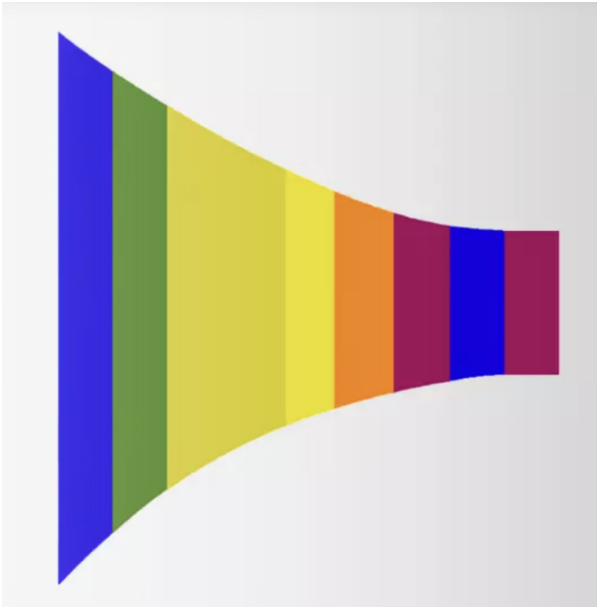
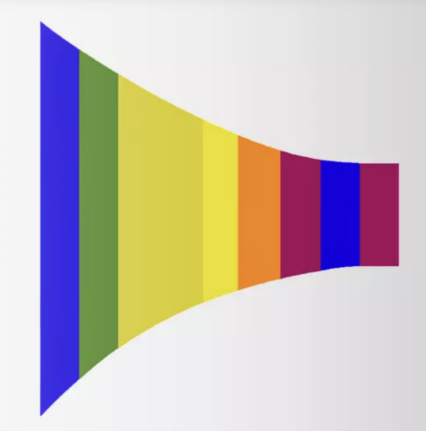


Proceedings of the 8th International Conference for STEM in Education (ISSE 2024)

Werklund School of Education, University of Calgary, Canada
Aug 1 - 3, 2024

Editors: Pratim Sengupta, Douglas Clark & Jennifer Lock



8th International Conference for STEM in Education (ISSE 2024)
Werklund School of Education, University of Calgary, Canada Aug 1 - 3, 2024
https://werklund.ucalgary.ca/stem2024

Welcome to STEM 2024, the 8th International STEM in Education Conference!

The 2024 STEM conference was held online from August 1 to 3, 2024, hosted by the University of Calgary's Werklund School of Education.

STEM 2024 brings together education researchers to promote a pan-continental conversation on critical issues pertaining to learning, teaching, design and development in Science, Technology, Engineering and Mathematics (STEM) and Computing Education.

This international conference is a biennial event hosted by a member of a worldwide consortium of universities: The International Society for STEM in Education (ISSE). Member universities include: Queensland University of Technology and University of Sydney (Australia); University of British Columbia and University of Calgary (Canada); Beijing Normal University, South East Normal University, North East Normal University, Southwest University, Shanghai Normal University and Shanghai Jiao Tong University (China).

The conference chairs express their sincere thanks to the ISSE Executive Committee, Dean Dianne Gereluk, Werklund School of Education, and administrative staff members of the Dean's office, without whose support the conference would not have been possible. Special thanks to Santanu Dutta, Valeriya Roshka and Megha Sanyal, PhD students in the Werklund School of Education, who worked tirelessly on various aspects of the conference, including hosting and chairing the online sessions. And finally, sincere thanks to the wonderful keynote speakers, Dr. Jennifer Adams, Dr. Greg Lowan-Trudeau, Dr. Aditi Wagh and Dr. Jrene Rahm, whose talks were universally appreciated by the audience.

Sincerely,

Pratim Sengupta, Doug Clark and Jennifer Lock (Conference Chairs).

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Countries represented by the authors:

Canada, China, United States, Nigeria, India, Kenya, UK, Australia, Sweden, Tunisia, Norway, Bangladesh, Uganda

Number of reviews and acceptance rate:

We received 55 submissions, out of which 19 submissions were accepted without revisions (34% acceptance without revisions), and 21 submissions were accepted with revisions. All submissions underwent a double-blind review process and received a minimum of two external reviews, with a total of 111 reviews.

Reviewers listed alphabetically by last name:

Our sincere thanks to the following colleagues for their contributions as reviewers:
David Anderson, Farzan Baradaran Rahimi, Reyhaneh Bastani, Janette Bobis, Feng-Kuang Chiang, Apoorve Chokshi, Douglas Clark, Santanu Dutta, Krista Francis, Bogusia Gierus Beaumie Kim, Somi Lee, Natacha Louis, Emily Marasco, Heather McMaster, Todd Milford, Marina Milner-Bolotin, Shuvo Chowdhury Rahul, Valeriya Roshka, Megha Sanyal, Pratim Sengupta, Lisa Taylor, Mohosina Jabin Toma, Tania Villalobos Lujan, Shyong Quin Yap, Yuanlin Zhang

Keynote 1: Dr. Jennifer Adams



Bio: Dr. Jennifer D. Adams is a Tier 2 Canada Research Chair of Creativity, Equity, and STEM and Professor at The University of Calgary in Department of Chemistry. She is the PI of the Creativity, Equity and STEM Lab where she leads her team in research on equity in STEM teaching and learning environments with an emphasis on identity-affirming, anti-deficit, desiring, and justice-oriented approaches. She is sought after for talks and workshops around her work in equity in postsecondary STEM. She is in leadership on several Canadian national projects including "Securing Black Futures" which seeks to increase the visibility and support the flourishing of Black students in STEM and the Canadian Black Scientists Network where she is the PI of the STEM Beyond Borders initiative that examines Black in STEMM equity-oriented research, policy and practice in Canada and the United States. Dr. Adams was recognized by the Calgary Black Chambers with an award for Black Achievement in STEM. Her prior appointments include Brooklyn College and The Graduate Center, City University of New York, the American Museum of Natural History, and The New York City Department of Education. She is a daughter of the Caribbean Mountains and Sea and a Type 2 fun junkie who enjoys open-ocean swimming and triathlon training.

