Integrating Generative AI into Inquiry-Based Learning for Mathematics Education

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Abstract: *This study explores the effectiveness of integrating Generative Artificial Intelligence (GenAI) within an Inquiry-Based Learning (IBL) framework to enhance personalized and active learning in mathematics education. The intervention used personalized and active learning pedagogies combined with prompt engineering applied to IBL activity construction related to their personal interest, hobbies and passions in a senior tertiary mathematics teacher education course. A comparative analysis was conducted between an experimental group exposed to GenAI-assisted IBL activities and a control group without GenAI integration. Generic Intended Learning Outcomes (GILOs) related to problem-solving, critical thinking, and written communication were assessed via surveys. Results indicated a statistically significant improvement in critical thinking skills in the experimental group compared to the control group. This suggests that integrating GenAI into IBL can positively influence critical thinking development in mathematics teachers.*

Keywords: Generative AI, Inquiry-Based Learning, Mathematics Education, Personalized Learning, Critical Thinking

1. Introduction

The rapid advancement of artificial intelligence (AI), particularly generative AI (GenAI), presents vast opportunities for education. GenAI tools, such as large language models (LLMs), offer the potential to personalize learning experiences, enhance student engagement, and foster deeper understanding of complex concepts, in particular for mathematic education (Matzakos, et. al., 2023). This study explores the integration of GenAI into an inquiry-based learning (IBL) environment for mathematics teachers, with emphasis on student-centered exploration and discovery using personalized learning capabilities of

GenAI. By leveraging GenAI, educators can design engaging learning experiences that cater to individual student needs and interests. This research aims to investigate the impact of GenAI integration on teachers' self-perceived problem-solving, critical thinking, and written communication skills, in the context of designing IBL tasks with the use of educational technology.

2. Literature Review

Inquiry-based learning (IBL) has been recognized as an effective pedagogical approach for promoting active learning (Justice, et al., 2009) and deeper understanding in mathematics (Rasmussen & Kwon, 2007). IBL encourages students to explore concepts, ask questions, and construct their own knowledge through investigation and collaboration (Lombard & Schneider, 2013). There has been extensive research highlighting the benefits of integrating technology into IBL to enhance learning outcomes (e.g., Susilawati, 2022). The emergence of transformative technology of GenAI offers new possibilities for personalizing IBL experiences and providing tailored support to learners. We also know that personalized learning interventions can lead to improved student engagement and academic performance (e.g., Lee et al., 2018). This study builds upon this existing research by examining the specific impact of GenAI integration on pre-teachers' preparedness and development of key skills within an IBL mathematics teaching course using technology.

3. Methods

3.1. Participants

Our study was conducted in a course on an IBL approach to teaching mathematics with the aid of technology in Semester 1 of the 2024-25 academic year at a Hong Kong tertiary institution. Participants were divided into two groups: an experimental group (n=9) exposed to GenAI-assisted IBL teaching material and activities and a control group (n=9) following traditional teaching methods without GenAI integration.

3.2. Intervention

In the experimental group, a personalized and active learning pedagogy involving prompt engineering with LLMs was integrated into lesson plans. The special personalized prompt was called the *concept prompt*. The concept prompt relates any topic in mathematics, to a student hobby, interest or passion. To be more precise, here is the precise prompt engineering form of the

> **Concept prompt:**
>
> *I am a α student who loves β. Please help me understand π in the subject Ω, relating it to β.*
>
> where
>
> *α* = grade level of student
> *β* = students' hobby, passion or personal interest/experiences
> *π* = specific (sub) topic/concept/idea in science or math
> *Ω* = course or subject area of (sub) topic

A specific example of the concept prompt is as follows:

> *I am a grade 12 student who loves the K-pop girl band, "Blackpink". Please help me understand the concept of a "limit" in the subject Calculus, relating it to Blackpink.*

The remarkable ability of LLMs to relate any two seemingly disparate topics is to be noted here, including relating limits in Calculus to a Korean girl pop group, must, at least intuitively, convince us of the power of LLMs to increase conceptual understanding of complex science and math topics.

