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INTEGRATING CREATIVE ART INTO ENGINEERING MATHEMATICS AND STATISTICS: STEAM-BASED FRAMEWORK TO ENHANCE CONCEPTUAL UNDERSTANDING AND STUDENT ENGAGEMENT

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A B S T R A C T

Engineering Mathematics and Statistics are often perceived as abstract, challenging, leading to low student engagement and limited conceptual understanding. Building on the previous "Calculus with Creative Art" study, this research extends creative and visual pedagogies to broader engineering mathematics and statistics topics. Activities in Operations Research included a Linear Programming crossword puzzle and graphical exploration of optimization problems, with students using GeoGebra to visualize feasible regions, constraints, and Simplex-based solutions. In Design of Experiments, students created manual and R-based heatmaps and interaction plots for two-factor cross classifications with and without interaction, using colour gradients to represent effects and variability. Quantitative results, including paired t-tests, showed significant learning gains, while qualitative feedback reflected enhanced engagement, creativity, and conceptual clarity. Overall, findings support art-integrated approaches as effective for interdisciplinary learning.

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1. INTRODUCTION

Engineering and IT students frequently face challenges in mastering mathematical and statistical concepts due to their abstract nature and limited opportunities for visualization. Topics such as optimization and experimental design often result in low engagement, rote learning, and difficulty in applying theory to practical scenarios. Recent research underscores the effectiveness of interdisciplinary, creative, and visual pedagogies in fostering conceptual understanding, critical thinking, and motivation, consistent with STEAM (Science, Technology, Engineering, Arts, and Mathematics) educational frameworks.

1.1 Literature review

STEAM and interdisciplinary learning

STEAM education extends the traditional STEM framework by incorporating art to promote creativity, innovation, and design thinking alongside scientific and

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mathematical reasoning (Yakman & Lee, 2012). This holistic approach encourages learners to integrate analytical and aesthetic dimensions, fostering deeper conceptual understanding. In engineering and mathematics education, STEAM principles encourage students to make meaningful connections between abstract concepts and real-world applications (Henriksen, 2017). Interdisciplinary learning environments have been shown to enhance both engagement and cognitive flexibility, equipping students with skills essential for problem-solving in complex, technology-driven contexts (Bequette & Bequette, 2012).

The relationship between art and mathematics has been long established, evident in the use of geometry, symmetry, and proportion in artistic and architectural design (Sinclair, 2006). Integrating artistic practices into mathematics instruction supports visualization and creativity, helping students conceptualize abstract ideas such as transformations, curves, and proportions. In engineering education, creative expression enhances spatial reasoning, innovation, and critical thinking, which are essential for technical problem-solving (Shernoff, Sinha, Bressler, & Ginsburg, 2017). However, despite these advantages, art-based approaches remain underutilized in quantitative disciplines, often due to rigid curricula and perception of art as peripheral to engineering education (Henriksen, 2017).

Challenges in Engineering Mathematics and Statistics education

Engineering mathematics and statistics are foundational yet often perceived as difficult and abstract by students (Charalambides, Panaoura, Tsolaki, & Pericleous, 2023). Traditional teaching methods, mainly lecture-based and formula-driven, may not effectively support conceptual understanding or engagement (Ainley, Pratt & Hansen, 2006). Concepts such as optimization, probability, and Design of Experiments (DOE) require learners to interpret both analytical results and contextual implications. Studies suggest that incorporating visualization and real-world examples can alleviate math anxiety and enhance understanding (Ramirez, Shaw & Maloney, 2018). Therefore, innovative instructional methods integrating creativity and visualization are increasingly being explored as means to promote deeper learning in quantitative subjects.

Visualization and creative art approaches in Engineering Mathematics and Statistics

Technological visualization tools play a key role in bridging theory and practice in engineering mathematics and statistics education. Applications such as Desmos, GeoGebra, MATLAB, and R provide interactive environments that allow learners to manipulate mathematical models and instantly visualize results (Ondes, 2021). Desmos, for example, enables students to graphically interpret optimization problems, while R supports statistical analysis and visualization of complex experimental designs. These tools support exploratory learning and creativity by allowing students to engage dynamically with mathematical relationships rather than passively receiving information (Boaler, Chen, Williams, & Cordero, 2016). Integrating technology with creative art-based approaches further strengthens students' analytical and imaginative capacities (Henriksen, 2017).

Art-based methods can provide tangible pathways for understanding complex mathematical and statistical concepts. In operations research, visualization of feasible regions and trade-offs can be enhanced through design-inspired graphical representations (Pinheiro, Landa-Silva, & Atkin, 2017). Similarly, visual mapping and artistic patterning can help students understand two-factor designs, replication, and interactions in DOE. Such activities encourage aesthetic appreciation, critical reasoning, conceptual clarity and skills that are vital in engineering disciplines. Moreover, integrating art with mathematics promotes learner autonomy and motivation, as students take ownership of their creative processes.

