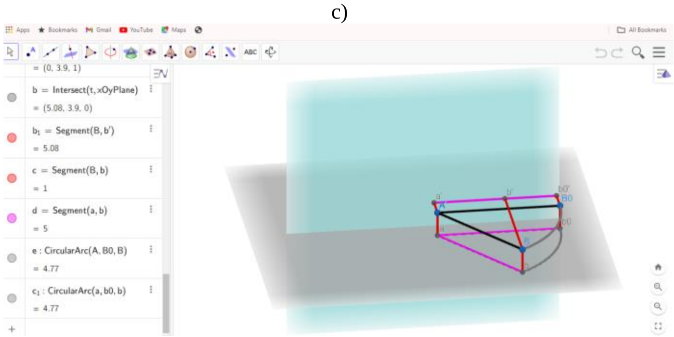

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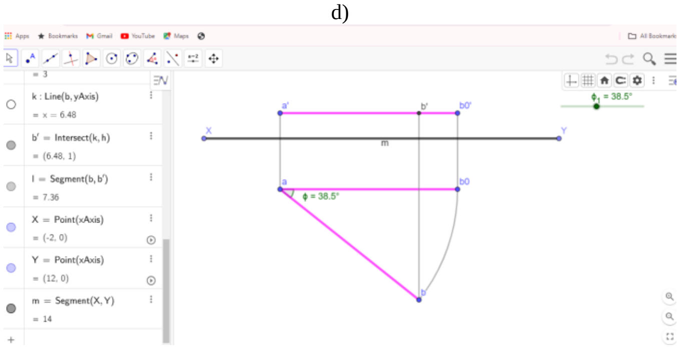

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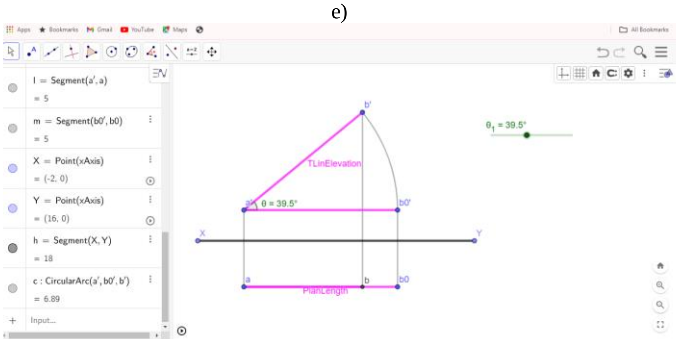

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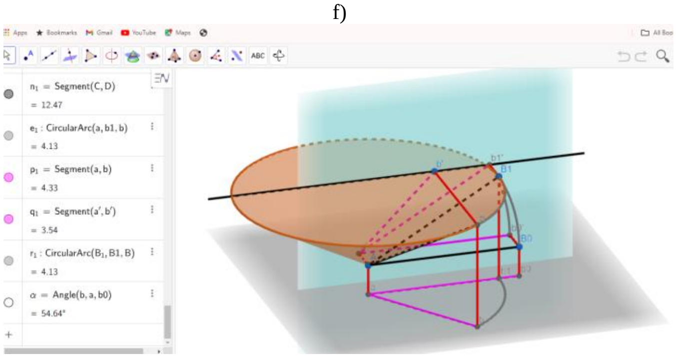

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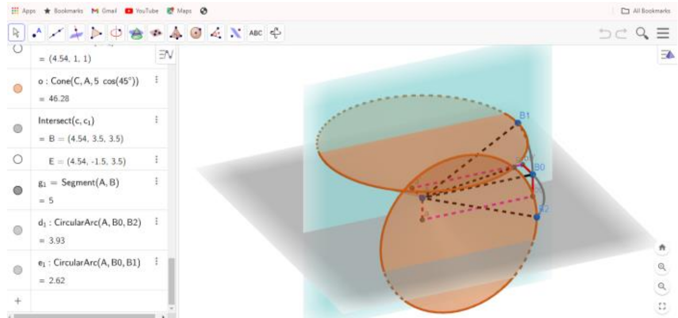

h)