Since this course is about teaching mathematics via IBL with technology, then we also outlined how a teacher may use generative AI to help kick start and aide the teacher in initially planning or getting the outline for an IBL activity in mathematics, using the following IBL prompt:

> **IBL activity prompt:**
>
> I *have to teach the topic of α in the subject β at grade level π. Please suggest an inquiry based learning activity, using technology Ω, to teach α.*
>
> where
>
> *α* = specific (sub) topic/concept/idea in science or math
> *β* = course or subject area of (sub) topic
> *π* = grade level
> *Ω* = technology you are using

In addition, according to the 5E model for IBL (Bybee & Landes, 1990) with the five e's being engage, explore, explain, evaluate and elaborate, we suggested to our student teachers to allow students to use GenAI in the 1^{st} and 2^{nd} stages of the 5E pedagogy: namely, in the engage and explore stages. We felt this has the advantage of letting the students personalizing the mathematics topic to their own interest, instead of having the teacher traditionally construct IBL questions for them in the 1^{st} and 2^{nd} stages. For example, for learning the topic of fractions in primary school, a good inquiry-based learning question would be, how would you divide a pizza into 3 equal shares – which would be the "vanilla" or textbook example – not personalized to individual students who do not particularly like pizza. We propose the student use the *concept prompt* for stages 1 and 2 of the 5E model of IBL.

We implemented the personalized learning prompts with GenAI using a collaborative online anonymous chatroom platform integrated with LLMs called, YoChatGPT (https://www.yochatgpt.io/). An actual example of a student concept prompts trying to understand the concept of a limit in Calculus, through his/her interest in yoga, in Figure 1 below:

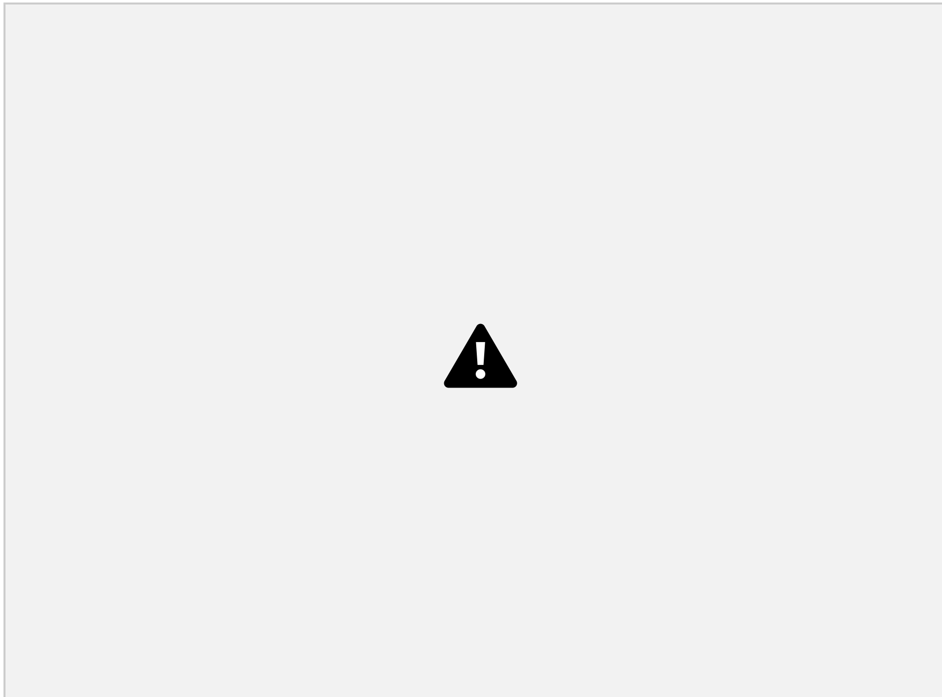

Figure 1. Example of concept prompt for understanding limits in Calculus, relating it to yoga.

We believe this is the best IBL question for a student to ask, instead of a teacher posing the questions in the engage and explore stage. Then, after the generative AI or LLM outputs the answer to the IBL student concept prompt, then students can work in groups of 4 or 5 to go through the rest of the steps of the 5E model, exploring, critically thinking, and quantitatively verifying the LLMs response to their concept prompt.