Numerous educational theories support integrating art into quantitative learning. Constructivist theory emphasizes learning through active engagement and meaning-making, aligning with creative, exploratory activities (Piaget, 1973). Gardner's (1993) theory of multiple intelligences recognizes the role of visual-spatial intelligence in understanding mathematical and geometric concepts. Paivio's (1990)Dual Coding Theory posits that combining verbal and visual representations enhances comprehension and retention. Furthermore, the VARK learning model (Fleming & Mills, 1992) identifies the diversity of learning preferences, visual, aural, read/write, and kinesthetic, suggesting that multimodal strategies, including creative arts, can effectively support a wider range of learners.

Summary and Research gap

Although prior research has explored in terms of theories and aesthetic connections between mathematics and art, empirical studies addressing the integration of art-based strategies in engineering mathematics and statistics remain limited (Henriksen, 2017). There is a need for more research investigating how creative and visual methodologies can enhance conceptual understanding, engagement, and critical thinking in engineering students. Moreover, few studies have examined such approaches within the South Asian higher education context. This study aims to address these gaps by applying a STEAM-based framework that combines creative art, technological visualization, and quantitative reasoning to improve learning outcomes in engineering mathematics and statistics.

1.2 Research scope

This research aims to develop and evaluate a STEAM-based instructional framework that integrates creative art into engineering mathematics and statistics to enhance the conceptual understanding, engagement, and

appreciation of mathematical applications in engineering contexts.

The specific objectives are to;

1. design and implement creative art–based learning activities for selected topics in Engineering Mathematics and Industrial Statistics (e.g. Calculus, linear programming, and design of experiments).

2. analyze the impact of art-integrated learning on students' performance and conceptual understanding using statistical analysis.

3. evaluate student engagement, creativity, and perception regarding the integration of mathematics and art in engineering education through structured feedback.

4. suggest a STEAM-based framework that demonstrates how creative art and visualization tools (e.g., GeoGebra, R) can effectively support mathematical and statistical learning in engineering curricula.

1.3 Significance of the research

Engineering education increasingly demands innovative pedagogical approaches that develop not only analytical proficiency but also creativity, problem-solving ability, and interdisciplinary thinking. Traditional methods of teaching engineering mathematics and statistics often emphasize procedural skills and symbolic manipulation, which can limit students' conceptual understanding and engagement (Ainley et al., 2006). Integrating creative art within the framework of STEAM (Science, Technology, Engineering, Arts, and Mathematics) offers a powerful avenue to bridge this gap by linking abstract mathematical ideas with visual and creative expression (Henriksen, 2017; Bequette & Bequette, 2012). Such integration encourages learners to approach mathematical problems through multiple perspectives: visual, conceptual, and experiential, thus supporting diverse learning styles (Fleming & Mills, 1992). Moreover, art-based approaches can enhance motivation, foster deeper learning, and cultivate transferable skills essential in modern engineering practice, including design thinking and innovation (Boaler et al., 2017). By adopting a STEAM-based approach, this study contributes to advancing pedagogical innovation in engineering education, promoting both cognitive understanding and creative engagement among learners.

In the Sri Lankan higher education context, engineering students often encounter difficulties in connecting mathematical theory with real-world applications, leading to reduced interest and confidence in the subject. The emphasis on exam-oriented and lecture-based instruction further limits opportunities for creative exploration and collaborative learning. Introducing creative art into engineering mathematics and statistics through a STEAM-based framework provides a novel avenue to address these challenges. By engaging students in visual and applied activities such as graphical modelling, art-integrated calculus, and design-based experiments, educators can promote conceptual understanding and nurture aesthetic appreciation and analytical reasoning. This approach not only aligns with global movements toward learner-centered pedagogy but also supports national goals of fostering innovation and interdisciplinary competence in STEM education (National Education Commission, 2023). Hence, the present study holds pedagogical and policy relevance by demonstrating how art-integrated strategies can transform the learning experience in engineering mathematics and statistics.

1.4 Rationale for the Current Study

The annual intake of the Institute of Technology, University of Moratuwa (ITUM), is approximately 800 students. In 2024, a VARK questionnaire was administered to Semester I students to identify their learning preferences, Visual (V), Auditory (A), Read/Write (R), Kinesthetic (K), or multimodal. Responses were received from about 30% of the cohort. The results indicated the following distribution: visual only (5%), auditory only (32%), read/write only (4%), kinesthetic only (34%), and multimodal learners (25%). These findings confirm that the majority of students prefer kinesthetic, multimodal, or visual learning styles. The study further emphasized that aligning teaching methodologies with students' learning preferences can foster a more inclusive and effective learning environment for first-year students in technology-oriented universities (Iroshani & Mathugama, 2024).

Motivated by these insights, interactive visualizations and creative tasks were integrated into teaching practices to enhance learning outcomes. Subsequently, a study titled *"Calculus with Creative Art"* was conducted for the 2025 intake, involving 650 students (Bandara, Jayathilake, & Mathugama, 2025). Building on this prior work, the present study designed a series of activities, including selected STEAM-based tasks, in engineering mathematics and statistics for 90, Semester IV Information Technology students, who had also participated in the VARK questionnaire study in 2024.

The STEAM-based activities are: Activity 1 with Linear Program (LP) crossword puzzle, Activity 2 involved Geogebra calculator-based exploration of optimization and sensitivity analysis, Activity 3 and 4 is designed with Simplex Method and post optimal analysis, while Activity 5 and 6 engaged students in creative visualization of two-factor experimental designs with replications, using heatmaps and interaction plots manually and with R. Together, these activities aim to connect analytical reasoning with creative expression, promoting engagement and deeper conceptual understanding.