Title: Expansivising Practices for meaningful science education: Centering teacher agency and desires for inspiring learners

Abstract: This talk is situated in a study of learning to teach science, informal science education and identity. The study initially aimed to learn how teachers' identities were influenced by teacher learning experiences in informal science institutions and sites. What emerged was how teachers transformed meanings, pedagogies and applications of informal science in ways that both resonated with their identities as teachers and social agents as well as the identities and needs of their students. In this talk I will first describe an overview of the study and then historically situate contemporary ideologies and corresponding practices. I will then describe the emergences from the study for educators who are committed to authentically enacting equity in learning spaces; that is learning that is attentive to and affirming of students' and teachers' identities and desirings to utilize education as a tool to create imaginations of alternative futures. Based on this I will discuss frameworks for designing professional development and learning experiences that afford critical awareness, creativity and culturally affirming science education both in formal and informal contexts.

Keynote 2: Dr. Greg Lowan-Trudeau



Bio: Greg Lowan-Trudeau, PhD is Associate Professor in Curriculum and Learning with the Werklund School of Education at the University of Calgary. His research occurs at the intersections of environmental education and communication with science, technology, and society (STS). Greg often explores topics related to critical media literacy, critical energy literacy, digital technologies, climate change, environmental politics, outdoor and experiential approaches, environmental justice, and intersectional perspectives. His current methodological interests include content, discourse, and framing analysis.

Title: Nuclear Technologies, Environmental Education, and News Media in Canada

Abstract: Amidst a rise in global conflicts and search for energy and climate change solutions, nuclear technologies have been prominent in recent news media and public discourse. In this presentation, Greg Lowan-Trudeau will share related insights from a comparative study of K-12 curricula and news media in Canada through a critical environmental lens. Examining nuclear-related news media coverage and K-12 curricula provides an opportunity to understand how media discourses relate to what students are learning in Canada. Increased understanding of nuclear topics will facilitate more active engagement in related educational conversations, news media, and societal decision-making processes.

Keynote 3: Dr. Aditi Wagh



Bio: Aditi Wagh is a Research Scientist in the Scheller Teacher Education Program at MIT. Her work sits at the intersection of learning sciences, science education and computing. Her research examines how computational modeling can become a tool for expression and sense-making for youth in classrooms and informal learning spaces. In one line of inquiry, she collaborates closely with teachers in school districts to make computational modeling a sustained practice in classroom communities. More recently, she has started thinking about how more expansive experiences with computational modeling can enable youth to relate modeling and scientific sense-making with everyday practices. Dr Wagh leads several NSF projects in science and computing education. She has a PhD in Learning Sciences from Northwestern University.

Title: Paying Attention to Our Teachers: Leveraging Teacher Resources & Practices to Make Computational Modeling a Sustained Practice in K-12 Classrooms

Abstract: Decades of research on the use of computational modeling in science education has shown that it supports both learning of science and computational practices. We know that teachers play a key role in supporting students' sense-making in classrooms. However, relatively less work has examined how to support teachers to make computational modeling a sustained practice in their classrooms. In this talk, I argue that as a field, we need to pay more attention to teacher resources and the existing systems they operate in to make computational modeling a sustained practice in science classrooms. Drawing on insights from long-term collaborations with teachers and districts, I will share lessons learned around resources teachers bring to this work, stories of teacher learning, and how to create structures within a district to support them. Finally, I will propose a framework - artifacts, practices and values - as a lens to think about how to study and support teachers as they bring this critical scientific practice into their classrooms in a sustained way.

Keynote 4: Dr. Jrene Rahm



Bio: Jrène Rahm is an Educational Psychologist and Full Professor at the Université de Montréal, Canada with an expertise in the learning sciences and educational anthropology. Through multi-sited and longitudinal studies grounded in sociocultural and critical theory, driven by a space-time lens, she explores diverse youths' navigations of community organizations, gardens, and other educational venues, driven by future aspirations of becoming somebody. That interest led to stories of counter-spaces and educational pathways in science marked by equity and social justice.

Title: Interrogating learning and identity in science by attending to embodied, affective, and more-than-human entanglements

Abstract: In this presentation, I interrogate learning and identity in science by attending to embodied, affective, and more-than-human entanglements. By bringing such a lens to science education, I aim to move away from a representational reading of learning and identity in science locked in time and space. Through case studies from dignity-affirming informal education, I put to work such a conceptual lens and address its methodological challenges. I center moments of learning and identity that uplift voices, that are future oriented, and that help us reimagine more socially just and equity driven science practices.

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A CRITICAL DISCOURSE ANALYSIS OF STEM EDUCATION POLICY DOCUMENTS OF BANGLADESH, INDIA and CANADA

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Educational Studies in Learning Sciences

University of Calgary – Werklund School of Education

Abstract

The study presents a comparative critical discourse analysis of the aims, objectives, aspirations as well as underlying ideologies and agenda behind science education in Bangladesh, India and Canada (Alberta in particular). We present a critical discourse analysis of science and STEM education policy documents in each country, and our analysis makes visible the underlying ideologies and geopolitical agendas and influences as evident in these documents. We found that there are significant similarities in the goals, aspirations, purpose and nature of science education in these three countries, but there are also differences in terms of how explicitly STEM and science education have been tied to nationalistic agendas and economic advancement. We interpret our findings in light of critical scholarship that positions STEM education as epistemologically complex, locally emergent and ideologically and geopolitically rooted.

Keywords: Science Education, Critical Discourse Analysis, Educational Policy, Curriculum.

BACKGROUND AND AIMS

Learning is inherently political (Philip et al., 2018). STEM education, in particular, has been illustrated to be epistemologically complex, locally emergent and ideologically and geopolitically rooted (Shanahan et al., 2016; Takeuchi et al., 2020). For example, in the US, the emergence of STEM as an educational construct has long been tied to economic, nationalistic and militaristic agendas (Shanahan et al., 2016). These influences are often visible in the texts that define STEM education experiences, such as curricula, government policies and classroom materials (Bazzul, 2014). This study focuses on making visible the underlying ideologies and geopolitical agendas and influences as evident in STEM education policy documents at the secondary levels in Bangladesh, India and Canada.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

The study is an analysis of a collection of education policy and curriculum documents from Bangladesh, India and Canada (Alberta), with a particular focus on science education. Using critical discourse analysis (CDA) (Fairclough, 2003) as our methodology, we identified the apparent and underlying aspirations, agenda and ideologies reflected in these documents. The portions we identified for analysis from each of the documents are shown in the table below:

Table 1
Documents and selected portions for analysis

Country		Page Number	Contents
Bangladesh	National Education Policy 2010	1-3	Aims and Objectives of Education
		13-15	Secondary Education
		30-31	Science Education
		62-63	Curriculum and Textbook
	National Curriculum Framework- 2021	1-13	Background-Mission
		48-59	Subject and subject Conceptualization (Science)
India	National Education Policy 2020	3-6	Introduction
		11-19	Curriculum and Pedagogy in Schools: Learning Should be Holistic, Integrated and Engaging
	National Curriculum Framework for School Education 2023	17-18	Aims and Curricular Areas of Learning
		211-250	Science Education
Canada (Alberta)	(Alberta) Science Grades 7-8-9 Programs of Studies	1-5	Rationale, Philosophy, Vision, Goals, Program Foundations
	Alberta Department of Education- Ministerial Order (#005/2024)	1-6	Whole Document

RESULTS AND CONCLUSION

All the policy and curriculum documents describe the significance of education for individual wellbeing, for society and for the advancement of human civilization. Education in general, and science education in particular, is described as essential for creating a healthy, joyful and well-rounded individual life as well as for building a modern, harmonious and responsible society. Despite these obvious commonalities, there are ideological differences in the narratives regarding the goals, visions, aspirations and nature of science and science learning across these three countries. For example, for Bangladesh and India, a strong emphasis has been given to economic and nationalistic benefits while defining the overall goal of education. Nurturing patriotism and developing a skilled workforce able to participate in global economy seems to be a recurrent ideological emphasis in the documents, which also position employability in the technology sector as essential for national interests. This is consistent with Takeuchi et al.'s (2021) finding that STEM education globally has been

shaped by US imperialistic ideologies, which in turn positions STEM education as essential for workforce readiness and national security. In comparison, in Canadian documents, social and economic dimensions and impacts of STEM disciplines are acknowledged, and civic and community responsibilities are also emphasized in the context of science and STEM education. Scientific and technological literacies are positioned in more expansive ways in the Canadian context, aligned with socio-ecological responsibilities both at the individual and societal levels.

The key finding in our study - the relatively more expansive vision of science and STEM education as reflected in Canadian documents compared to the Indian and Bangladeshi documents - must be interpreted in light of geopolitical forces that position people of the Global South as "endarkened bodies" (Philip & Sengupta, 2021), whose labour is extracted by the technology industries centred in the Global North (Banerjee, 2022). Our study thus contributes to the scholarship on ideological underpinnings of STEM and computing education from transnational and geopolitical contexts (Philip et al., 2017; Takeuchi et al., 2020).

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PLAYING BOARD GAMES IN SCHOOL TO ENCOURAGE SPATIAL EXPERIENCES OF GRID STRUCTURES

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BACKGROUND AND AIMS

Implementing board games in classrooms offers tremendous opportunities for accumulating embodied experiences with gridified space. Grids are a means for organizing two-dimensional space and establishing relationships between and actions on objects. In mathematics, understanding of grids is essential for understanding area, graphing, functions and so much more. Frequently, grids are taught as an object of rules and procedures, which can lead to a lack of student understanding. Rather than considering grids as the explicit focus of instruction, we suggest that implicit experiences with grids might lead to deeper knowing. In this presentation, we highlight findings from our three-year design-based research study exploring how commercial board games can provide opportunities for students to engage spatially with an underlying grid structure, which we call gridified space.

Framed by the enactivistic understanding that conceptual understanding is embodied in the sensory-motor system (Gallese & Lakoff, 2005), the connection of spatial reasoning and sensory motor skills (Khan et al., 2015), we situate our study in Davis et al.'s (2015) notion of spatial reasoning skills as the competencies associated with emerging co-evolving mental and physical actions on objects. Such skills include ALTERING (*dilating*/*contracting*, *scaling*), MOVING (*sliding*, *rotating*, *reflecting*), SITUATING (*dimension shifting*, *locating*, *orienting*, *pathfinding*, *intersecting*), SENSATING (*visualizing*, *imagining*, *tactilizing*), INTERPRETING (*modeling*, *comparing*, *relating*), [DE]CONSTRUCTING (*de/re/composing*, *re/arranging*, *fitting*). Sarama et al. (2010) found that sensory materials were useful for developing precise working concepts of grids, grid lines, points to spatially understand distance relationships in a grid system. Such active experiences helped student develop an intuitive sense of the patterns and relationships of gridified space.

PROCESSES UNDERTAKEN

To investigate the possibilities of encouraging spatial sensory motor experiences of the grid, we investigated children playing with different commercial board games. Each game was played 4 weekly sequential 60-minute classes Our data included video recordings of students as they played in groups of four, post-game reflection sheets, and field notes. In this presentation, we will show videos of students exploring both a fixed and emergent grid in two games. Our analysis highlights students' engagement in Davis et al.'s (2015) spatial reasoning skills.

RESULTS AND CONCLUSIONS

Shifting Stones is a fixed grid tile-manipulating game. Students engaged in *moving* or *flipping* tiles to match placements illustrated on cards, *situating* and *orienting* the patterns of their cards to "North" (*directioning*), investigating the possible paths (*pathfinding*) to change the *location* of the tiles on the grid to match their cards. Qwirkle is an attribute game forming an emergent grid. Student engaged

in *comparing* and *matching* tiles by shape or colour to form adjoining *vertical* and *horizontal* line(s) to form an emerging grid structure. The videos show frequent gesturing along grid features indicating their sensori-motor experiences with the grid structures of the game. Our findings illustrate that students accumulated multiple sensory motor and spatial experiences with gridified space.

To conclude, playing games in mathematics classes can immerse students in spatial rich sensory motor experiences, and expand students' mathematical possibilities for developing an intuitive understanding of grid. While it is beyond the scope of this paper, we speculate that these spatial experiences will be valuable in learning mathematics concepts like algebra, geometry, and graphing.

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ONLINE GRADUATE PROGRAM AS A CATALYST FOR SCIENCE TEACHERS' PEDAGOGICAL TRANSFORMATION: FROM NEW TECHNOLOGIES TO NOVEL PEDAGOGIES

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BACKGROUND AND AIMS

With rapid advances in educational technology, STEM teachers face mounting pressure to implement modern pedagogies (Ben-David Kolikant et al., 2020). However, updating their teaching repertoire is challenging (Milner-Bolotin, 2020). This qualitative study leverages Fullan's Theory of Educational Change (Fullan, 2006) to examine the transformative potential of a research-based asynchronous online graduate Science Education program (https://pdce.educ.ubc.ca/med_science/), focusing on innovative STEM pedagogies.

