Enhancing Secondary Mathematics Learning Through STEAM2C: Creative Assessment With Graphing Technology

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Abstract

This study examines the integration of STEAM2C (Science, Technology, Engineering, Arts, and Mathematics with Creative and Critical Thinking) into the teaching and assessment of the topic "Graphs of Functions" among secondary school students in Southeast Asia. The project aimed to move beyond traditional instruction and rote-based evaluation by incorporating alternative assessments approaches that emphasise creativity, reasoning, and application, supported by digital graphing technologies such as Desmos, GeoGebra, and graphing calculators. The intervention began with a two-day professional development workshop for mathematics teachers, followed by classroom implementation of inquiry-based learning activities. A student-led creative graph design project served as the core assessment task and was evaluated using a structured rubric emphasizing mathematical reasoning, design aesthetics, and reflective thinking. Data collected through teacher interviews, student reflections, and rubric-based evaluations revealed that the STEAM2C approach significantly enhanced engagement, deepened conceptual understanding, and encouraged students' creative self-expression. Teachers perceived STEAM2C as a promising alternative assessment approach aligned with 21st-century learning goals, while highlighting the need for curriculum alignment and stakeholder support for sustainable implementation.

Keywords: STEAM2C, mathematics education, alternative assessment, graphing technology, creative and critical thinking

Introduction

The integration of STEAM2C into mathematics focuses on the application of STEAM (Science, Technology, Engineering, Art and Mathematics) in the learning of Secondary Mathematics and the process involved in showcasing the 2C (Creative and Critical Thinking) in Mathematics lessons (Bertrand & Namukasa, 2020; Wannapiroon & Pimdee, 2022). The Mathematical technological tools such as Desmos, graphing calculator and GeoGebra was proposed in this study.

The new mathematics curriculum for secondary schools requires students to demonstrate their mathematical skills associated with creativity, showcasing originality in thinking and ability to connect with their surroundings in a new perspective. Emphasis should be given on promoting knowledge and skills such as creative thinking, innovation, problem-solving and leadership (Yean et al., 2024).

Tasks that require creative and critical thinking with technology can be introduced to the current generation of technology natives. In fact, they ought to be given tasks that will challenge them to do better in the presence of more thought-provoking higher order thinking questions from the knowledgeable teacher. Therefore, the role of a teacher as a compulsive facilitator is very pertinent and relevant.

Statement of the Problem

While STEM initiatives have gained momentum, many mathematics teachers still lack the confidence, resources, or pedagogical frameworks to integrate technology, creativity, and critical thinking into their lessons. Assessment practices remain focused on procedural fluency and do not capture students' ability to reason, design, or model mathematically.

Furthermore, although software like Desmos and GeoGebra are available, their classroom usage is often limited to teacher demonstrations rather than student exploration. There is a need to explore how such tools, when used creatively through a STEAM2C lens, can enhance student agency and conceptual understanding. This research is designed to address the following key problem: How can STEAM2C be applied effectively in the teaching and learning of Graphs of Functions to promote creative expression, mathematical reasoning, and alternative assessment.

Literature Review

Research over the last decade the concept of STEAM education has gained significant momentum over the past decade as a response to the growing demand for interdisciplinary learning. Originally rooted in STEM (Science, Technology, Engineering, and Mathematics), the integration of the Arts ("A") broadens the educational scope by emphasising creativity, innovation, and aesthetic understanding (Sousa & Pilecki, 2013). The shift toward STEAM has been validated by studies that show improved student engagement and critical thinking when lessons incorporate visual and performance arts (Colucci-Gray et al., 2019).

Incorporating technology tools such as GeoGebra and Desmos into mathematics education has also demonstrated strong potential in improving conceptual understanding. Research by Pierce and Stacey (2010) highlighted how digital tools can transform static mathematics problems into dynamic, interactive experiences that foster deeper comprehension. Similarly, Saha et al. (2010) found that the use of GeoGebra in teaching coordinate geometry significantly improved students' performance and engagement. Integrated STEM (Science, Technology, Engineering and Mathematics), a well-known acronym in the education fraternity is implemented widely to increase students' academic achievement in both mathematics and science. However, studies show that new ideas are still in demand to increase the students' interest especially in learning of mathematics.