2. METHODOLOGY

The results of the VARK questionnaire analysis indicated that most students were visual, kinesthetic and multimodal learners, suggesting that graphical, interactive, and hands-on activities would be most effective in enhancing engagement and understanding.

2.1 Integration of Calculus-art activities

The original "Calculus with Creative Art" study conducted with Semester I students served as the foundation for this extended research. Students engaged in two primary activities:
(1) art-integrated calculus exercises, including mind maps, posters, and conceptual diagrams for limits, hyperbolic functions, extreme value problems, and curve sketching, and
(2) artistic visualization of calculus principles, where shading, gradients, and symbolic representations illustrated mathematical relationships (Bandara et al., 2025).

A paired-samples *t*-test was used to evaluate students' performance before and after Activity 2. The paired-samples *t*-test compares the means of two related measurements obtained from the same group at different time points, such as pre- and post-intervention scores (Dean & Illowsky, 2023).
The hypotheses for the test were formulated as:

$H_0: \mu_d = 0$; $H_1: \mu_d > 0$, where μ_d represents the population mean of the paired differences between post- and pre-activity scores.
The test statistic is given by:.

$$T = \frac{\bar{d}-\mu_d}{SE(\bar{d})} \sim t_{n-1,\alpha} \quad (1)$$

$\bar{d}$: the sample means of the paired differences
$SE(\bar{d})$: standard error of the mean difference
$n-1$: degree of freedom where n is the number of paired observations.

The decision to reject or fail to reject the null hypothesis was based on the *p*-value at a significance level α, which represents the probability of observing the sample data assuming the null hypothesis is true.

2.2 Extended study with STEAM-based activities

The "Calculus with Creative Art" study was extended to Semester IV students, covering topics in Operations Research and Design of Experiments. STEAM-based Learning Activities (LA) are designed to enhance conceptual understanding, and Continuous Assessment Tasks (CAT), were used to test their learning of these concepts. These LAs were planned as group activities, ensuring active engagement and peer learning among the groups.

a. Linear programming crossword puzzle
A group activity was designed, incorporating a crossword puzzle, to enhance students' conceptual understanding of LP concepts. Students were grouped, and each group was given a crossword puzzle with Across and Down clues representing basic concepts in linear programming.

b. GeoGebra-based optimization
Students explored linear programming problems using GeoGebra graphing calculator to visualize feasible regions, constraints, and objective functions. They created colour-coded feasible regions, annotated constraint lines, and identified optimal solutions. Sensitivity analyses were performed by adjusting coefficients to observe changes in the solution, linking abstract concepts to interactive visual experiences.

c. A creative tableau activity with the simplex method
This activity was designed to help students develop a conceptual understanding of the simplex method in linear programming through collaborative and visual learning. The simplex method is an algorithm used to solve LP problems where the goal is to maximize or minimize a linear objective function subject to linear constraints. It works by moving from one feasible solution to another in a step-by-step manner, improving the objective function at each stage (Taha, 2016). Students were divided into small groups and provided with A3 sheets and colour pens to represent each stage of the simplex tableau on a single page.

d. Dual dimensions: post-optimal analysis in LP
This activity enabled students to visualize and understand the relationship between primal and dual problems in LP and to explore the effects of post-optimal (sensitivity) changes through a collaborative, art-integrated approach. Within the group activity framework, each student was assigned a specific role in constructing and analysing the dual problem. Each group represented all primal and dual equations on their A3 sheet using distinct colour codes (e.g., blue for primal, red for dual). Arrows or shading were used to visually link corresponding variables and constraints. Changes from post-optimal analysis were shown with highlighted or gradient colours, symbolizing how small parameter changes influence the feasible region or optimal solution.

e. Creative visualization of two-factor designs
This activity focused on two-factor experimental designs with replications, using a 2 × 3 factorial example. First, the concepts of heatmaps and interaction plots were introduced to students. Then they were guided to create these plots manually using A3 paper and colours as a group activity. Next, individual students used R to generate heatmaps and interaction plots, where colour gradients and patterns represented main effects, interactions, and variability. Replications were represented as repeated motifs within cells to

demonstrate experimental error visually. A sample heat map and sample interaction plot are shown in Figure 1.

Finally, the students were instructed to perform a two-way Analysis of Variance (ANOVA) to confirm main and interaction effects. ANOVA is a statistical technique used to determine whether there are significant differences between the means of three or more groups. Instead of comparing means pairwise, ANOVA evaluates all groups simultaneously by partitioning the total variability in the data into between-group variability (differences caused by the factor being studied) and within-group variability (natural randomness or error), (Berger, Maurer, & Celli, 2017).

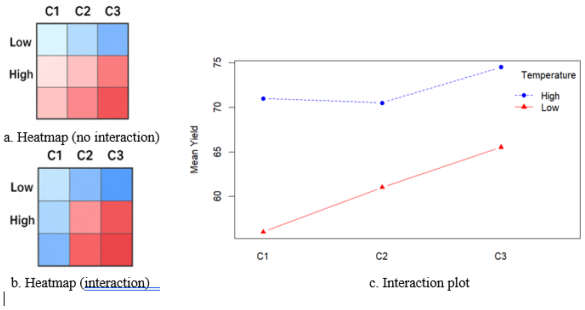


Figure 1. Sample heatmaps and interaction plot

All these learning activities connected mathematical rigor and statistical reasoning with creative visualization, aligning with students' learning preferences.