As online asynchronous graduate programs gain popularity, their impact on STEM teachers remains under-explored. This research aims to examine practising STEM educators' perspectives on how participating in this 2.5-year online asynchronous science education cohort-based graduate program influenced their pedagogy, educational thinking, and attitudes towards research, helping them persevere in their graduate studies. The program is particularly valuable for educators in remote areas with few colleagues to discuss teaching, as its asynchronous nature offers flexibility and removes time-zone and location barriers.

METHODOLOGY

This five-year qualitative study triangulated data from repeated focus groups (N=25) conducted during and after the program, along with observations from program facilitators and instructors. The consequent data analysis revealed three major interrelated themes that addressed the study research goals.

RESULTS AND CONCLUSIONS

Three major themes emerged on the program's impact: (1) deeper engagement with science education research, leading to (2) shifts in pedagogical paradigms that inspired confidence, resilience, and self-reflection, and (3) empowerment for pedagogical transformation within and across educational contexts. This online graduate program removed barriers for practicing teachers to access and implement education research. STEM educators were exposed to and encouraged to implement novel educational technologies in their classrooms (Milner-Bolotin, 2020). Our findings align with other studies on increasing access to graduate education for practicing teachers to foster pedagogical transformation. These insights highlight the significant effects of asynchronous online programs on educators' pedagogical understandings and attitudes, emphasizing their critical role in shaping science educators' approaches and attitudes and contributing to the field of online educational development.

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A COMPARATIVE ANALYSIS OF THE PRIMARY LEVEL SCIENCE CURRICULUM STRUCTURES IN BANGLADESH AND SINGAPORE

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BACKGROUND AND AIMS

This paper compares the primary-level science curricula of Bangladesh and Singapore, aiming to improve Bangladesh's curriculum based on Singapore's practices. Despite a similar GDP (Gross Domestic Product) percentage of education budgets, Singapore ranks much higher on the Human Development Index for education. This study employed Tyler (1949) recommended four curriculum key components to analyze and compare the two curricula.

RESULTS AND CONCLUSIONS

The first component, educational purposes, compared the clarity of goals, vision, and used framework in the science curricula of Bangladesh and Singapore. While the Singapore curriculum had a clear goal and vision for scientific literacy and focused on core ideas, values, ethics, and attitudes, the Bangladesh curriculum lacked explicit direction. This paper suggested Bangladesh articulate clear goals to provide essential direction for science teachers. The second component, educational experiences, explored the approaches of both countries. Singapore adopted a comprehensive approach with five thematic areas and emphasized values guided by the Nature of Science. Singapore teachers can select students' learning experiences based on professional judgment. In contrast, the Bangladesh curriculum outlined subject-specific competencies, learning outcomes, and definite experiences. This paper suggested a balanced approach for Bangladesh, incorporating teacher flexibility while providing explicit guidance on multiple potential learning experiences. The third component, the organization of educational experiences, discussed deficiencies in both vertical and horizontal organizational principles in the Bangladeshi curriculum (Bain & Siddique, 2017) and recommended exploring research-backed sequencing principles like simple to complex, whole to part, and chronological sequencing (Print, 1993) for curriculum development. The final component, determination of purpose attainment, focused on assessing learning outcomes. While the Singapore curriculum included a section on assessment, the Bangladesh curriculum lacked any reference to assessment throughout the document. This paper advocated for incorporating assessment guidance to empower teachers in navigating student learning. The analysis of these two science curricula offered valuable insights for curriculum developers, educators, and policymakers. The recommendations emphasize the need for clear goals, flexibility in educational experiences, improved organizational frameworks, and explicit guidance on assessment to enhance the effectiveness of primary science education in Bangladesh.

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PROPOSING A FRAMEWORK FOR SUPPORTING PRE-SERVICE TEACHERS IN DESIGN

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Abstract

Guided by contemporary theory and research from design fields and education, we propose a framework for conceptualizing K-12 teachers' stances toward designerly thinking. We developed the framework following Crismond and Adams' (2012) scholarship of integration approach combined with an inductive content analysis of 43 pre-service teachers' conceptualizations of design across two versions of a design course. The resulting framework focuses on five themes including: (a) problem solving versus problem framing, (b) problem complexity and structure, (c) inquiry and stakeholder engagement, (d) idea fluency and scope, and (e) conceptualization of the design process. We elaborate each theme, proposing anchor points and examples based on the literature and an inductive content analysis of the data. A final deductive content analysis of the data using the framework explores the prevalence of different levels of understanding and the potential feasibility of the goals suggested by the framework.

Keywords: Design, Backward Design, Design Thinking, Teachers

BACKGROUND AND AIMS

Design in education has typically involved a narrow focus on backwards design and communicating disciplinary content and practices. This narrow focus in school jurisdictions and teacher education programs may partially explain why education as practiced in K12 classrooms has changed so little in North America over the last century (Cuban, 2020; Payne, 2008).

METHODOLOGY

Guided by contemporary theory and research from design fields and education, we propose a framework for conceptualizing K-12 teachers' stances toward designerly thinking in STEM subjects and beyond. We developed the framework following Crismond and Adams' (2012) scholarship of integration approach combined with an inductive content analysis of 43 pre-service teachers' conceptualizations of design across two versions of a design course.

RESULTS AND CONCLUSIONS

The resulting framework focuses on six dimensions including: (a) problem solving versus problem framing, (b) problem complexity and structure, (c) inquiry and stakeholder engagement, (d) idea fluency and scope, (e) conceptualization of the design process, and (f) attitude toward ambiguity. We elaborate each dimension, proposing anchor points and examples based on the literature and an inductive content analysis of the data. A final deductive content analysis of the data using the framework explores the prevalence of different levels of understanding and the potential feasibility of the goals suggested by the

framework, reinforcing the idea that learning progressions are not developmentally determined but are instead influenced by curriculum.

While this study highlights possibilities, it also has limitations. First, it is important to reiterate that teachers are not the only ones responsible for bringing change. Administration, government, universities, the public, and other stakeholders are all implicated in the need for change. That said, all teachers have opportunities to design for some degree of change in their classroom practices. Teachers should be supported in developing this potential.

Second, the current study focuses on pre-service teachers' written reflections and design project artifacts, but these data sources raise other questions in terms of what data would be of most value in assessing teachers' understanding of design. Future research should also explore process data from group work to triangulate with other sources of data in understanding how pre-service teachers are conceptualizing and enacting design.

