International Journal of Modern Education
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

INTERNATIONAL JOURNAL OF MODERN EDUCATION (IJMOE)
www.ijmoe.com

USE OF COMPUTATIONAL TOOLS TO ENHANCE THE STUDY OF MICRO- AND MACROMECHANICS BEHAVIOR OF COMPOSITE LAMINA AND LAMINATE IN THE MECHANICS OF COMPOSITE MATERIALS COURSE

Irfan Hadi Jashri[1], Ahmad Sufian Abdullah[2*], Halim Ghafar[3]

[1] Faculty of Mechanical Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, 13500, Malaysia
Email: 2020995135@student.uitm.edu.my
[2] Advanced Mechanics Research Group, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, 13500, Malaysia
Email: ahmadsufian@uitm.edu.my
[3] Advanced Mechanics Research Group, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, 13500, Malaysia
Email: halim4346@uitm.edu.my
[*] Corresponding Author

Article Info:

Article history:
Received date: 24.04.2025
Revised date: 05.05.2025
Accepted date: 28.05.2025
Published date: 23.06.2025

To cite this document:

Jahri, I. H., Abdullah, A. S., & Ghafar, H. (2025). Use Of Computational Tools To Enhance The Study Of Micro- And Macromechanics Behavior Of Composite Lamina And Laminate In The Mechanics Of Composite Materials Course. *International Journal of Modern Education, 7* (25), 664-679.

DOI: 10.35631/IJMOE.725045

Abstract:

This paper presents the outcomes of an innovative learning experience in the field of composite materials mechanics at the undergraduate level. The primary objective is to develop a tool that serves as a learning aid, allowing students to focus more on the fundamental concepts behind problems rather than being overwhelmed by complex equations and lengthy arithmetic operations. Utilizing Microsoft Excel, a specialized calculator was developed to handle intricate calculations involved in micromechanics and macromechanics of composite lamina and laminates. The calculator's accuracy was pre-tested before being deployed to the target students enrolled in the course. Students were then tasked with solving a set of problems both manually and using the calculator to evaluate its efficiency. Results showed that the calculator significantly improved students' performance, reducing average solution times by nearly 50% for simpler tasks and over 60% for more complex problems. It also proved to be a valuable educational tool, aiding in conceptual understanding and manual calculation verification.

Keywords:

Interactive Learning, Outcome-Based Learning Tools, Mechanics Of Composite Materials, Composite Calculator

International Journal of Modern Education
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

Introduction

In the undergraduate course Mechanics of Composite Materials in Universiti Teknologi MARA with course code MEC613, various formulas and material parameters are used to calculate the mechanical properties, strength, and responses of a lamina. The complexity of these calculations, involving numerous numerical values, can be time-consuming. Students often need to refer to textbooks to identify the necessary formulas, making the process less efficient (Savage, 2008).

In mechanics of composite materials, a lamina, also referred to as a ply, is a single layer of unidirectional fibers or woven fabric embedded in a matrix. The lamina exhibits orthotropic material properties, with its principal material axes defined along three directions: the longitudinal direction (aligned with the fibers), the in-plane transverse direction (perpendicular to the fibers within the plane), and the out-of-plane direction (normal to the lamina). These axes are conventionally denoted as 1, 2, and 3, respectively (Gay et. al., 2002).

Meanwhile, a laminate consists of multiple laminae (or plies) stacked in different orientations, with variations in thickness and material properties. Since the principal material axes differ between plies, laminates are typically analyzed using a fixed coordinate system (x, y, z) for consistency. Hybrid composites, specifically interply hybrid composites, incorporate plies made of two or more different materials, such as glass/epoxy, carbon/epoxy, and aramid/epoxy, arranged in a specific stacking order. Composite laminates are classified based on the number, type, orientation, and stacking sequence of their plies. The layup refers to the overall configuration of the laminate, specifying ply composition, while the stacking sequence provides the precise order and positioning of each ply (Gay et. al., 2002).

The above explanation highlights the foundational concepts of lamina and laminate mechanics, which inherently involve numerous variables, complex material behaviors, and coordinate transformations which are concepts that must be learned by students and effectively taught by instructors. These principles translate into lengthy calculations, intricate equations, and detailed arithmetic procedures, posing significant challenges for students in learning the mechanics of composite materials. Consequently, mastering both the theoretical and computational aspects becomes a demanding task that often hinders learning efficiency. One significant issue is the complexity of calculations, which can overwhelm students, resulting in cognitive overload. As highlighted by research in engineering education, students regularly struggle with maintaining accuracy in their calculations and often encounter common pitfalls such as miscalculations and conceptual misunderstandings (Solis et. al., 2012). Therefore, developing an application for these calculations could streamline the process and enhance efficiency in learning Mechanics of Composite Materials at undergraduate level.

In recent years, the integration of artificial intelligence (AI) and digital learning tools in higher education has advanced rapidly, reshaping how students engage with learning materials and how instructors design and deliver instruction. Large Language Models (LLMs) such as ChatGPT, CoPilot, and Sora now facilitate personalized, interactive learning environments across disciplines, offering capabilities from content generation to assessment support

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045
(Papadakis et al., 2022). In parallel, the evolution of Massive Open Online Courses (MOOCs) has provided scalable, global access to education, particularly during disruptions such as the COVID-19 pandemic, which witnessed unprecedented spikes in online course enrolments (Papadakis, 2023). Given these advancements, there is a growing need to evaluate how digital tools especially task-specific ones like educational calculators impact cognitive outcomes, learning efficiency, and user experience. This study explores the deployment of a structured spreadsheet calculator in composite mechanics learning, responding to calls from the literature for targeted evaluation of educational technologies beyond generic software tools (Papadakis et al., 2023).