3. RESULTS AND DISCUSSION

3.1 Calculus with creative art – Baseline analysis

This section provides the baseline analysis of student engagement and feedback from the two activities reported in the "Calculus with Creative Art" study. These findings are incorporated to support the comparative and extended analysis undertaken in the STEAM-based activities.

Mathematics as a Creative Tool- Activity 1

Students' engagement in the original Calculus-Art activities (Figure 2) demonstrated the effectiveness of integrating creative expression with mathematical concepts.

The activity aimed to develop imaginative and critical thinking, consolidating creative and conceptual artistic competencies by challenging students to produce ten different artworks, illustrated in Figure 2, using black ink pens, markers, selected colours, and pencil shading, enhancing depth and visual impact.



Figure 2. Ten created art pieces

Each artwork involved a variety of mathematical concepts, including symmetry, measurement, proportion, geometry, the Fibonacci spiral, hyperbolas, parabolas, and algebraic patterning, expressed through geometric grids, patterns of rotational and radial symmetry, spirals, optical illusions, and mixed structural designs. Throughout the compositions, students built visually balanced and conceptually rich patterns with repetitive line structures, concentric formations, distorted grids, and mathematically guided curves. Marks were awarded on how clearly and accurately these mathematical concepts were portrayed, showing the effectiveness of translating abstract mathematical ideas into expressive forms that can be used to represent and express the close relation between mathematics and art.

Creative Approaches to Teaching Mathematics - Activity 2

Key learning outcomes of activity 2 were:

LO1 - Demonstrate the indeterminate forms of limits

LO2 - Derive definitions of hyperbolic functions

LO3 - Solve hyperbolic equations

LO4 - Solve extreme value problems

LO5 - Sketch curves including hyperbolic functions and polar coordinates.

These activities were carried out as group tasks of 5–10 students, engaging a total of 650 participants, with each creation linked to specific mathematical topics as presented in Table 1.

Table 1. Details of artistic creations used to demonstrate mathematical concepts

No	Creation Name	Mathematic Topic	Description	Learning outcomes
1	Mind Maps	Applications of Differentiation and Hyperbolic Functions	Started with a main topic and branched out to related subtopics, keywords, or images with creativity	LO1, LO2, LO5
2	The Art of Slopes	Applications of Differentiation	Used the derivative to highlight the function's behaviour across regions.	LO1, LO4
3	Recreate the first letter of your name or a given letter	Functions and Their Graphs	Created using different mathematical curves or lines	LO2, LO3, LO5
4	Design Fractals	Hyperbolic and Trigonometric Functions	Explored hyperbolic and trig functions in GeoGebra by changing equations and visualizing effects.	LO2, LO3, LO5
5	Design with polar curves	Polar Curves	Created using different polar curves	LO5
6	Poster for IDM	Hyperbolic curves, Polar curves.	Created a poster for the International Day of Mathematics.	LO2, LO3, LO5
7	Math Poetry with creative art	Any Topic	Combining mathematics with language, arts by writing poetry.	LO1, LO2, LO3, LO4,
8	Math Games with creative art	Any Topic	Designed a game with mathematics.	LO1, LO2, LO3, LO4, LO5

Students' performance was evaluated using a paired t-test by comparing their marks before and after activity 2, Creative Approaches to Teaching Mathematics. The test statistic is $T = 9.08$ with a p-value less than the significance level, $\alpha = 0.05$. Thus H_0 is rejected at the 5% significance level, confirming significant improvement in post-activity performance.

Feedback analysis for Calculus with Creative Art activities

Feedback analysis is presented by Figures 3 and 4. Although students reported varying degrees of initial interest in art and mathematics (Figure 3), the majority subsequently evaluated the activity as highly beneficial for their learning.