In addition to the directions outlined above, future research needs to elaborate our understanding of the pathways and intermediate points through which K12 teachers move as they develop in design sophistication. The current study provides a foundation, upper and lower anchors, and an initial set of intermediate points, but there are clearly many paths and perspectives through which design sophistication might evolve. Helping K12 teachers move toward more designerly stances will support them in becoming more comfortable exploring and addressing the complex challenges and needs of their students. The proposed framework could thus further support the development of K12 teachers as informed designers who might better serve the full range of students in our classrooms.

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DESIGNING STEAM TASKS THAT ENGAGE YOUNG STUDENTS IN LEARNING MATHEMATICS

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BACKGROUND AND AIMS

Science, technology, engineering, and mathematics (STEM) education has been proposed as a potential solution to improve student engagement in school mathematics (Murphy et al., 2019). Research shows that utilising an enriched and diverse range of STEM contexts is an approach that can excite students, help them to relate content to real contexts, cultivate their curiosity and improve engagement (Marmon, 2019). However, concerns have been raised by mathematics educators that the depth and breadth of the mathematics itself may be lost in an integrated STEM (English, 2016; Little, 2019) or, in the case of the current project, STEAM task ('A' = Arts).

Given the critical nature of the early years of students' mathematical experiences and the relatively limited resources for teaching mathematics within a STEM or STEAM context, this study focuses on designing tasks that emphasise learning mathematics in an enriched STEAM context (steaM tasks) for students aged 5-8 years. The capitalisation of the M in steaM reflects the emphasis on mathematics. The study's first objective is to design high quality steaM tasks for early years students. We focus on this objective by presenting an evidence base in support of a set of characteristics indicative of high-quality steaM tasks. Illustrative examples of tasks are also presented.

METHODOLOGY OR PROCESS UNDERTAKEN

One strategy to ensure tasks are engaging for students, is to design them according to principles of Variation Theory (VT). VT is applied by varying some aspect of the task while other aspects remain constant. In this way, learners can focus their awareness on critical aspects, and the varying aspect can be discerned more easily (Watson & Mason, 2006). The principles of VT were applied to guide the design of steaM tasks.

Characteristics of quality tasks derived from the literature and included in the design process implementation include tasks that:

- involve variation of either content or context (Watson & Mason, 2006).
- have high cognitive demand and are appropriately challenging (Sullivan et al., 2016)
- promote creative reasoning (Craft, 2011),
- have a low floor, high ceiling (Sullivan et al., 2016),
- include inquiry opportunities (Boaler, 2015), and
- are open-ended or have solutions that can be obtained via multiple methods (open-middled) (Boaler, 2015).

Consider the following example task that focuses on students' capacities to conceptually subitise arrangements of dots to help calculate the total using equal groupings. Students discuss the dot art of Yayoi Kusama and Indigenous paintings. They are then challenged to:

Create your own dot painting but arrange the dots so that you can easily find the total of dots without counting them by ones.

This task and others will be presented to illustrate the application of VT and highlight how characteristics of quality tasks have been used to develop challenging and engaging steaM tasks suitable for young students.

RESULTS AND CONCLUSIONS

The example task and others will be presented to illustrate the application of VT and highlight how characteristics of quality tasks have been used to develop challenging and engaging steaM tasks suitable for young students. Implications for designers of curriculum materials and for classroom practice will be presented.

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INFLUENCE OF UNIVERSITY-ENTERPRISE AI EDUCATION PROGRAM ON HIGH SCHOOL STUDENTS' ATTITUDES TOWARD AI AND MOTIVATION TO PURSUE AI-RELATED CAREERS

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BACKGROUND AND AIMS

Amidst the burgeoning domain of Artificial Intelligence (AI), integrating effective AI education in primary and secondary schools remains a challenge, primarily due to a scarcity of specialized talent and practical learning opportunities. This study initiates the "Learning-Creation-Competition" University-Enterprise AI Education Program (UEAIEP), a 7-day intervention for high school students aimed at enhancing AI comprehension and reshaping student perceptions of AI.

Research Questions
RQ1. Do the attitudes of students towards AI and their motivation to pursue AI careers change after they attend the program? Do gender differences exist in this context?
RQ2. How satisfied are students with the University-Enterprise AI education program?

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

This study adopted a one-group pretest–posttest design. To answer the research questions, both quantitative and qualitative data were collected(figure.3). Forty-nine Chinese high school students were recruited to participate in a 7-day UEAIEP. The present study was approved by the Human Research Ethics Committee of the researchers' university.

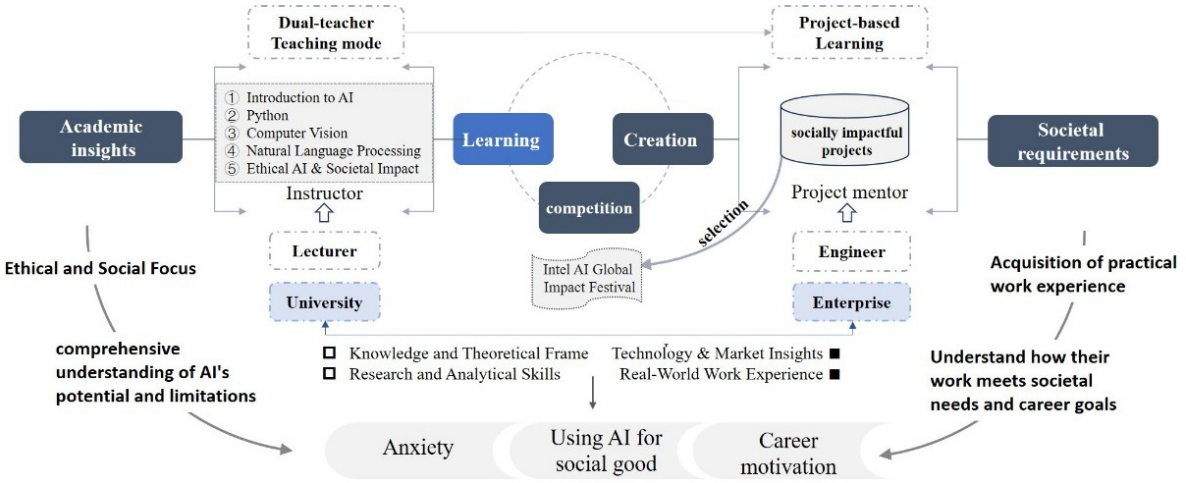


Figure.1"Learning- Creation-Competition" University-Enterprise AI Education Program (UEAIEP)

The questionnaire was adapted based on previous studies to measure participants' attitudes towards AI, motivation to pursue AI-related careers, and satisfaction with the program (Chai et al., 2020; Zhang et al., 2022), using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The reliability of the questionnaires was verified by assessing their Cronbach's α.