One of the suggested methods is to introduce cross curriculum and move away from the traditional mathematics curriculum. Therefore, by incorporating the "A" in arts through mathematical activities, students should be able to appreciate the beauty and aesthetics values of mathematics through engaging activities that are more explorative and connected with real-world tasks (Bush et al., 2016). Thus, STEAM integrated instructional practice are expected to inculcate positives attitudes related to motivation, anxiety, confidence towards learning Mathematics with the inclusion of 21st Century Skills such as creativity, collaboration, communication and critical thinking. Studies conducted by Sousa and Pilecki (2013), shows that the arts component added into STEM is able to create more critical thinking, problem solving and communication opportunities.

There is growing recognition that the mainstream education needs to be more innovative and creative in developing knowledge and pertinent skills to face the challenges in the 21st century. Therefore, teaching of mathematics should focus on activities that could lead students to their own learning with the introduction of more explorative, connected and the real-world tasks. Meanwhile, learning outcomes will be measured in students' abilities to build new knowledge that could lead to effective self-learning that would sustain life-long learners.

Researchers (Bahrum et al., 2017; Conradty & Bogner, 2018) suggests that students should be exposed to more challenging activities that needs thinking at a higher level of cognition. Taking this into consideration, higher order thinking is not only about making the questions more complicated, but rather should be the one that can transform any child into a person that appreciate mathematics and its application in real life. This scenario can be changed with the intervention of more visualisation tool that can benefit students especially the heterogenous group of high, average and low ability students.

Methodology

This research employed a mixed-methods design integrating both quantitative and qualitative data collection to provide a comprehensive evaluation of the STEAM2C implementation. The three-phase structure allowed for iterative professional learning, practical application, and reflective analysis. It focuses on the application of STEAM (Science, Technology, Engineering, Art and Mathematics) in the learning of Secondary Mathematics and the process involved in showcasing the 2C (Creative and Critical Thinking) in Mathematics lessons in the presence of graphing technological tool such as Desmos and GeoGebra.

Tasks that require creative and critical thinking with technology was introduced to the current generation of technology natives. In fact, they were given tasks that will challenge them to do better in the presence of more thought-provoking higher order thinking questions from the knowledgeable teacher. Therefore, the role of a teacher as a compulsive facilitator is very pertinent and relevant.

Instruments used included pre- and post-workshop questionnaires to gauge teacher perceptions, reflection journals, observation checklists, and interview protocols. Google Forms and structured templates were used for uniform data collection. Technology tools used in lessons included Desmos, Graphing Calculator and GeoGebra.

Quantitative data were analysed using descriptive statistics to assess teacher learning outcomes and perceptions. Qualitative data, including classroom observations, open-ended responses, and interview transcripts to identify recurring patterns and challenges. Evidence from each phase was analysed to ensure reliability.

Results and Discussion

Here are the general findings from this research project according to Phase 1, Phase 2 and Phase 3.

Phase 1 (Hands-On Workshop)

32 mathematics teachers participated in an immersive, two-day professional development workshop designed to build capacity in using Desmos, GeoGebra, and graphing calculators within the STEAM2C framework. Quantitative findings showed a significant increase in teacher confidence and willingness to apply graphing technologies in their teaching practices, with mean perception scores improving markedly. Qualitative feedback revealed that teachers appreciated the ability of these tools to facilitate conceptual understanding, student creativity, and interdisciplinary integration. Their participation not only enhanced pedagogical skills but also cultivated enthusiasm for alternative assessment strategies grounded in mathematical reasoning and visual design.

They also responded positively in post-workshop surveys. Many indicated that the graphing technologies enabled students to visualise mathematics conceptually. One participant noted, “Desmos allowed my students to create and manipulate functions with meaning.” Another shared, “GeoGebra helped even my lower-performing students see how changes in variables affected the graph.” These reflections are consistent with findings by Pierce and Stacey (2010), who assert that the instructional value lies not just in the tool, but in how it is used to facilitate deeper mathematical understanding. Refer to table 1 and 2 for the Pre-test/ Post-test items and its related mean score.