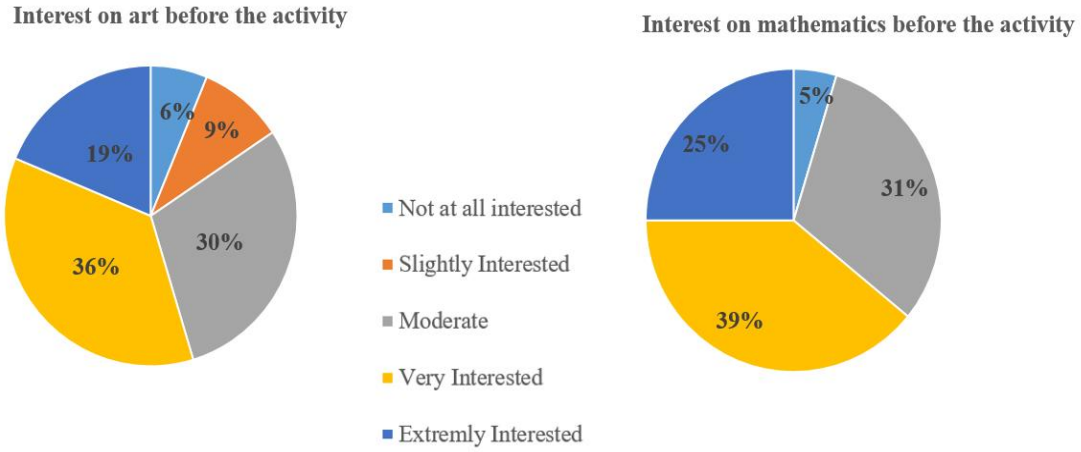


Figure 3. Student interest on activity 1 and activity 2

The strong positive response, despite modest prior interest among a considerable proportion of participants, indicates that the creative, art-integrated approach effectively facilitated understanding across diverse learner profiles (Figure 4). These findings underscore the pedagogical value of incorporating creative methodologies into mathematics instruction.

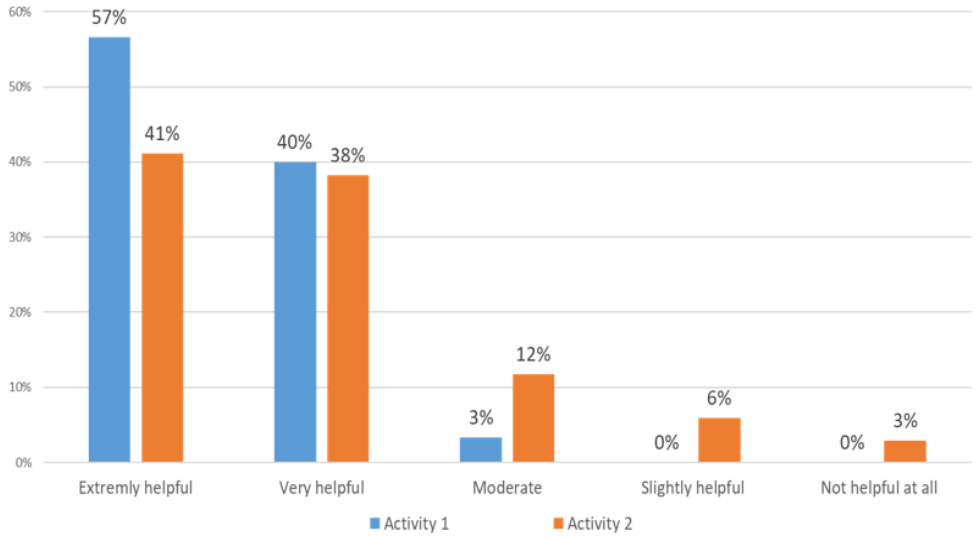


Figure 4. Helpfulness of activities to learn subjects

3.2 STEAM-based activities with Engineering Mathematics and Statistics

The learning activities and continuous assessments tasks are presented in Table 2.

The learning outcomes (LO's) covered under the Learning Activities (LAs) and Continuous Assessment Tasks (CATs) are as follows;
LO1 - Understand the basic concepts of Linear Programming (LP)
LO2 - Formulate a given application as a Linear Programming Problem (LPP)
LO3 - Use the graphical method to find a solution to linear programming problem
LO4 - Apply the simplex method to linear programming problems
LO5 - Find a computer solution to linear programming problem
LO6 - Discuss sensitivity analysis
LO7 - Construct the dual problem from the primal
LO8 - Conduct post-optimal analysis
LO9 - Perform single-factor ANOVA
LO10- Discuss two-factor designs and two-factor ANOVA

Table 2. Learning activities and continuous assessment tasks

Activity/ Task	Type	Topic covered/Details	LO's tested/ achieved	Week number
LA1	Group activity	Crossword puzzles with the concepts of LP	LO1	2
LA2	Individual activity	Graphical LPP solution using GeoGebra graphing calculator and graphical sensitivity analysis	LO3 LO6	3
LA3	Group Activity Individual activity	Simplex Method Representation in A3 papers with colours Computer solution for LPP with MATLAB/EXCEL	LO2 LO4 LO5	4
CAT1	Individual activity	LP solution and sensitivity analysis with EXCEL solver	LO1-LO6	5
LA4 CAT2	Group/Individual Activity	Duality and Post-optimal analysis	LO7 LO8	7
CAT3	Individual activity	Single-factor ANOVA with EXCEL	LO9	10
LA5	Group/Individual Activity	Heatmaps and interaction plots representation A3 papers with colours, and using R for two-factor designs, performing two-factor ANOVA	LO10	11
CAT4	Individual activity	Heatmaps and interaction plots with R, performing two-factor ANOVA	LO10	12

At the end of the course a google form was shared among students to collect their feedback on these LAs. Five-point Likert Scale (1-Strongly Disagree to 5 - Strongly Agree) was used to collect their response on each learning activity and their feedback is summarized in Table 3 and Table 4. Since there were no responses recorded for 'Disagree' and 'Strongly Disagree', these two categories are combined.

3.3 LA1, LA2 and LA3 with CAT1

A sample crossword LP puzzle (LA1) and illustration of LPP using a GeoGebra graphing calculator (LA2) are shown in Figure 5 and Figure 6, respectively. Table 3 presents the feedback summary for LA1-LA3.