Fig. 14. Simulation of projection of lines using Geogebra, a) 3D horizontal plane(HP) and Vertical planes(VP), b) Projection of line on HP and VP, c) Projection of line inclined to HP, d) Projection of line inclined to VP, e) Projection of line above HP inclined to VP, f) Projection of line above HP inclined to HP, g) Locus of line in HP, h) Locus of line in HP and VP

GeoGebra serves as an excellent tool for simulating the projection of lines in engineering graphics, particularly in the context of understanding projections on Horizontal Plane (HP) and Vertical Plane (VP). Through its 3D workspace, as depicted in Fig. 14a, GeoGebra allows students to visualize the intersection of HP and VP, providing a foundational understanding of how 3D objects are translated into 2D projections. This foundational setup is crucial for grasping the fundamentals of orthographic projections. In Fig. 14b, GeoGebra simulates the projection of a line onto both HP and VP, dynamically adjusting the projections as the line is manipulated. This reinforces the connection between 3D space and its 2D representations, making it easier for students to visualize spatial relationships.

The tool also facilitates an exploration of more complex concepts, such as a line inclined to HP (Fig. 14c) and VP (Fig. 14d). Students can rotate and adjust the inclination of the line, observing how these changes affect its projections on both planes. This dynamic interaction helps clarify how angles and inclinations cause distortions in projection views, deepening their understanding of orthographic projection. In more advanced cases, like a line above HP and inclined to VP (Fig. 14e) or a line above HP and inclined to HP (Fig. 14f), GeoGebra allows students to see the true spatial position of the line and how it impacts both its projections. This highlights the relationship between a line’s actual position in 3D and how it is represented on HP and VP.Moreover, GeoGebra can simulate the movement or locus of a line on HP (Fig. 14g), showing its changing projection on VP as it moves. This dynamic simulation offers a clear view of how 3D movement translates into 2D projections. In Fig. 14h, where the locus of a line is observed on both HP and VP, GeoGebra provides a comprehensive overview of how the line’s movement in 3D space is reflected in its horizontal and vertical projections. These simulations offer students an immersive learning experience, allowing them to connect the behavior of lines in space with their projections on different planes, thus enhancing their overall comprehension of projection concepts in engineering graphics.

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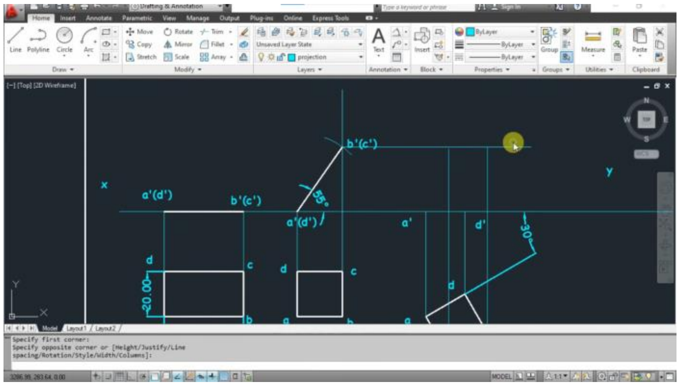
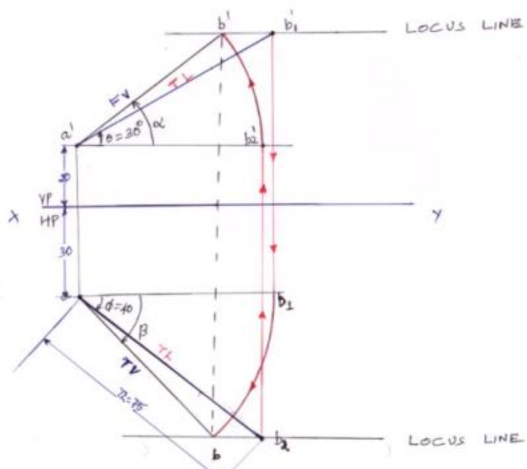


Fig. 15. Simulation of projection of plane using Autocad

Fig. 14 and 15 shows the effective use of simulation tools for imagination of all projections in engineering graphics. The integration of simulation tools not only strengthens the mapping between course outcomes and program outcomes but also enhances the overall educational experience by providing practical, interactive, and effective learning methods.