Table 1
Pre-test / Post-test Mean Score of Phase 1

Item No	Pre-test / Post-test Statement	Pre-test		Post-test	
		Mean	SD	Mean	SD
1.	Are you planning to use any graphing technology in your teaching and learning sessions in the classroom?	3.06	0.66	4.44	0.52
2.	Have you attended any sharing session with graphing technology?	2.76	0.75	4.50	0.51
3.	Do you think graphing technology can enhance the learning of mathematics?	3.41	0.71	4.50	0.53
4.	Will you share the knowledge you gained in this workshop with other teachers at your school or other educational institutions?	3.18	0.53	4.50	0.57
5.	Do you think you can create a creative design with graphing technology just by using mathematical functions?	3.00	0.61	4.31	0.52
6.	Do you think the task to create a creative design with Graphing technology can be used as part of classroom-based assessment (CBA)?	2.94	0.75	4.25	0.60
7.	Will you recommend the use of graphing technology to other mathematics teachers?	3.00	0.61	4.50	0.63

Table 2
Overall Mean Score for Pre-test, Post-test Survey, and Mean Gained Score for Overall Score of Phase 1

	Pre-test		Post-test		Mean Gained Score
	Mean	SD	Mean	SD	δ
Overall	3.05	0.66	4.42	0.55	1.37

The comprehensive analysis of the post-test results reveals remarkable improvements in participants' acceptance and application of the workshop content. The overall post-test mean score of 4.42, paired with a standard deviation (SD) of 0.55, indicates a substantial positive impact on learning outcomes. Compared to the pre-test mean score of 3.05 (SD = 0.66), the mean gain score of 1.37 highlights a significant increase in knowledge among the 32 participants. This growth is further underscored by the reduced dispersion of post-test scores, suggesting more consistent performance across participants. Additionally, all post-survey means scores exceeded 4.0, ranging from 4.00 to 4.50, reflecting a high level of comprehension and engagement (Nunnally & Bernstein, 1994).

Phase 2: Multiplier Effects in School Mathematics Departments

In Phase 2, the Phase 1 teachers were encouraged to conduct sharing sessions with colleagues at their respective schools. These multiplier sessions served as a bridge to scale professional learning and disseminate the STEAM2C approach. Teachers successfully conducted sharing sessions using lesson exemplars, rubrics, and student artifacts developed during Phase 1. Pre- and post-session data from their peers indicated a significant rise in awareness, interest, and readiness to implement STEAM2C in their own classrooms. These multiplier effects demonstrate the model's scalability and the efficacy of peer-led professional learning in fostering instructional change. Refer to Table 3 for the overall score.

Table 3
Overall Mean Score for Pre-test, Post-test Survey, and Mean Gained Score for Overall Score- Phase 2

	Pre-test		Post-test		Mean Gained Score
	Mean	SD	Mean	SD	δ
Overall	2.48	0.72	4.13	0.60	1.65

These findings suggest that the STEAM2C sharing successfully enhanced the mathematics teachers foundational knowledge on graphing technology and eventually on the ability to design a creative design with just mathematical functions. Even tough, there is a drop in the post-test mean score to 4.13 compared to 4.42 recorded from the teachers involved in Phase 1, it still records a higher mean gained score of 1.65. The statistically significant improvements found in this study reaffirms the relevance of graphing technology knowledge to be incorporated in the teaching and learning of mathematics especially with topics related to graphs of functions.

Qualitative feedback corroborated the quantitative gains: teachers recognised the benefit of instant visualisation, perceived graph-art tasks as catalysts for higher-order questioning, and requested extended hands-on time for deeper exploration. Collectively, the data indicate that brief, well-structured multiplier sessions can effect a substantial shift in teachers' awareness and practical readiness to operationalise STEAM2C, thereby amplifying the workshop's impact beyond the original cohort.

Phase 3: Classroom Implementation and Observations

The third phase involved actual implementation of STEAM2C lessons in three selected schools. These lessons featured graphing tasks where students used technology to explore, model, and design functions.