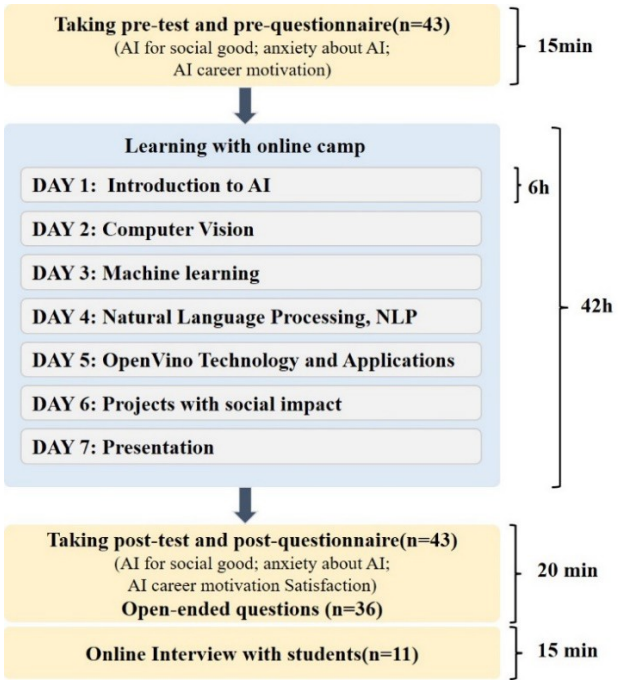


Figure.2 Experimental procedure

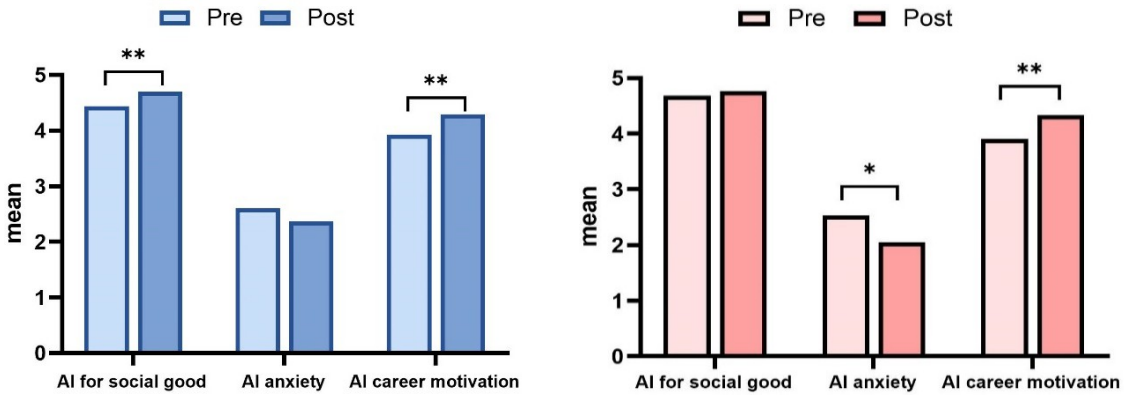
Research questions	Data collection	Data analysis
RQ1	a) AI attitude questionnaire b) AI career motivation questionnaire c) Demographic information survey	Matched-pair t-test Independent samples t-test
RQ2	a) Satisfaction questionnaire b) Participants' responses to open-ended questions and online interview	Descriptive statistics Coding and content analysis

Figure 3. Data collection and analysis

RESULTS AND CONCLUSIONS

Results

For RQ1, significant changes were observed in using AI for social good, AI anxiety, and AI career motivation, with no notable gender differences. Regarding RQ2, participants expressed satisfaction with the program, particularly in teacher-student interactions. Analysis of open-ended responses and interviews identified key themes: slowing down the pace, ways of thinking, uneven distribution of group work, and the female instructor serving as a role model, which can motivate female students to pursue careers in STEM fields.



$* p < 0.05, ** p < 0.01, *** p < 0.001$

Figure 4. Comparison of mean value for male (left) and female (right) participants before and after the program

Implications

This study highlights the benefits of University-Enterprise collaborations in AI education, suggesting that such partnerships offer a dynamic curriculum aligned with current AI industry needs. It encourages policymakers and educators to adopt similar models across various STEM subjects, promoting an integrated and practical educational approach. This approach not only boosts technical skills but also fosters social responsibility and ethical awareness among future AI professionals.

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CONCEPTUAL METAPHORS FOR QUANTUM PHYSICS IN POPULAR ONLINE SCIENCE MEDIA

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Abstract

In the era of ubiquitous information, influencers shape perceptions, even in quantum physics education. Modern students, influenced by online platforms like YouTube and TikTok, enter quantum physics classes with preconceived notions, visuals, and metaphors of quantum concepts. This study explores the quality and messages of popular science media, focusing on conceptual metaphors in YouTube short videos explaining quantum physics. In the aim to uncover conceptual metaphors, in which abstract concepts, such as quantum theory, are made available through concrete mappings, the analysis of the videos unveiled patterns in language, visuals, and gestures, shedding light on how these media influence students' meaning-making. Recognizing the impact of online education sources, this research strived to inform how the content shapes students' perspectives.

Keywords: Conceptual Metaphors, YouTube, Quantum Physics, Science Education, Video Analysis

BACKGROUND AND AIMS

Conceptual metaphor theory (Lakoff & Johnson, 1999; Shapiro, 2019) suggests we understand abstract concepts by mapping them to concrete experiences. This theory explores how conceptual metaphors, in language and visuals, help us grasp abstract ideas like quantum physics (Amin, 2015; Danesi, 2017; Lakoff, 2006). Pop culture bombards students with these conceptual metaphors for abstract physics concepts through short online videos, which are readily available, visually engaging, and can shape their understanding before entering a physics class (Bentley et al., 2019; Richtberg & Girwidz, 2019). This study investigates the quality and messages conveyed by these popular media sources, specifically within quantum physics.

METHODOLOGY

This study focused on conceptual metaphors within popular media, specifically video shorts related to quantum physics. YouTube Shorts, introduced in 2021, are typically under a minute and have become a dominant format (Violot et al., 2024). Given the short duration, I explored how these videos utilize metaphors to explain complex concepts of quantum physics.