B. Automatic Engineering Drawing Sheet Evaluator Algorithm

An **Automatic Engineering Drawing Sheet Evaluation Algorithm** has been developed and copyrighted by the Government of India. This algorithm uses **image processing techniques in Python** to evaluate engineering drawing sheets submitted by students, marking a significant advancement in **modern assessment methods**.



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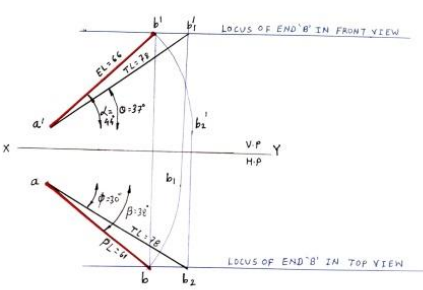

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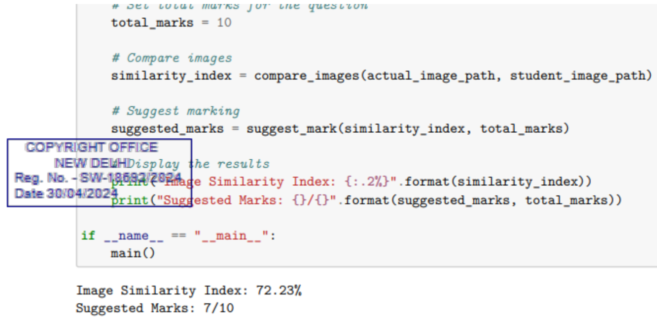

c)

Fig. 16 a) Actual Solution, b) Students Solution, c) Snap of Software algorithm of Automatic Engineering Drawing Sheet Evaluator

1. **Time Efficiency**: Traditional manual evaluation of engineering drawing sheets is time-consuming and prone to human error. This algorithm automates the process, significantly reducing the time required to check drawings. It can assess large numbers of submissions in a fraction of the time it would take manually.
2. **Improved Accuracy**: By leveraging **image processing**, the algorithm ensures precise and consistent evaluation. It compares the student's drawing to a pre-defined standard, checking for accuracy in dimensions, alignments, and compliance with drawing standards (e.g., line weights, projection views, or geometric accuracy). This eliminates subjectivity in the assessment process.
3. **Python-Based Implementation**: The algorithm is implemented using **Python**, a versatile programming language commonly used for image processing through libraries such as **OpenCV** and **NumPy**. These tools allow the algorithm to:
   - o Detect and interpret line thickness, shapes, and angles.
   - o Compare orthographic projections, isometric views, and other geometric features.
   - o Analyze dimensions and scale in comparison with a reference drawing.
4. **Integration with Simulation Tools**: The algorithm can work in conjunction with simulation tools like **BricsCAD** or **GeoGebra**, where students upload their drawings. The system then evaluates the submissions based on predefined rubrics, ensuring that the drawings conform to **engineering drawing standards** and conventions.

1) Impact on Assessment as a Modern Tool:

- **PO5 (Modern Tool Usage)**: This algorithm aligns with **modern tool usage**, enabling students and instructors to integrate advanced technology in assessment practices.
- **PO10 (Communication)**: It provides clear, automated feedback to students on their performance, helping them understand their mistakes and areas for improvement.
- **PO12 (Life-long Learning)**: By incorporating such advanced algorithms, students are encouraged to engage with modern assessment tools and image processing techniques, which are becoming increasingly relevant in engineering fields.

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2) Conclusion:

The **Automatic Engineering Drawing Sheet Evaluation Algorithm** represents a forward-thinking approach to educational assessment, combining Python-based image processing with modern engineering tools to enhance both the speed and accuracy of evaluations. This innovation not only saves time for instructors but also ensures a more accurate and objective evaluation process, enhancing the overall learning experience for students.