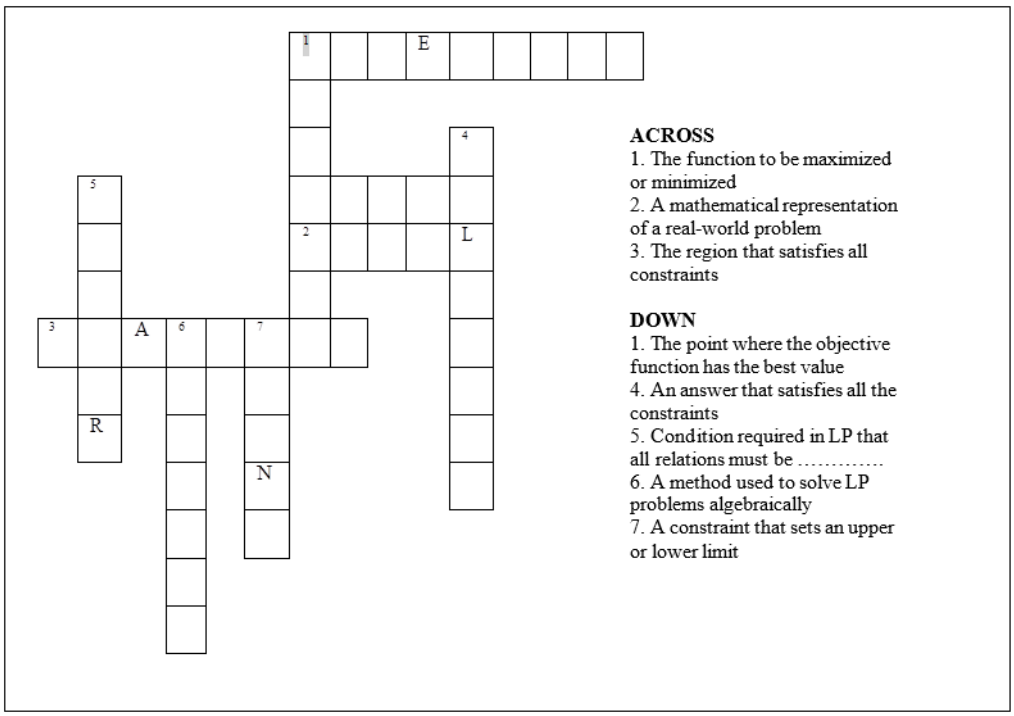


Figure 5. Linear programming crossword puzzle

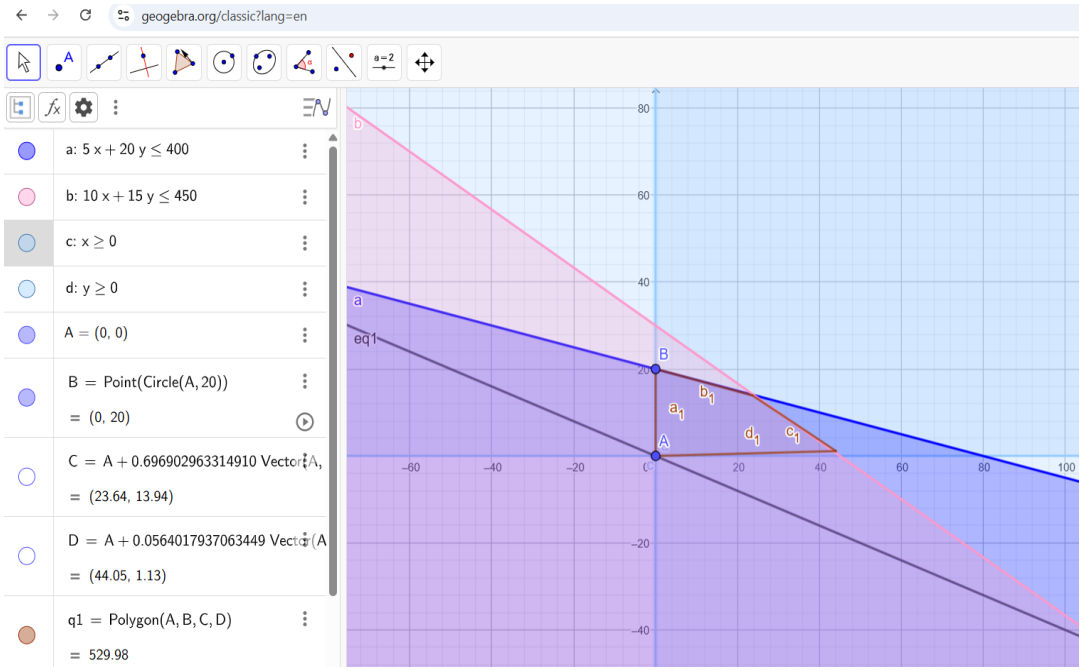


Figure 6. LPP example with GeoGebra graphing calculator

Table 3. Student feedback summary for LA1, LA2 and LA3

Activity	Aspect	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree/ Strongly Disagree
LA1 Linear programming crossword puzzle	1. The activity strengthened my recall of key Linear Programming concepts.	67%	33%	-	-
	2. The activity helped me think critically about the relationships among variables, constraints, and solutions.	42%	58%	-	-
	3. I was actively engaged throughout the activity.	50%	50%	-	-
	4. The activity increased my motivation and made learning more enjoyable.	42%	58%	-	-
LA2 GeoGebra-based optimization	1. I could clearly observe how each inequality shapes the feasible region	42%	58%	-	-
	2. The activity improved my understanding of feasible solution spaces.	50%	50%	-	-
	3. I could modify objective function coefficients and see the effects in real time.	42%	58%	-	-
	4. The visualization helped me convert abstract optimization ideas into observable patterns.	42%	58%	-	-
LA3 A creative tableau activity with the simplex method:	1. Visually map the step-by-step Simplex procedure, from the initial feasible solution to the final optimal solution.	33%	67%	-	-
	2. Differentiate clearly between decision variables, slack/surplus variables, and pivotal elements in each tableau.	33%	67%	-	-
	3. Track how entering and leaving variables changed across iterations, and understand how these transitions influenced the objective function value.	33%	67%	-	-
	4. Strengthen my conceptual understanding of the overall optimization process through colour-coding and structured group collaboration.	50%	50%	-	-

LA1: According to students' responses, the LP puzzle activity strengthens conceptual recall, as students must connect definitions to technical terms such as "objective function," "feasible region," and "optimal solution". It also promotes active learning, encouraging students to think critically about the relationships among variables, constraints, and methods in LP. Additionally, the puzzle format supports student motivation and enjoyment, making abstract concepts more approachable.

LA2: GeoGebra approach provided an interactive visual platform to connect algebraic formulations with geometric interpretations. Resposes highlight that, the graphical representation of constraints helped students to observe how each inequality shaped the feasible region and enabled them to understand feasible solution spaces clearly. GeoGebra's dynamic sliders allowed students to modify objective function coefficients in real time and immediately see how the optimal solution shifted with these changes. To enhance clarity, students applied colour-coding to distinguish individual constraints and highlight overlapping feasible regions. This visualization further supported conceptual understanding, transforming abstract optimization principles into concrete, observable patterns.