Literature Review

A specialized calculator serves as a computational tool designed to assist students in university-level engineering courses, as well as researchers and engineers, and represents a forward-looking solution (Theis, 2015). Research highlights that the integration of computational tools into engineering curricula allows educators to shift their focus from theoretical content to practical applications. This shift fosters a deeper understanding of complex concepts and reflects the way engineering is practiced in industry (Mago & Luck, 2014). Lambert (2020) and Shah et al. (2022), show that learners value utility, course quality, and time efficiency, while also struggling with engagement and understanding fundamentals (Lambert, 2020 and Shah et al, 2022). These insights underline the importance of designing educational interventions such as domain-specific calculators that not only perform accurate computations but also optimize user engagement and task completion time. Specifically, the implementation of spreadsheet applications in engineering education exemplifies how these tools liberate students from extensive calculations, enabling them to concentrate on analysis and design aspects (Zhang et. al., 2021). Moreover, as students grapple with complex arithmetic, they may miss critical theoretical constructs that are essential for grasping composite material mechanics. The demanding nature of detailed arithmetic can detract from the overall learning experience, leading to missed opportunities to engage with and understand core principles (Hanson, 2022). In applying more advanced methodologies like Finite Element Analysis, students can become entrenched in calculations, potentially neglecting the physical phenomena behind the mathematics (Brinkgreve & Post, 2015). This emphasizes the risk of becoming technically adept at calculation while simultaneously failing to develop a robust conceptual framework.

Unlike a standard pocket calculator, specific-topics engineering calculator enables users to input complex problems similarly to how they would solve them on paper, incorporating proper units and systematically identifying quantities to facilitate problem-solving. The calculation results are presented with appropriate units of measurement and a precise number of significant figures. The features of this specialized calculator are designed to help students focus on scientific reasoning while formulating well-structured and mathematically accurate solutions to quantitative problems, rather than spending excessive time on manual computations (Thomas et. al., 2008). Besides, the use of applications as learning tools has also been reported to enhance students' engagement and experience in learning the topic (Ishak et. al, 2025). Deng and Benckendorff elucidate that the ability to relate theoretical knowledge to practical applications in real-world contexts is vital for enhancing the online learning experience. They specifically mention that when instructors demonstrate the relevance of scientific concepts through multimedia, learners engage more deeply with the material (Deng & Benckendorff, 2021). This principle is supported by evidence from Sarsar et al., who point out that tools like MOOCs and mobile learning applications, including augmented and virtual reality, have

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

proven effective in engineering education. These tools enrich the learning experience by employing multimedia resources, which help illustrate complex topics, thereby promoting engagement (Sarsar et al., 2018). Furthermore, the application of interactive technologies like virtual reality, discussed by Dinis et al., provides immersive learning experiences that improve students' grasp of complex engineering concepts. These technologies foster a deeper understanding of real-world applications, helping bridge the gap between theory and practice (Dinis et al., 2018). Lee et al. also emphasizes the benefits of simulation games in construction management education, wherein students actively engage in project planning and management within a controlled simulation, leading to enhanced educational outcomes (Lee et al., 2015). The preceding discussion underscores how technological tools, including purpose-built calculators, can significantly enhance educational outcomes through active engagement and learning experiences.

The aim of this study is to develop a computational tool that replicates the results of analytical calculations taught in the mechanics of composite materials course, ensuring accuracy and reliability. Additionally, this study seeks to assess the calculator's potential to support students in performing complex calculations more efficiently by comparing the time taken by students to solve composite mechanics problems manually and using the developed calculator.

Methodology

Determination Of Equations For The Calculator

The developed calculator is capable of performing various micro- and macromechanical calculations at both the lamina and laminate levels, covering orthotropic and isotropic materials. Its application is restricted to elastic responses under plane stress conditions.

For micromechanical analysis at the lamina level, the mechanics of materials approach was adopted. This method enables the determination of the elastic moduli or stiffness of a composite lamina based on the elastic properties of its constituent materials. The assumptions underlying this approach are summarized in Table 1. Four mechanical properties calculation were developed: stiffness of lamina in fiber direction (E_1), lamina stiffness perpendicular to fiber direction (E_2), Poisson's ratio of lamina, (v_{12}) and shear modulus of lamina (G_{12}) as given in equation 1 – 4, respectively (Daniel & Ishai, 2006). In these equations, E is the Young's modulus or elastic stiffness, G is the shear modulus, v is the Poisson's ratio and V is the volume fraction. The subscript f and m indicate the constituents either fiber or matrix respectively.

$$E_1 = E_f V_f + E_m V_m \qquad \text{Eq. 1}$$

$$E_1 = \frac{E_f V_m}{V_m E_f + V_f E_m} \qquad \text{Eq. 2}$$

$$v_{12} = v_m V_m + v_f V_f \qquad \text{Eq. 3}$$

$$G_{12} = \frac{G_m}{V_m + V_f\left(\frac{G_m}{G_f}\right)} \qquad \text{Eq. 4}$$

International Journal of Modern Education
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

Table 1. Basic Assumptions On Micromechanis Approach (Jones, 1999).

Item	Assumptions	
Lamina	• initially stress-free • linearly elastic • no voids can exist	• macroscopically homogeneous • macroscopically orthotropic
Fibers	• homogenous • linearly elastic • isotropic • no voids can exist	• regularly spaced • perfectly aligned • perfectly bonded
Matrix	• homogenous • linearly elastic • no voids can exist	• isotropic • void-free

For macromechanics calculation of a laminate, two material options were made available in the calculator: isotropic material and orthotropic material. Equation 5 - 10 are the isotropic mechanics calculations available in the calculator (Daniel & Ishai, 2006). Respectively, they calculate the shear modulus (G), volumetric strain variation 1 (θ), volumetric strain variation 2 (θ), volumetric strain variation 3 (θ), strains and stresses.