TABLE IV
PROGRAM ATTAINMENT VALUES FOR BATCH 1 AND BATCH 2

PO/PSO	Batch 1 without integrating simulation tools	Batch 2 with integrating simulation tools in all subjects	Percentage Increase (%)
PO1	2.12	2.56	20.75
PO2	1.93	2.34	21.24
PO3	1.84	2.1	14.13
PO4	1.78	2.06	15.73
PO5	1.05	2.04	94.29
PO6	1.71	1.86	8.77
PO7	1.87	1.87	0.00
PO8	1.86	1.99	6.99
PO9	1.75	1.95	11.43
PO10	1.32	2.01	52.27
PO11	1.66	1.9	14.46
PO12	1.63	2	22.72
PSO1	1.67	1.96	17.37
PSO2	1.66	2.02	21.69

As shown in table 4 and fig. 17, the integration of simulation tools in engineering education has led to significant improvements in the mapping of Course Outcomes (COs) to Program Outcomes (POs). For instance, the use of simulation tools has enhanced the effectiveness of CO-PO mapping across various outcomes. Specifically, PO5, which saw an extraordinary increase of 94.29%, reflects how simulation tools significantly impact the understanding and application of manufacturing and design processes. Similarly, PO10 experienced a 52.27% improvement, highlighting the substantial benefits of simulation tools in project management and engineering practice. Other outcomes such as PO2 and PO12 also demonstrated notable increases of 21.24% and 22.72%, respectively, indicating that simulation tools enhance the application of knowledge and problem-solving skills. The overall positive trend across most outcomes illustrates that integrating simulation tools enhances students' ability to apply theoretical concepts to practical scenarios, thereby improving educational effectiveness and aligning learning with real-world engineering practices. All attainment values for both the batches are calculated by considering Simulation Based Learning for maximum subjects from first year to final year.

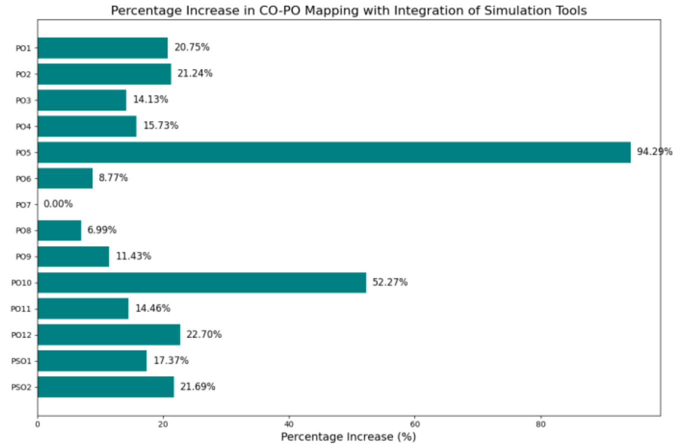

Fig. 17. Percentage increase in PO Attainment from batch 1 to batch 2

While simulation-based learning offers numerous advantages, including enhanced visualization and practical application of theoretical concepts, it does come with limitations, particularly for certain Program Outcomes (POs).

1. PO5: Modern Tool Usage
   - Limitation: Although simulation tools are advanced, they may not fully capture the complexity of real-world constraints and limitations. For instance, while simulations can model idealized scenarios, they may not account for all factors present in actual engineering environments, such as unexpected material behavior or real-world operational conditions. This limitation can affect the accuracy of predictions and analyses derived from simulations.
2. PO7: Environment and Sustainability
   - Limitation: Simulation tools often focus on technical and performance aspects rather than environmental impacts and sustainability. For example, while simulations can optimize design performance, they may not adequately address the environmental consequences of manufacturing processes or material usage. This gap can lead to a lack of comprehensive understanding regarding sustainable practices and their integration into engineering solutions.
3. PO8: Ethics
   - Limitation: Simulation-based learning may not fully address ethical considerations and real-world ethical dilemmas. For instance, while simulations can model engineering processes and outcomes, they might not incorporate ethical implications such as safety, fairness, or societal impact. This limitation can result in an incomplete understanding of the ethical responsibilities associated with engineering practices.
4. PO9: Individual and Team Work
   - Limitation: Simulation tools can sometimes emphasize individual problem-solving skills rather than teamwork and collaboration. Although simulations are valuable for

individual learning, they may not effectively simulate the dynamics of working in diverse teams or the complexities of collaborative problem-solving. This limitation can affect the development of teamwork and leadership skills crucial in real-world engineering projects.