LA3: Using different colours to denote variables, constraints, and pivot operations, student groups visually mapped the entire simplex procedure from the initial feasible solution to the optimal one. This helped them distinguish the roles played by each component in the algorithm. As they progressed through successive tableaus, the consistent colour scheme allowed students to clearly track how entering and leaving variables changed across iterations and how these transitions affected the objective function value. The combination of colour and deliberate spatial organization on A3 sheets helped students identify patterns and relationships among tableaus such as cycles in pivot choices, shifts in the basis, and the progression toward optimality.

3.4 Other learning activities and assessment tasks

LA4 and CAT2 activities took place simultaneously incorporating LO7 and LO8 with duality and post optimal analysis. LA5 and CAT4 are associated with two-factor cross-classification designed by generating heatmaps and interaction plots manually and in R for a given sample response data. Table 4 presents the feedback summary on LA4, LA5 and group work approach.

LA4: Majority of the students agreed that this activity helped them to understand the relationship between primal and dual problems and concepts of post optimal analysis.

LA5: The heatmaps used colour gradients and patterns to visualize mean responses and replications, while interaction plots highlighted additive versus interactive effects. According to students' feedback this activity helped them to improve their understanding of factor

effects, interaction, and replication. By conducting statistical analysis via two-way ANOVA for their dataset, students were able to confirm the identified main effects and interactions, supporting visual interpretations.

Table 4. Student feedback summary for LA4 and LA5

Activity	Aspect	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree/ Strongly Disagree
LO Dual dimensions: Post-optimal analysis in LP	1. Visualize and understand the relationship between the primal and dual problems in Linear Programming.	42%	58%	-	-
	2. Identify the optimal inverse matrix and sensitivity information from the final Simplex tableau	42%	50%	8%	-
	3. Observe how small changes in parameters (RHS values or objective coefficients) influence the feasible region and the optimal solution	33%	50%	17%	-
LO5 Creative visualization of two-factor designs	1. Colour-coded heatmaps helped me understand main effects.	33%	67%	-	-
	2. The activity improved my ability to identify interaction effects.	34%	58%	8%	-
	3. The use of colours and patterns improved my conceptual clarity.	42%	50%	8%	-
	4. I was able to compare observations from plots with ANOVA findings	42%	50%	8%	-
Creative Group activities	1. These creative activities improved my conceptual understanding.	42%	58%	-	-
	2. I feel more confident in mathematics/statistics after these activities.	42%	58%	-	-
	3. The integration of art and visual tools made learning interesting.	50%	50%	-	-
	4. These activities enhanced teamwork and peer learning,	42%	58%	-	-
	5. Creative tasks articulate reasoning and consolidate understanding in a low-stress, creative environment	33%	67%	-	-
	6. These activities supported collaborative problem-solving	42%	58%	-	-
	7. I would like similar activities in future modules	50%	50%	-	-

Creative group activities: Students' responses confirm that creative group activity approach enhances teamwork and peer learning, builds more confidence on learning process and helps students articulate reasoning and consolidate understanding in a low-stress, creative environment.