Shear modulus, $G = \frac{E}{2(1+v)}$ Eq. 5

Volumetric strain, $\theta = \varepsilon_x + \varepsilon_y + \varepsilon_z$ Eq. 6

$$\theta = \frac{P}{\frac{E}{\{3(1-2v)\}}} \quad \text{Eq. 7}$$

$$\theta = \frac{P}{K} \quad \text{Eq. 8}$$

Strain-stress relationship, $\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{12} & S_{11} & 0 \\ 0 & 0 & 2(S_{11} - S_{12}) \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix}$ Eq. 9

Stress-strain relationship, $\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{11} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix}$ Eq. 10

In equations above, θ is volumetric strain, P is hydrostatic pressure, K is bulk modulus, ε is normal strain, γ is shear strain, σ is normal stress and τ is shear stress. Ther term Q_i in equation 10 refers to the reduced stiffness matrix and S_{ij} in equation 9 denotes the reduced compliance matrix, which is the inverse to the reduced stiffness matrix. These stiffness and compliance matrices are among the many equations that students are required to calculate for various types of laminae. Using this calculator, user can also calculate both matrices using only the basic mechanical properties of the lamina. The relationship embedded in this calculator to determine these matrices are shown in equation 11 and 12 (Daniel & Ishai, 2006).

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

The compliance matrix elements:

$$S_{11} = \frac{1}{E_1} \qquad S_{12} = -\frac{v_{12}}{E_1} = -\frac{v_{21}}{E_2} \qquad S_{22} = \frac{1}{E_2} \qquad S_{66} = \frac{1}{G_{12}} \qquad \text{Eq. 11}$$

The stiffness matrix elements:

$$Q_{11} = \frac{E_1}{1-v_{12}v_{21}} \; Q_{12} = \frac{v_{12}E_2}{1-v_{12}v_{21}} = \frac{v_{21}E_1}{1-v_{12}v_{21}} \qquad Q_{22} = \frac{E_2}{1-v_{12}v_{21}} \qquad Q_{66} = G_{12} \quad \text{Eq. 12a}$$

$$Q_{11} = \frac{S_{22}}{S_{11}S_{22}-S_{12}^2} \qquad Q_{12} = \frac{S_{12}}{S_{11}S_{22}-S_{12}^2} \qquad Q_{22} = \frac{S_{11}}{S_{11}S_{22}-S_{12}^2} \qquad Q_{66} = \frac{1}{S_{66}} \quad \text{Eq. 12b}$$

For orthotropic composite laminates, the calculator was set to calculate up to the force reaction (*N*) and material's moment reaction (*M*). To determine these reactions, the laminate stiffness matrices [A], [B] and [D] must be calculated as shown in equation 13 to 15 where z_k is the directed distance from the mid-plane of the laminate to the bottom of the k_{th} layer, where positive values are measured downward and negative values upward (Daniel & Ishai, 2006). The term $\bar{Q}_{ij}$ refers to the transformed reduced stiffness matrix, which is also computed based on the fiber orientation angle of each ply.

$$A_{ij} = \sum_{k=1}^{N} \left(\bar{Q}_{ij}\right)_k (z_k - z_{k-1}) \qquad \text{Eq. 13}$$

$$B_{ij} = \frac{1}{2}\sum_{k=1}^{N} \left(\bar{Q}_{ij}\right)_k ({z_k}^2 - {z_{k-1}}^2) \qquad \text{Eq. 14}$$

$$D_{ij} = \frac{1}{3}\sum_{k=1}^{N} \left(\bar{Q}_{ij}\right)_k ({z_k}^3 - {z_{k-1}}^3) \qquad \text{Eq. 15}$$

Calculator Development

The development of the calculator involved not only determining the relevant equations and parameters used in learning and applying the mechanics of composite materials, but also carefully considering how students would interact with the tool. As a learning aid, students typically use the calculator for two main purposes: (1) to calculate specific behaviors or parameters based on given input data, or (2) to verify manual calculations they have performed. The latter requires the calculator to provide final answers that align with the expected results, while the former demands flexibility in how computations are initiated—depending on the type of input data the student already possesses. For instance, the reduced stiffness matrix Q_{ij} can be determined either directly from the mechanical properties of the lamina or by inverting the compliance matrix S_{ij}. Therefore, the calculator is designed to handle both approaches.

Microsoft Excel was utilized to develop this integrated calculator, featuring an interactive user interface that facilitates efficient user interaction. Functionalities such as sheet protection, hyperlinks, and data validation were implemented to enhance usability and ensure calculation accuracy.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

Self-Test And User-Test Deployments

During the self-test deployment, each cell in the calculator was thoroughly tested to ensure full functionality, including the protection of specific cells, proper data validation, and working hyperlinks. Input fields intended for user entry were checked to confirm they only accepted values within the designated scope. For example, only positive numeric values could be entered into the input boxes for shear modulus and Young's modulus. The final stage of the self-test involved running all available calculations in the calculator using sample values and comparing the results to manually computed answers, which were required to match 100%.

In the user-test deployment, 15 undergraduate students enrolled in the Mechanics of Composite Materials course (course code: MEC613) were invited to participate in the study on a voluntary basis. While the sampling was not random, efforts were made to include students with varying levels of academic performance to reduce bias and increase representativeness of the sample. Participation was entirely voluntary, and students were informed that the activity would not affect their course grades or evaluations. This course is a final-semester subject in the Bachelor of Mechanical Engineering (Manufacturing) with Honour (programme code: EM241) at Universiti Teknologi MARA, Penang Branch. The test covered subtopics from the course, specifically the Rule of Mixtures (ROM) and Material Moment Reaction.

This study utilised two main instruments: a stopwatch and a set of structured problem-solving tasks. The stopwatch was used to record the time taken by each participant to complete specific composite mechanics problems under two different conditions: (1) manual calculation using pen and paper, and (2) calculation using a custom-built spreadsheet-based calculator. The problem-solving tasks were drawn from topics in the Mechanics of Composite Materials course, specifically focusing on Rule of Mixtures and Material Moment Reaction. The first task on Rule of Mixtures (ROM), specifically the calculation of lamina stiffness in the fiber direction (E_1), was of moderate difficulty, whereas the second task involved a more complex calculation and was expected to require more time when performed manually. For both questions, students were instructed to work at a steady pace, not in a rush, to ensure accuracy in their answers.