5. PO11: Project Management and Finance
    - Limitation: While simulations can model technical aspects of projects, they may not fully encompass the complexities of project management, including budgeting, scheduling, and resource allocation. Simulation tools might provide insights into technical performance but might not adequately simulate the financial and managerial aspects of project execution, leading to a gap in understanding project management principles.

Overall, while simulation-based learning significantly enhances technical education, its limitations in addressing real-world complexities, ethical considerations, and collaborative skills highlight the need for a balanced approach that includes practical experiences and other learning methods to ensure comprehensive engineering education.

Fig. 18 shows the Feedback ratings before and after simulation tools for first year engineering graphics course.

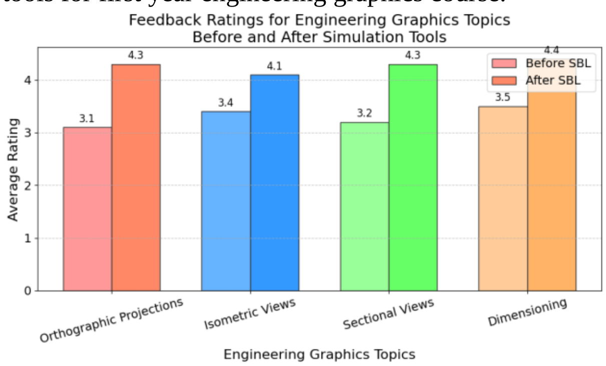

Fig. 18. Feedback ratings before and after simulation tools

The feedback ratings from 844 students for various topics in engineering graphics reveal a notable enhancement in student understanding following the integration of simulation tools. Before the introduction of simulation-based learning (SBL), topics such as Orthographic Projections, Isometric Views, Sectional Views, and Dimensioning received average ratings of 3.1, 3.4, 3.2, and 3.5, respectively. These ratings reflect the traditional learning methods, which often struggled to fully engage students or convey complex concepts effectively. After incorporating simulation tools, the average ratings for these topics saw significant improvements: Orthographic Projections increased to 4.3, Isometric Views to 4.1, Sectional Views to 4.3, and Dimensioning to 4.4. The most substantial gains were observed in Dimensioning, which saw the highest increase from 3.5 to 4.5. This suggests that simulation tools have provided students with a more interactive and visual learning experience, thereby improving their ability to understand and apply key concepts in engineering graphics.The data indicates that simulation-based learning has markedly enhanced students' comprehension and engagement. The higher ratings for each topic underscore the effectiveness of simulation tools in making complex technical drawings more accessible and easier to grasp. This improvement highlights the value of integrating such tools into engineering graphics education, demonstrating their potential to significantly boost learning outcomes and student satisfaction.

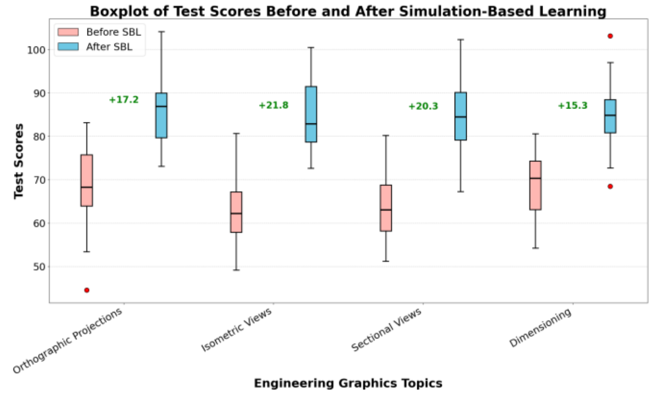

Fig. 19. Performance of students in class test before and after simulation tools for engineering graphics

The boxplot analysis as shown in fig. 19, illustrates the substantial impact of simulation-based learning (SBL) on student performance in engineering graphics by comparing test results conducted before and after the implementation of SBL. The data shows a clear enhancement in scores across various topics following the introduction of simulation tools.