We gave both experimental and control classes a Preparedness of use of GenAI and Generic Intended Learning Outcomes (for problem solving, critical thinking and written communication skills) survey – see e.g., https://docs.google.com/forms/d/e/1FAIpQLSczLrIDVsjIUBs-D8vXxSTDOH8F1mv8TyX8URHMov2jqBSsFw/viewform

3.4 Measures

Generic Intended Learning Outcomes (GILOs) related to problem-solving, critical thinking, and written communication were assessed using a survey adapted from the "Self-Assessment of Generic Intended Learning Outcomes (GILOs)" developed by the Education University of Hong Kong (EdUHK, 2018). The survey employed Likert-scale questions to gauge students' self-perceived skills and readiness.

3.5. Procedure

Both groups completed the preparedness and GILOs survey at the end of the course. The experimental group engaged with GenAI-assisted prompts throughout the semester, while the control group participated in standard IBL activities without GenAI support. Data were analyzed using Independent Samples t-tests to compare mean scores between groups.

4. Results

The analysis focused on three GILO categories: Problem-Solving (PS), Critical Thinking (CT), and Written Communication (WC). The group statistics and Independent Samples Test results are summarized Table 1 and Table 2, below, respectively.

Table 1: Group Statistics

Group		N	Mean	Std. Deviation	Std. Error Mean
PS	Exper.	9	4.0278	1.01892	.33964
	Cont.	9	3.2222	.53684	.17895
CT	Exper	9	4.1667	.85696	.28565
	Cont.	9	3.2500	.57282	.19094
WC	Exper	9	3.9722	.97183	.32394
	Cont.	9	3.5000	.43301	.14434

Table 2: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PS	Equal variances assumed	6.173	.024	2.098	16	.052	.80556	.38390	-.00827	1.61938

	Equal variances not assumed			2.098	12.124	.057	.80556	.38390	-.02994	1.64105
CT	Equal variances assumed	1.671	.214	2.668	16	.017	.91667	.34359	.18828	1.64505
	Equal variances not assumed			2.668	13.959	.018	.91667	.34359	.17953	1.65380
WC	Equal variances assumed	2.069	.170	1.332	16	.202	.47222	.35464	-.27959	1.22403
	Equal variances not assumed			1.332	11.056	.210	.47222	.35464	-.30786	1.25230

The results indicated that there was a statistically significant difference in the mean score of Critical Thinking between experimental group ($M = 4.1667$, $SD = 0.85696$) and control group ($M = 3.2500$, $SD = 0.57282$), $t(16) = 2.668$, $p = .017$, with equal variance assumed.

5. Discussion and Future Directions

The findings suggest that integrating GenAI into an IBL framework can significantly enhance critical thinking skills in student teachers learning how to implement IBL using technology in mathematics classes. The personalized approach, facilitated by concept prompts and IBL activity prompts in LLMs, likely contributed to increased engagement and deeper cognitive processing, enabling our student teachers to draw meaningful connections between how to connect mathematical concepts and their students' personal interests.

However, we did not find any significant differences in self-perceived problem-solving and written communication skills. This may indicate that while GenAI effectively supports critical thinking by fostering analytical and evaluative capacities of GenAI responses. Additional strategies may be required to impact other GILO skill areas. Future studies will explore other prompt engineering techniques, such as "chain of thought" prompting to comprehensively address various learning outcomes related to problem solving.

Limitations of this study include the small sample size and the short duration of the intervention, which may affect the generalizability of the results. Additionally, the reliance on self-reported measures may introduce bias. Our future research will incorporate larger, more diverse populations and employ objective assessments to validate the findings. In addition, investigating the long-term effects of GenAI integration and its applicability across different STEM related topics and educational levels will provide a more holistic understanding of its potential.

In conclusion, this study contributes to the growing body of evidence supporting the use of GenAI in personalizing mathematics education. By leveraging students' interests and fostering an active learning environment implemented through an anonymous online integrated chatroom with LLMs, GenAI can play a pivotal role in enhancing critical thinking skills, thereby preparing students for complex problem-solving and adaptive reasoning in STEM related contexts.

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