Results and Discussions

The Calculator & Self-Test Deployment

The interactive calculator for Mechanics of Composite Materials was successfully developed using Microsoft Excel and can be distributed to students and academia. Figure 1 shows the home screen of the calculator, offering two main options to begin with: micromechanical behavior or macromechanical behavior. Figure 2a presents the first page of the micromechanical behavior calculator, which includes fundamental introductions and outlines the scope of the calculator's capabilities. The user is interactively guided through a structured workflow, from selecting problem categories to inputting values and obtaining computed results as illustrated in Figures 2b–2f. As shown in Figure 2c, the user selects one of the categories to be calculated. For example, the highlighted yellow section indicates the calculation of the stiffness of a lamina in the fiber direction, based on the stiffness of the fiber, stiffness of the matrix, and their volume fractions. Once this option is selected, the user is prompted with a more specific output to be computed, as shown in Figure 2d. After selecting the desired output, the user is presented with several blank input fields, and the final answer is

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

displayed at the bottom, as demonstrated in Figure 2e. Figure 2f displays the final computed result based on the user's input.

This same procedure and options for inputs and end product were also available for the macromechanical behaviour of isotropic and orthotropic laminates. A self-test deployment was carried out to check the functionality of every variation available in the calculator. The accuracy of the calculations made by the calculator was 0% error. A self-test deployment was conducted to verify the calculator's functional accuracy, revealing 0% error across all implemented variations. This result confirms the tool's computational reliability. However, recent studies suggest that the effectiveness of digital learning tools is not solely measured by technical precision, but also by how well they support learner autonomy, engagement, and perceived usefulness (Lavidas et al., 2024; Papadakis et al., 2023). In this context, the structured, decision-guided interface of the calculator aligns with design principles that enhance user experience and reduce cognitive load in complex learning tasks (Papadakis et al., 2023; Shah et al., 2022)

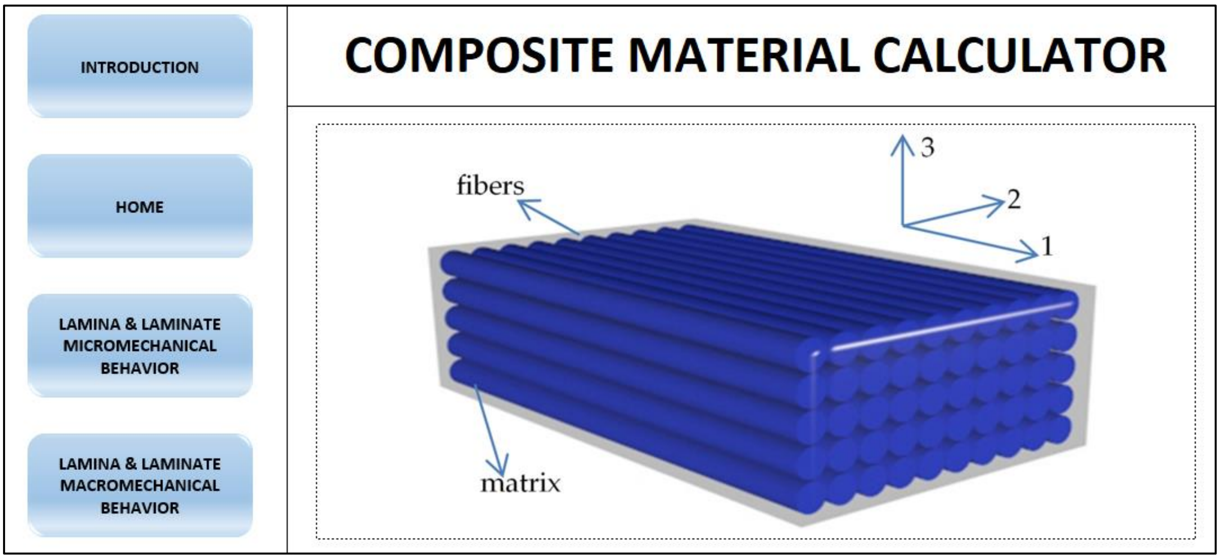


Figure 1: Home Screen Of The Composite Mechanics Calculator.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