3.5 Performance of students

After completion of LA1, LA2 and LA3, CAT1 was conducted to assess their learning on the learning outcomes from LO1 to LO6. Summary statistics of students' performance of CAT1 and CAT2 are shown in Table 5.

Table 5. Students' performance in continuous assessment tasks

Descriptive statistics	CAT1	CAT2
Marks allocated	40	60
Mean	38.32	57.95
Median	40	60
Mode	40	60
Standard deviation	2.73	3.46
Minimum	30	48
Maximum	40	60
Student count	90	90

Results revealed that all students have performed well with a mean of 38.31 and a standard deviation of 2.73 for CAT1. Similarly, the students scored over 80% for CAT2 with a mean of 57.95 and standard deviation of 3.46 confirming the achievement of the underlying learning outcomes.

3.6 Discussion

The findings of this study highlight the strong potential of integrating creative art and visualization into the teaching of calculus, engineering mathematics, and statistics. The previous work, "Calculus with Creative Art" intervention established that artistic representation of mathematical concepts can transform students' perceptions of traditionally abstract topics. Students reported greater enjoyment, deeper conceptual understanding, and improved motivation when mathematical ideas were expressed through drawings, colour patterns, and creative compositions. These outcomes align with research indicating that multisensory and creative tasks enhance retention and comprehension among visual, kinesthetic, and multimodal learners.

Building on these foundations, the current study extended creative pedagogies to more advanced domains such as linear programming, optimization, and two-factor experimental designs. GeoGebra-based explorations enabled students to dynamically visualize

feasible regions, constraint boundaries, and optimal solutions, promoting intuitive understanding of concepts that are often difficult to grasp through algebraic methods alone. The ability to manipulate input conditions and observe instantaneous geometric and numerical changes strengthened students' critical reasoning and supported the development of problem-solving strategies.

Similarly, integrating R-based visualizations such as heatmaps, interaction plots, and colour-gradient encodings allowed students to interpret main effects, interaction effects, and variability in two-factor designs more clearly. Generating these visual outputs both manually and digitally deepened their understanding of experimental design logic while simultaneously building computational literacy. These activities encouraged students to move beyond rote learning and engage in data-driven, exploratory thinking.

4. CONCLUSION, IMPLICATIONS AND FURTHER WORK

4.1 Conclusion

Integrating creative art with both calculus and engineering mathematics/statistics activities demonstrated that visualization, interactivity, and artistic expression enhance learning outcomes. Quantitative analyses (paired t-tests) confirmed that students improved in problem-solving and interpretation of abstract mathematical and statistical concepts. Qualitative feedback and student-created visualizations indicated that STEAM-based activities motivated learners, encouraged creative expression, and made abstract topics more intuitive. The use of visual, kinesthetic, and interactive methods, guided by VARK profiling, supported students with different learning preferences, highlighting the value of learner-centered pedagogy. The approach effectively bridges mathematics, statistics, and creative art, demonstrating the potential of STEAM-based interdisciplinary pedagogy in engineering education.

Overall, the study argues that creative-art–based and visualization-driven pedagogies can serve as powerful complements to traditional teaching methods in engineering education. By bridging intuitive visual experiences with formal analytical procedures, such approaches promote interdisciplinary understanding, enhance conceptual clarity, and encourage flexible thinking skills essential for future engineers.

4.2 Implications for practice and future research

Educators in engineering, mathematics, and statistics can adopt creative visualization tools (GeoGebra, Desmos, MATLAB graphics, R plots) to enhance learning outcomes. These tools enable students to move beyond symbolic manipulation and engage with concepts through dynamic, interactive representations. For example, GeoGebra and Desmos allow real time manipulation of constraints in linear programming, helping learners observe how feasible regions and optimal solutions shift with parameter changes. MATLAB and R provide advanced graphical capabilities for visualizing statistical relationships, interaction effects, and experimental outcomes. Such tools bridge the gap between abstract theory and practical interpretation, catering especially to visual and kinesthetic learners. Incorporating these platforms into lessons encourages exploration, improves retention, and supports deeper conceptual understanding.

The integration of art and interactive visualization can be extended to other quantitative and analytical modules to support conceptual understanding and engagement. Beyond linear programming and design of experiments, artistic and visual approaches can be applied to modules such as differential equations, numerical methods, probability theory, operations management, and quality engineering. For instance, fractal art can be used to illustrate recurrence relationships, while colour-coded state diagrams can help students understand Markov chains and stochastic processes. In numerical methods, students can generate geometric patterns to visualize approximation errors or algorithmic iterations. Such creative extensions transform abstract content into tangible representations, encouraging curiosity, interdisciplinary thinking, and sustained engagement.

Future studies could expand the sample size, include additional engineering disciplines, and explore longitudinal effects on learning outcomes and creativity development. Scaling the study across multiple cohorts and institutions would strengthen the generalizability of findings and reveal differences across engineering domains such as civil, mechanical, electrical, and computer engineering. Larger samples could also allow for subgroup analyses based on learning styles, academic performance levels, or prior exposure to visual tools. Longitudinal research spanning multiple semesters or entire academic programs could track how creative visualization influences long term retention, problem solving ability, and the development of creative confidence. Additionally, qualitative investigations could examine how students transfer these skills to real-world engineering tasks and collaborative project environments.

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