To select videos, I used Google Search with keywords "quantum physics" within the "Shorts Videos" category. As such, 26 videos were chosen and came from YouTube, Facebook, Instagram, and TikTok. An emergent thematic analysis was conducted to identify themes, conceptual metaphors, and imagery within the videos.

RESULTS AND CONCLUSIONS

The selected videos were mostly from 2023 and 2024, had an average duration of 1 minute 5 seconds with 329K views. Three videos were outliers, using "quantum physics" in the title but not actually discussing the topic, but the remaining videos typically depicted scientists explaining

quantum mechanics to a novice interviewer. These scientists, including notable figures like Carlo Rovelli and Neil deGrasse Tyson, employed multiple metaphors, averaging 6.1 per video. While having multiple perspectives can be helpful to a more complete understanding of an abstract concept (Lakoff & Johnson, 1999; Podolefsky & Finkelstein, 2007), such a variety might overwhelm students seeking understanding (Amin, 2019).

The analyzed video cluster showed diverse interpretations of quantum mechanics. While some videos explored wave-particle duality, others emphasized probability. Notably, a good portion focused on the particle model, with only a few considering the wave model. One video even debated if particles have definite paths, reflecting the ongoing scientific debate about a unified interpretation of quantum physics. This range of interpretations accurately represents the current state of the field, but for students, it might portray quantum physics as fragmented concepts rather than a unified theory.

In addition, the videos often portrayed quantum physics as strange and separate from daily life, with interviewers often emphasizing this disconnect. While many scientists acknowledged its applicability to everything, they also acknowledged its contrast to classical physics. Moreover, scientists across the videos consistently emphasized the centrality of mathematics in describing quantum physics, where math seemed almost inseparable from the core concepts.

In summary, the videos featured reputable scientists and generally accurate information. However, most perpetuated the "weirdness" stereotype and focused on the particle-nature metaphor. Importantly, interpretations of quantum mechanics were diverse, except for the undisputed reliance on math. By analyzing popular science videos, this study explored potential student exposure to quantum physics content through their online media consumption.

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REDESIGNING FORBIDDEN ISLAND BOARDGAME: AN INTERDISCIPLINARY APPROACH TO COMPLEX STEM EDUCATION

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Abstract

We propose boardgame redesigning as an innovative method to foster complex interdisciplinary STEM learning. Engaging students in creating playable games links various disciplines, from crafting narratives using humanities expertise to applying mathematical thinking for game mechanics and spatial reasoning. The study illustrates a five-month design-based research tabletop game redesign project involving one hundred culturally diverse middle school students. A team's fantasy-themed game redesign, replacing squares with hexagonal tiles, exemplifies how this shift influenced mechanics and inspired further decisions, integrating science concepts like creature adaptations. By examining the real-time evolution of the game redesign process, we observed the inherently interdisciplinary nature of this project, providing a spontaneous and meaningful integration of STEM topics and skills intertwined with humanities and arts.

Keywords: Boardgame redesign, interdisciplinary approach, STEM education, middle-school students, design-based research

BACKGROUND

In middle school, integrating science with humanities or arts is challenging, despite the call among education researchers for a more interdisciplinary approach to science education (Johnson & Czerniak, 2023; You, 2017). Teaching diverse concepts simultaneously may be difficult, but showcasing the interconnectedness of disciplines is important for authentic education (Cone et al., 2009; Nissani, 1995). We propose that boardgame redesigning can provide interdisciplinary STEM learning by engaging learners with the game's narrative, material creation, and rules.

METHODOLOGY

In the boardgame redesign process, students aim to create a playable game, requiring diverse knowledge and skills (Bastani & Kim, 2022; Morris et al., 2013). This complex endeavor involves crafting a narrative backstory using humanities expertise and transitioning to mathematical thinking for game mechanics and spatial reasoning. Drafting rules parallels composing a clear procedure in a science lab, while artistic and technical skills are vital for designing the board, cards, and game pieces. Even spelling, grammar, and punctuation are tested. While complex, this process motivates students with autonomy in decision-making, leading to the creation of a final, enjoyable, and easily playable game.

This paper illustrates the interdisciplinary nature of our boardgame redesign project, implemented over five months with one hundred middle school students in a culturally

diverse neighborhood of a Canadian city. Conducted in both science and humanities classrooms, teams of four seventh-grade students redesigned the tabletop game Forbidden Island (Leacock, 2010).

RESULTS AND CONCLUSIONS

We provide examples from one team's fantasy-themed game redesign, featuring numerous changes from the original. Early on, the team opted for hexagonal tiles rather than squares to offer players more movement options (see Figure 1). This slight change to the original game had a profound impact on the mechanics and inspired additional decisions.



Figure 1: Students playing their game on hexagonal tiles rather than rectangular ones as in the original game.

Now with hexagonal tiles, the gameboard resembled a map with distinct regions, fostering a more earthly appearance. Inspired by the organic look, students applied lessons from their science class, integrating creature adaptations for specific biomes into their fantasy game by selecting monsters that matched their region's characteristics.

Choosing hexagonal tiles also increased the movement complexity for both players and monsters. The students systematized the monsters' behaviour, so that the rules, rather than the players were controlling them. To accomplish this, students had to "program" monster movements by creating pre-scripted motion cards before playing the game and ensuring compatibility with the hexagonal grid. Thus, students were practicing spatial reasoning, transformations, and mappings, akin to the function unit in math class, without specific direction from the teacher, or external insistence for accuracy. The game mechanics and gameboard served as their problem–feedback system, and their motivation to solve this emergent complication came from their desire to create an entertaining and playable game.

Boardgames have proved to be beneficial in enhancing learning in specific disciplines, especially in mathematics (Civil, 2002; Balladares et al., 2023). Through this study, we add to the literature and highlight the meaningful integration of STEM topics and skills within the game redesign process, interweaved with humanities and the arts. Unlike the artificial isolation often encountered in science and math classes, STEM learning occurs

spontaneously through game redesign, with students addressing complex concepts without realizing the depth of the challenges they are tackling.

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The Effects of Intelligent Drone Course on Primary students' AI Learning Attitude, Motivation, Self-efficacy and Collaborative Problem Solving Ability

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Abstract

This study aims to investigate the impact of interdisciplinary applications of drones on students' self-efficacy, attitudes toward AI, and collaborative problem-solving skills. The findings indicate that integrating drones into STEM education can lead to positive learning outcomes.