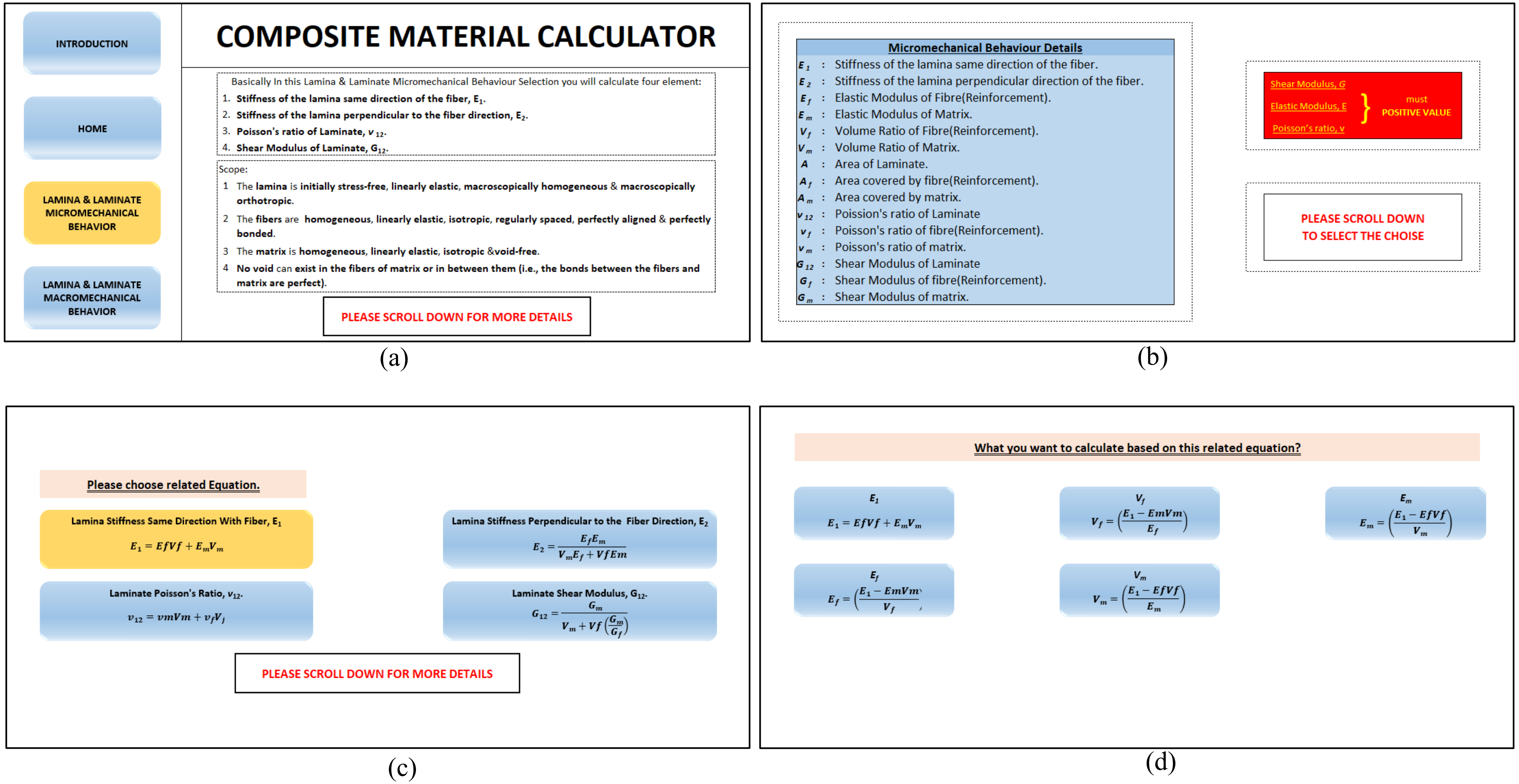
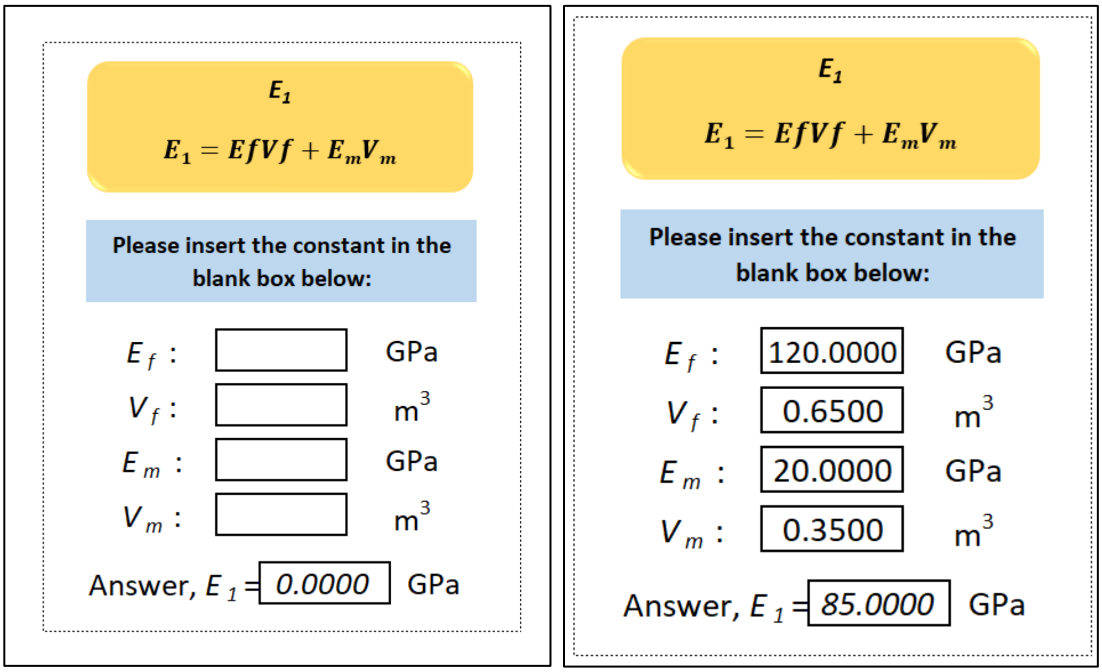


Figure 2 (A): Home Screen Of The Micromechanical Behaviour Calculator, (B): Details And Nomenclature Of The Micromechanical Behaviour Calculator, (C): Options Of Categories Available In Micromechanical Behaviour Calculator And (D): Options Of Specific End-Product Available In Micromechanical Behaviour Calculator.

International Journal of Modern Education
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045



(e) (f)

Figure 2 (e): Blank Cell For Input And The Final Answer Shown At The Bottom Of The Calculator, (f): Final Answer With The Input From User.

Performance User-Test Deployment

Two calculation variations were tested among 15 students from the Mechanics of Composite Materials course (course code MEC613) where they performed both variations manually and using the developed calculator. The variations were: (1) calculation of stiffness of a lamina in the fiber direction using Rule of Mixture (ROM) and (2) calculation of Material's moment reaction of a composite laminate. The aim was to further test the accuracy and time efficiency of the calculator.

Performance on Rule of Mixture (ROM) Calculation

The first task, calculating lamina stiffness (E_1) using the Rule of Mixtures, was simpler than the moment reaction calculation, requiring fewer inputs and steps to reach a result. For both manual calculation and calculator deployment, all the users managed to get the final answer within tens of seconds as shown in figure 3. Manually, the time taken to solve the problem was in between 28.64 to 71.36 seconds meanwhile for calculation using calculator it was in between 9.63 to 45.57 seconds. Interestingly, the same person recorded the slowest for both type of calculation, similarly for the record for the fastest. This pattern can be observed across all individuals participating in this test. For example, consider person number 1 and 2 where person number 1 took longer than person number 2 during manual calculation. If it were a competition, person number 2 would still win when using the calculator. This suggests that individual proficiency in conceptual understanding, problem-solving efficiency, and familiarity with the procedure significantly affects performance, regardless of the calculation method. It also indicates that students with higher competence continue to perform better even

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

when assisted by the calculator. The variation in performance is less about access to the calculator or technology in general, and more about the student's grasp of the problem, their strategy, and their execution of the solution. This trend supports previous findings that tool adoption alone does not equalize performance outcomes (Lavidas et al., 2024). Instead, calculators serve as accelerators for students already competent in problem-solving, while still offering time-saving benefits for all users (Papadakis et al., 2023). However, the most evident takeaway is that the calculator improves calculation time for all users, regardless of their level of proficiency.