The actual classroom observation was divided into three parts; the first one was the first session on the sharing of knowledge on graphing technology by the mathematics subject teachers followed by some techniques on answering more effectively the exam-based questions. The following observation focused on the students' presentation of the design they created through their creative thinking with mathematical functions. Each students was also given a good opportunity to evaluate critically their friends work and will make use of a verified evaluation rubric. The presenting student has to explain and justify his/her creative design with mathematical graphs of functions. Eventually, teacher would choose three different best designs based on both teacher and peer evaluation and the critical justifications presented.

On the whole, the graphing technological tools were able to inculcate students Higher Order Thinking (HOTS) through the Question – Answer sessions such as:

1. What is the name of the shape of quadratic equation? (Remember)
2. Is there any general pattern that you observe? Please explain (Understand and Analyse)
3. Could you explain the effect of a, b and c value? (Analyse the shape in terms of wideness and position of the graph)
4. What happens to the graph when b = 0, b > 0, b < 0? Please explain. (Analyse)
5. How is the graph when a = 0? (Understand)
6. What is the effect of the c value? (Analyse)
7. In your opinion which one is more different? Why? (Analyse)
8. What are the strategies you employed to make sure it works? (Apply, Analyse & Evaluate)
9. What did you learn after completing this design activity? (Creative)
10. What are the other types of functions and its associated graphs that you know? (Creative and Critical)
11. How are these graphs and functions that we learn is useful for us? (Analyse & Creative)

There are also more critical thinking questions that can be posed either by the students to their presenting peers or by the teachers themselves. Some example questions are:

- What are the possible values?
- Write down your understanding…
- Can you explain the connection that you observe?
- How do you arrive at the answer? Explain your findings.
- What do you understand about the x-intercept?
- What do you understand about the y-intercept? Explain your answer
- Compare your answers. Are they the same?
- Please elaborate on your answer.

Thus, students could be given opportunity to explore, investigate, explain and give reasons to support their answers.

Meanwhile, the role of the teacher is to:

- Observes and listens to students as they present and explain their work.
- Plays the role of a facilitator.
- Corrects any misconceptions that appears during their explanation.
- Pose more thinking questions.
- encourages and create opportunity for other students to ask questions

Graphing tools such as Desmos, Graphing Calculator and GeoGebra were used as the cognitive tool, whereby the participants will do the thinking as Graphing Technology will be able to show the relationship between the Graphical (visual), Algebraic (equation) and Numerical (tabular). (Talib et al., 2019).

Conclusion

The outcome of this study can support the need for a change in today's education. Taking into consideration the fast-paced, ever changing 21st century workplace demands for critical thinkers, confident problem-solvers and technology savvy innovators with a thirst for lifelong learning. Students are also required to be equipped with skills that will ensure their prosperity in tomorrow's world (Budhai & Taddei, 2015).

Importance should be given to the expansion of students' creativity and critical thinking in solving mathematical tasks as well (Abdullah et al., 2016). This means, the solution to a task should not be a fixed answer or at least should give the student an opportunity to try to solve the task in multiple methods. This will automatically create a room for students to reflect on their cognitive strategies that requires planning, monitoring and evaluating their own strategies. Eventually, the lesson can inculcate them to be risk takers and more logical in exploring the mathematical concepts especially in the presence of technology.

Students ought to be given an exposure to "Think out of the box" before throwing all the difficult questions at them. Therefore, there is a need to improve the instructional method in the classroom so that it is not always the end results (students score) that matters. Opportunity should be given to explore the knowledge that students have gained in the classroom and then apply it in more creative manner according to their critical thinking ability (Bellanca, 2014; Kivunja, 2015).

The positive findings from this study can also be used to justify that the focus on teacher training should move away from isolated technology training and gear towards integration of technology into the curriculum to help teachers use technology to support student-centered pedagogy which allows more interaction and expression of students creative and critical thinking and learning as evidence of active learning (Rohid & Rusmawati, 2019; Saldo & Walag, 2020).

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