TABLE V
STATISTICAL ANALYSIS OF STUDENT'S PERFORMANCE IN CLASS TESTS

Statistic	Orthographic Projections (Before SBL)	Orthographic Projections (After SBL)	Isometric Views (Before SBL)	Isometric Views (After SBL)	Sectional Views (Before SBL)	Sectional Views (After SBL)	Dimensioning (Before SBL)	Dimensioning (After SBL)
Mean	72.4	85.3	68.7	82.1	70.2	83.7	74.5	87.2
Median	73	86	69	83	71	85	75	88
Standard Deviation	8.5	5.9	10.2	6.7	9.8	6.3	8.9	5.8
Minimum	56	70	52	65	50	68	55	72
Maximum	89	98	85	95	90	98	90	98
Interquartile Range (IQR)	12	7.5	14.5	8.3	11.5	7.2	10.5	7

Table 5 displays the comprehensive statistical analysis of student performance for each topic before and after the introduction of simulation-based learning. Mean scores show notable improvements, indicating enhanced understanding and application of engineering graphics concepts. Reduced standard deviations and interquartile ranges reflect decreased variability and more consistent performance among students following the implementation of simulation-based learning. Orthographic Projections, Isometric Views, Sectional Views, and Dimensioning exhibit significant improvements in test scores post-SBL. Before the integration of SBL, the test scores for these topics varied widely, with medians positioned at lower values and a broader range of scores. After incorporating SBL, the boxplots reveal a shift towards higher median scores and a reduction in score variability. This indicates a more consistent and elevated performance across students following the use of simulation tools. The interquartile range (IQR) for each topic has narrowed after SBL, demonstrating decreased variability and suggesting that simulation-based learning has contributed to a more uniform understanding among students. The reduction in outliers further emphasizes the effectiveness of SBL in reducing performance discrepancies. Notably, Orthographic Projections and Dimensioning show particularly large improvements, with median scores significantly increasing. The boxplot results underscore the positive influence of simulation-based learning on test outcomes in engineering graphics, highlighting improved consistency and higher average scores following the integration of SBL. This analysis confirms the effectiveness of simulation tools in enhancing students' understanding and performance in complex engineering topics.

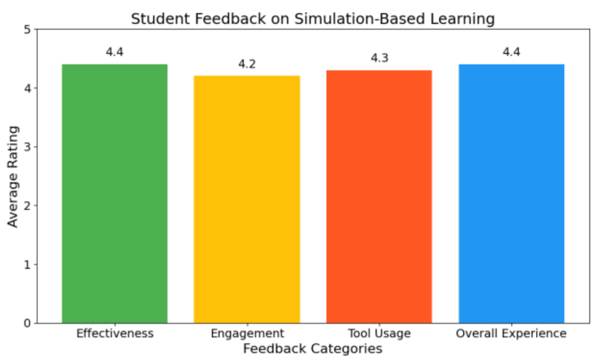

Fig. 20. Students feedback on Simulation Based Learning

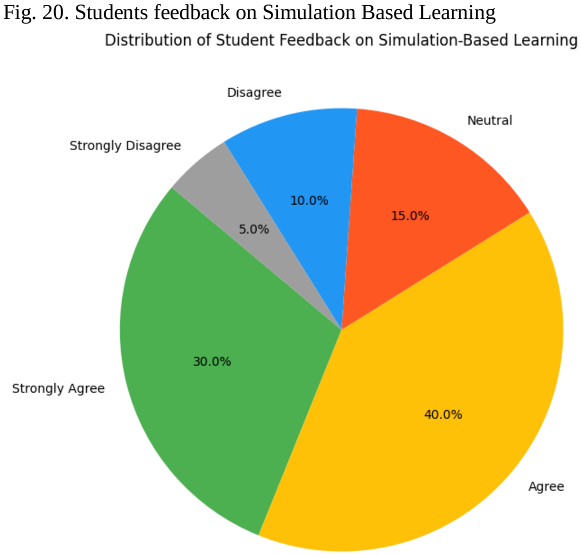

Fig. 21. Distribution of Student Feedback on Simulation Based Learning

The feedback data from students on Simulation-Based Learning (SBL) was analysed as shown in fig. 20 and 21, to assess its impact and effectiveness. The collected feedback focused on several key categories: effectiveness, engagement, tool usage, and overall experience. The bar chart representing average ratings across these categories revealed that SBL received high ratings in effectiveness (4.4) and overall experience (4.4), indicating strong approval from students regarding its impact on their learning. Engagement and tool usage also received favorable ratings (4.2 and 4.3, respectively), though slightly lower than effectiveness and overall experience. This suggests that while students find SBL highly effective and satisfactory, there may be room to enhance engagement strategies and the utilization of simulation tools.