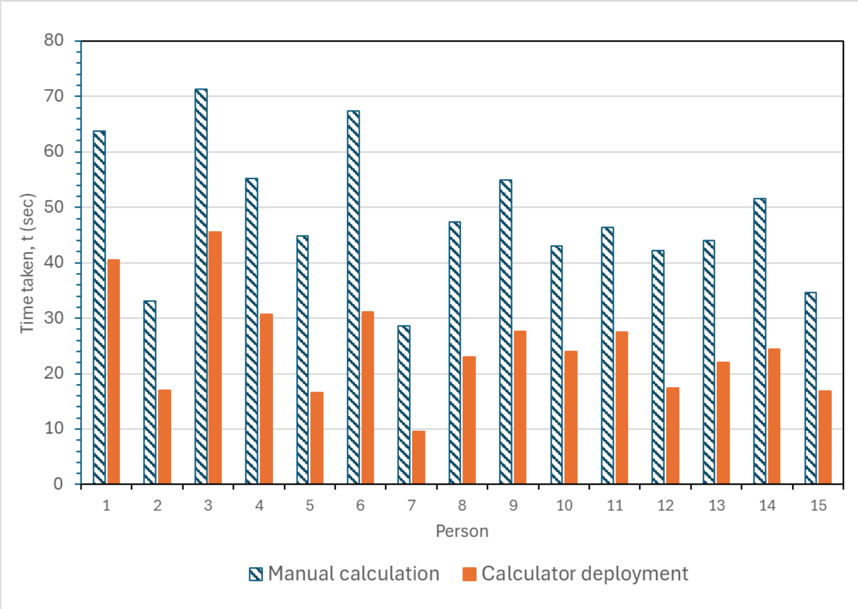


Figure 3: Calculation of ROM Performed Manually And Using Calculator.

Table 2 shows how each user improved their time efficiency, with time efficiency increases ranging from 36.14% to 66.38%. On average, using this calculator increased time efficiency by 49.85%, which can be described as roughly halving the solution time. As mentioned earlier, time savings were observed across the board, with every individual showing a reduction in time when using the calculator. However, not everyone managed to save the same amount of time percentage-wise, as the difference between the best and worst time savings was 30.24%. Persons 5 and 6 showed unusually high time efficiency gains (62.98% and 66.38%), which may suggest that their slower manual calculations were due to weaker arithmetic skills rather than poor conceptual understanding.

Table 2. Time Efficiency Of Calculator Usage In Solving the ROM

Person	Manual calculation time taken, t (sec)	Calculator deployment time taken, t (sec)	Difference (Manual - Calculator) Time taken, t (sec)	% reduction
1	63.68	40.47	23.21	36.45%
2	33.11	16.98	16.13	48.72%
3	71.36	45.57	25.79	36.14%
4	55.26	30.76	24.50	44.34%
5	44.90	16.62	28.28	62.98%
6	67.44	31.20	36.24	53.74%

International Journal of Modern Education
EISSN: 2637-0905
IJMOE
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

7	28.64	9.63	19.01	66.38%
8	47.38	23.09	24.29	51.27%
9	54.97	27.66	27.31	49.68%
10	42.98	23.94	19.04	44.30%
11	46.41	27.43	18.98	40.90%
12	42.17	17.39	24.78	58.76%
13	44.00	22.04	21.96	49.91%
14	51.64	24.44	27.20	52.67%
15	34.66	16.81	17.85	51.50%
	Average		**23.638**	**49.85%**

Performance On Moment Reaction Calculation

The moment reaction task, involving multiple input parameters and more advanced matrix operations, was significantly more complex than the ROM calculation. For manual moment reaction calculations, all users took more than 1000 seconds but less than 2000 seconds to solve the problem, except for one. In minutes, they solved the problem in the range of 27 to 34 minutes. This large difference compared to calculating ROM was expected due to the enhanced complexity of the problem. By using the calculator, all users managed to get the final answer within 9 to 11 minutes, as shown in Figure 4. As observed in the ROM task, individual performance trends remained consistent in which students who were slower manually also took longer when using the calculator, underscoring the role of intrinsic problem-solving speed. This indicates that students who took longer manually generally still took longer with the calculator, suggesting that fundamental problem-solving speed is a key factor that the calculator cannot eliminate which is not what it is intended to do (Lavidas et al., 2024).

Table 3 shows how each user improved their time calculation efficiency, with efficiency increases ranging from 61.08% to 67.06% which suggests that the calculator boosts efficiency for both faster and slower individuals alike. Compared to the calculation of ROM, the time efficiency gains were more consistent, with the difference between the least and most improvement being just 5.98%, suggesting that the calculator plays a stronger compensatory role in tasks with higher computational demand. This aligns with studies highlighting the value of AI-enhanced tools in reducing cognitive load during complex, multi-step problem-solving (Papadakis et al., 2023; Semerikov et al., 2023). On average, using this calculator increased time efficiency by 63.88%, which can be described as more than halving the solution time, nearly two-thirds. For person number 3, he/she had both the highest manual time and the highest percentage time reduction (67.06%). This suggests that this person benefited the most from using the calculator, likely due to a reduction in arithmetic-skill-related delays. For moment reaction calculations, it is evident that this calculator is a significant time-saving tool. This demonstrates a clear benefit in deploying calculators for tasks such as moment reaction calculations, which involve repetitive numerical operations.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

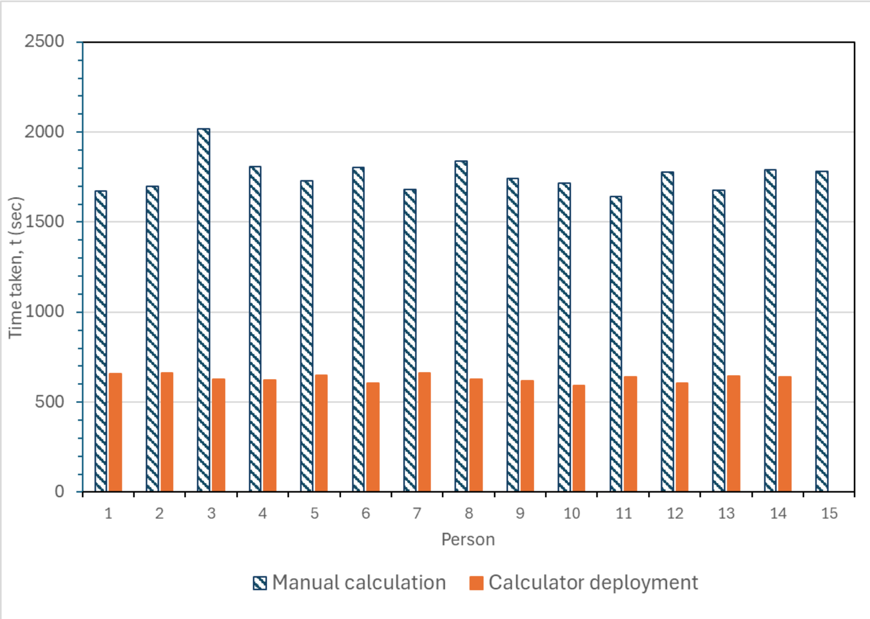


Figure 4. Calculation Of Moment Reaction Performed Manually And Using Calculator.

Table 3: Time Efficiency Of Calculator Usage In Solving The Material's Moment Reaction

Person	Manual calculation time taken, t (sec)	Calculator deployment time taken, t (sec)	Difference (Manual - Calculator) Time taken, t (sec)	% reduction
1	1674.26	651.64	1022.62	61.08%
2	1698.59	658.63	1039.96	61.22%
3	2017.24	664.56	1352.68	67.06%
4	1806.30	628.64	1177.66	65.20%
5	1727.72	622.49	1105.23	63.97%
6	1805.27	650.43	1154.84	63.97%
7	1682.70	606.27	1076.43	63.97%
8	1836.82	661.80	1175.02	63.97%
9	1741.95	627.62	1114.33	63.97%
10	1717.78	618.91	1098.87	63.97%
11	1641.24	591.33	1049.91	63.97%
12	1779.47	641.14	1138.33	63.97%
13	1675.76	603.77	1071.99	63.97%
14	1789.97	644.92	1145.05	63.97%
15	1780.27	641.42	1138.85	63.97%
Average			**1124.118**	**63.88%**

Conclusions

This user-test deployment involving 15 students from the Mechanics of Composite Materials course (Course code: MEC613) assessed the accuracy and time efficiency of a newly developed interactive calculator for solving common composite mechanics problems, namely the stiffness of a lamina in the fiber direction using the Rule of Mixtures (ROM) and the moment reaction

International Journal of Modern Education
EISSN: 2637-0905
IJMOE
Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045
of a composite laminate. The results of this study clearly demonstrate the successful development and deployment of a functional, time-saving interactive calculator. In both calculation variations tested, the calculator significantly reduced solution time for all participants. For ROM calculations, the time savings ranged between 36.14% and 66.38%, with an average reduction of 49.85%, effectively halving the time required. For the more complex moment reaction calculations, the time savings were even more substantial, ranging from 61.08% to 67.06%, with an average time efficiency increase of 63.88%, or nearly two-thirds reduction in time. These results confirm that the calculator is highly effective as a computational aid and stands as a practical tool to support both teaching and learning activities in the subject of composite materials. While the calculator proved highly time efficient in reducing calculation time, the user-test also revealed that performance rankings remained consistent across both manual and calculator-based calculations. This suggests that conceptual understanding, problem-solving ability, and familiarity with procedures are still the dominant factors in student performance. Students who were stronger manually continued to perform better even with calculator assistance. This insight reinforces the idea that the calculator does not replace understanding but complements it by offloading time-consuming arithmetic tasks. Students benefit by having more time and cognitive space to focus on problem interpretation, equation selection, and reasoning. Therefore, the calculator serves as an effective learning aid rather than just a shortcut.

The deployment of this calculator introduces several important implications for both students and educators as listed below.

i. Conceptual reinforcement:
Students can use the calculator to better understand the fundamentals behind equations. By seeing how different inputs affect outputs instantly, they develop a more intuitive grasp of mechanics concepts.

ii. Verification tool:
The calculator acts as a reliable cross-check for students' manual solutions or their finite element analysis (FEA) results, reducing human error and reinforcing their confidence in the problem-solving process.

iii. Improving project efficiency:
Students may improve productivity in their mini projects as the calculator helped streamline lengthy calculations, allowing more time for analysis, reflection, and report writing.

iv. Instructional support for lecturers:
Lecturers may benefit from the calculator when verifying students' work, especially in collaborative or modular courses where students may use materials or equations introduced by other lecturers. The calculator provides a standard, consistent platform for evaluation.

Acknowledgements
The authors would like to express their sincere gratitude to Universiti Teknologi MARA, Malaysia for providing the facilities and support necessary to carry out this study. Special thanks are also extended to the students of MEC613 – Mechanics of Composite Materials – for their enthusiastic participation in the calculator validation and user-testing activities.

References
Brinkgreve, R. and Post, M. (2015). Geotechnical ultimate limit state design using finite elements.. https://doi.org/10.3233/978-1-61499-580-7-464

Daniel, I. M., & Ishai, O. (2006). Engineering mechanics of composite materials (2nd ed.). Oxford University Press.