In addition, the pie chart illustrating the distribution of feedback responses highlights the overall student sentiment towards SBL. A substantial portion of students strongly agreed (30%) or agreed (40%) with the effectiveness of the simulation-based approach, reflecting a positive reception. However, 15% of students remained neutral, and a small percentage disagreed (10%) or strongly disagreed (5%). This distribution underscores that while the majority of students support SBL, there are areas for further refinement to address concerns of the neutral and dissenting students. The high ratings and positive feedback suggest that SBL is a beneficial educational strategy, but continued efforts are necessary to enhance its implementation and address any areas of improvement highlighted by the feedback.

CONCLUSION

Integrating simulation tools into the first-year Engineering Graphics course has greatly improved both Course Outcomes (CO) and Program Outcomes (PO), with PO5 (Modern Tool Usage) seeing a 94.29% increase. Tools like AutoCAD and GeoGebra have enhanced student understanding of Orthographic Projections and Isometric Views, as evidenced by improved test performance and positive feedback. Case studies demonstrate the application of various simulation tools to different Program Outcomes:

1. Fluid Flow in Heat Exchangers: ANSYS Fluent improves design and optimization (PO1, PO2, PO3, PO4, PO5, PO7).
2. Automotive Component Design: SolidWorks and FEA focus on stress analysis and safety (PO1, PO2, PO3, PO4, PO5, PO6).
3. Mechatronic Systems: MATLAB/Simulink and LabVIEW enhance system integration and teamwork (PO1, PO2, PO3, PO4, PO5, PO9).
4. Robotic Arm Dynamics: RoboAnalyzer aids in kinematics and control strategies (PO1, PO2, PO3, PO4, PO5, PO9).
5. Material Science: Python and MATLAB analyze phase diagrams and material properties (PO1, PO2, PO3, PO4, PO5, PO7).
6. Manufacturing Processes: GeoGebra, Fusion 360, and MasterCam optimize various processes (PO1, PO2, PO3, PO4, PO5, PO9).
7. Robotics in Automation: RoboAnalyzer and GeoGebra simulate robotic systems (PO1, PO2, PO3, PO4, PO5, PO9).
8. Mechanical Systems and Controls: Fluidsim and MATLAB/Simulink evaluate system performance (PO1, PO2, PO3, PO4, PO5, PO9).

9. Machine Learning: ML Playground is used for predictive analysis and model optimization (PO1, PO2, PO3, PO4, PO5, PO12).

3) Limitations

1. **Simulation Accuracy**: Simulations may not fully capture real-world complexities like material imperfections.
2. **Limited Real-World Interaction**: SBL lacks the hands-on experience essential in engineering.
3. **Ethical & Collaborative Gaps**: Simulations often overlook teamwork and ethical decision-making.
4. **Project Management**: SBL does not fully address the complexities of real-world project management.

4) Future Scope

1. **Real-World Data Integration**: Future tools could incorporate real-world conditions for greater realism.
2. **Collaborative Features**: Adding team simulations to enhance collaboration and leadership skills.
3. **Ethical Scenarios**: Introducing ethical decision-making challenges in simulations.
4. **Project Management Modules**: Integrating financial and resource management elements.
5. **Broader Applications**: Expanding SBL to other engineering fields like mechanics and thermodynamics.
6. **VR Integration**: Using VR for a more immersive learning experience.

By addressing these areas, SBL can continue to enhance engineering education.

Appendix
Geogebra Simulations-
https://www.geogebra.org/classic/bg9umbgz

https://www.geogebra.org/classic/yuswt3cj

https://www.geogebra.org/classic/sjqrdvsz

https://www.geogebra.org/classic/nt238dfa

https://www.geogebra.org/classic/c36qtcgb

https://www.geogebra.org/classic/wsr8vfxn

https://www.geogebra.org/classic/erxrhnhe

https://www.geogebra.org/classic/dhqcqqwb

https://www.geogebra.org/classic/d8tud5u2

https://www.geogebra.org/classic/kh4e2db9

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