Deng, R. and Benckendorff, P. (2021). What are the key themes associated with the positive learning experience in moocs? an empirical investigation of learners' ratings and reviews. International Journal of Educational Technology in Higher Education, 18(1). https://doi.org/10.1186/s41239-021-00244-3

Dinis, F., Martins, J., Rangel, B., & Guimarães, A. (2018). Disseminating civil engineering through virtual reality: an immersive interface. International Journal of Online and Biomedical Engineering (Ijoe), 14(05), 225-232. https://doi.org/10.3991/ijoe.v14i05.7788

Gay, D., Hoa, S. V., & Tsai, S. W. (2002). Composite materials: Design and applications. CRC Press. https://doi.org/10.1201/9781420031683

Ishak, Z., Roslan, W. A. Q. W., & Helmi, R. A. A. (2025). Enhancing the students' engagement in learning English alphabet by using Arphabet application. International Journal of Modern Education (IJMOE), 7(24), 65–79. https://doi.org/10.35631/IJMOE.724004Hanson, J. (2022). Teaching students how to evaluate the reasonableness of structural analysis results. Journal of Civil Engineering Education, 148(1). https://doi.org/10.1061/(asce)ei.2643-9115.0000053

Jones, R. M. (1999). Mechanics of composite materials (2nd ed.). Taylor & Francis. https://doi.org/10.1201/9781498711067

Lambert, S. R. (2020). Do MOOCs contribute to student equity and social inclusion? A systematic review 2014-18. Computers & Education, 145, 103693. https://doi.org/10.1016/j.compedu.2019.103693

Lavidas, K., Voulgari, I., Papadakis, S., Athanassopoulos, S., Anastasiou, A., Filippidi, A., Komis, V., & Karacapilidis, N. (2024). Determinants of Humanities and Social Sciences Students' Intentions to Use Artificial Intelligence Applications for Academic Purposes. Information, 15(6), 314. https://doi.org/10.3390/info15060314

Lee, S., Nikolić, D., & Messner, J. (2015). Framework of the virtual construction simulator 3 for construction planning and management education. Journal of Computing in Civil Engineering, 29(2). https://doi.org/10.1061/(asce)cp.1943-5487.0000388

Mago, P., & Luck, R. (2014). Use of computational tools to enhance the study of psychrometric processes for buildings in an air conditioning course. International Journal of Mechanical Engineering Education, 42(3), 251–266. https://doi.org/10.7227/ijmee.0013

Papadakis, S., Kiv, A. E., Kravtsov, H. M., Osadchyi, V. V., Marienko, M. V., Pinchuk, O. P., Shyshkina, M. P., Sokolyuk, O. M., Mintii, I. S., Vakaliuk, T. A., Azarova, L. E., Kolgatina, L. S., Amelina, S. M., Volkova, N. P., Velychko, V. Ye., Striuk, A. M., & Semerikov, S. O. (2023). Unlocking the power of synergy: The joint force of cloud technologies and augmented reality in education. In S. O. Semerikov & A. M. Striuk

Volume 7 Issue 25 (June 2025) PP. 664-679
DOI: 10.35631/IJMOE.725045

(Eds.), Joint Proceedings of the 10th Workshop on Cloud Technologies in Education, and 5th International Workshop on Augmented Reality in Education (CTE+AREdu 2022) (Vol. 3364, pp. 1–23). CEUR-WS.org. https://ceur-ws.org/Vol-3364/paper00.pdf

Papadakis, S. (2023). MOOCs 2012-2022: An overview. *Advances in Mobile Learning Educational Research*, *3*(1), 682-693. https://doi.org/10.25082/AMLER.2023.01.017

Papadakis, S., Kiv, A. E., Kravtsov, H. M., Osadchyi, V. V., Marienko, M. V., Pinchuk, O. P., Shyshkina, M. P., Sokolyuk, O. M., Mintii, I. S., Vakaliuk, T. A., Striuk, A. M., & Semerikov, S. O. (2023). *Revolutionizing education: Using computer simulation and cloud-based smart technology to facilitate successful open learning*. In S. Papadakis (Ed.), *Joint Proceedings of the 10th Illia O. Teplytskyi Workshop on Computer Simulation in Education and Workshop on Cloud-based Smart Technologies for Open Education (CoSinEi and CSTOE 2022)* (Vol. 3358, pp. 1–18). CEUR-WS.org. https://ceur-ws.org/Vol-3358/paper00.pdf

Sarsar, F., Andiç-Çakır, Ö., Bohórquez, M., & Leeuwen, M. (2018). Learners' and instructors' views on technology supported engineering education: initial outcomes in a cross-cultural study sample. Universal Journal of Educational Research, 6(12), 2764-2771. https://doi.org/10.13189/ujer.2018.061210

Savage, G. (2009). Sub-critical crack growth in highly stressed Formula 1 race car composite suspension components. Engineering Failure Analysis, 16(2), 608–617. https://doi.org/10.1016/j.engfailanal.2008.02.016

Semerikov, S. O., Foki, M. V., Shepiliev, D. S., Mintii, M. M., Mintii, I. S., & Kuzminska, O. H. (2024). Teaching WebAR development with integrated machine learning: A methodology for immersive and intelligent educational experiences. Educational Dimension, 10, 198–234. https://doi.org/10.55056/ed.660

Shah, D., Pickard, L. & Ma, R. (2022). Massive List of MOOC Platforms Around The World in 2022. https://www.classcentral.com

Solís, M., Romero, A., & Galvín, P. (2012). Teaching structural analysis through design, building, and testing. Journal of Professional Issues in Engineering Education and Practice, 138(3), 246-253. https://doi.org/10.1061/(asce)ei.1943-5541.0000097

Theis, K. (2015). PQcalc, an online calculator for science learners. Journal of Chemical Education, 92(11), 1953–1955. https://doi.org/10.1021/acs.jchemed.5b00366

Thomas, M. O. J., Hong, Y. Y., Bosley, J., & delos Santos, A. G. (2008). Use of calculators in the mathematics classroom. Electronic Journal of Mathematics and Technology, 2(2), 228–242 [Online]. Available: https://ejmt.mathandtech.org/Contents/eJMT_v2n2n3.pdf

Zhang, J., Cho, H., & Mago, P. (2021). Improving student learning of energy systems through computational tool development process in engineering courses. Sustainability, 13(2), 884. https://doi.org/10.3390/su13020884