Keywords: Intelligent Drone STEM Course, Artificial Intelligence (AI), Collaborative Problem Solving, Primary schools

BACKGROUND AND AIMS

Integrating drones in STEM education has significant pedagogical implications, contributing to critical thinking (Sattar et al., 2017), interdisciplinary learning (Chen et al., 2018), student engagement (Bai & Chu, 2021) and computational thinking skills (Sattar & Nawaz, 2023), while enhancing 21st-century skills (Yepes et al., 2022). However, further research is needed to fully understand the potential of cross-curricular applications of drones. Based on the above, the present study employed Artificial Intelligence (AI) perception and computer vision technology to develop a comprehensive drone course consisting of six thematic units, aiming to investigate its efficacy in enhancing primary school students' attitudes towards AI learning, motivation, self-efficacy, and collaborative problem-solving (CPS) skills.

METHODOLOGY

In this study, an intelligent drone course (lasting four weeks) was conducted in a small school in Shanghai in March 2023, two to three times per week, with an average of 1.5 hours each time, and a total of 14 lesson hours for six topics. A single-group pre- and post-test quasi-experimental design was used, and questionnaires were administered to the course participants' AI attitudes, learning motivation, self-efficacy, and collaborative problem-solving (CPS) ability before and after the experiment (see Figure 1).

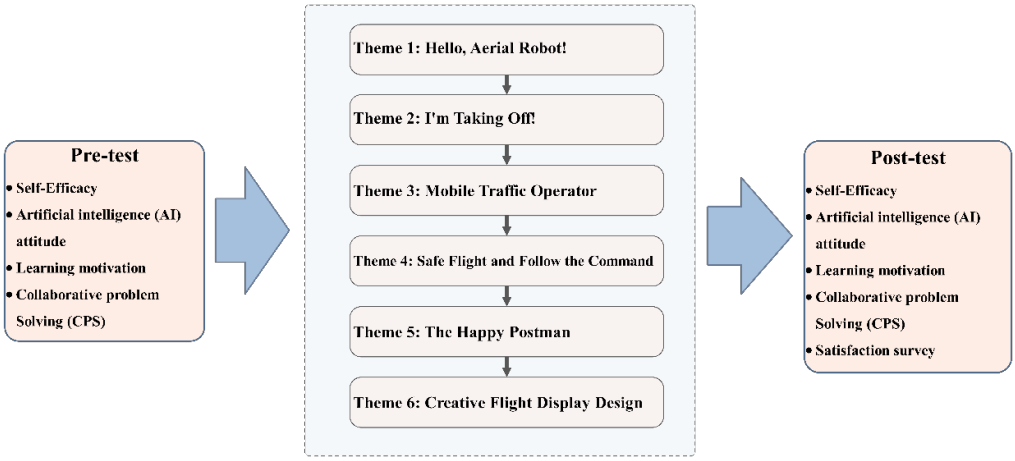


Fig. 1 Research Procedure

A total of 24 students, comprising 19 boys and 5 girls from Grade 4 and 5, willingly enrolled in this program with the consent of their parents. The average age of the participants is 10.6 years. The teaching practice process is shown in Figure 2.



Fig. 2 Instructional Practice process

RESULTS AND CONCLUSIONS

The paired sample T-test was conducted on the data of 24 students before and after participating in the experiment, and it was found that the self-efficacy of the students was higher (t=-3.22, p<0.05), AI attitude (t=-2.36, p<0.05), AI motivation (t=-2.87, p<0.05) and collaborative problem solving (t=-2.38, p<0.05) and other dimensions have improved, and all have statistical significance (see Figure 3). These results indicate that intelligent UAV activities can significantly improve the self-efficacy, AI attitude, learning motivation and CPS ability of primary school students.

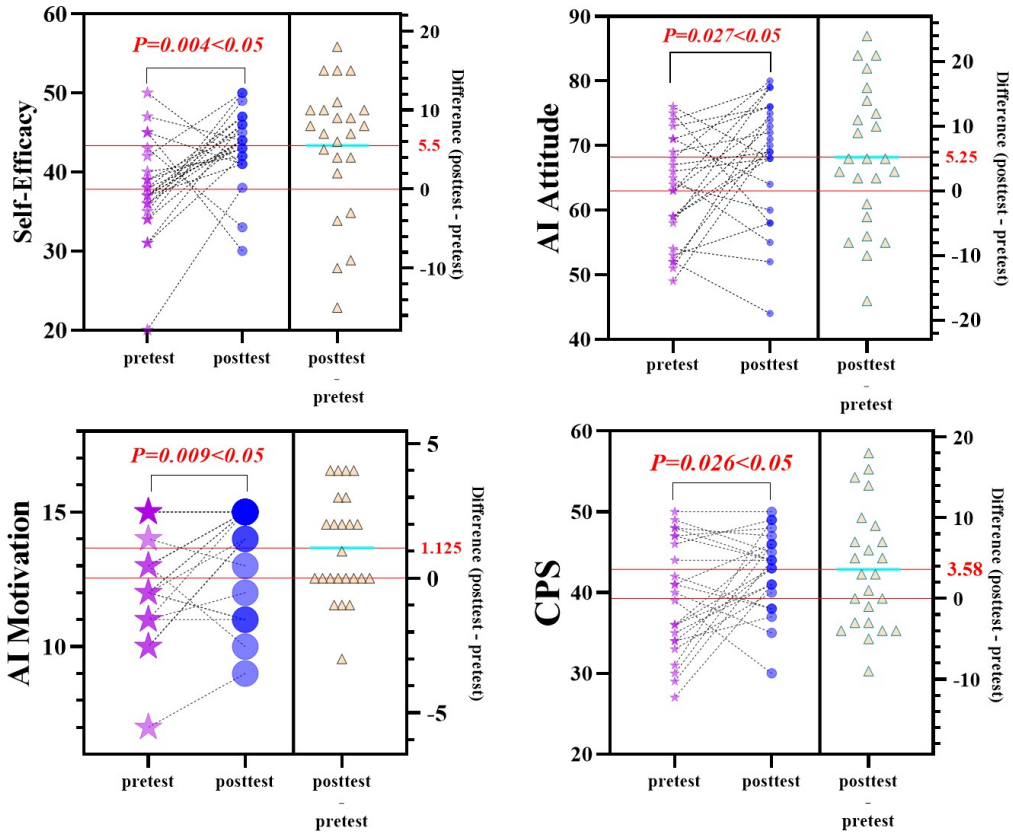


Fig. 3 Effects of intelligent drone Course on pupils' self-efficacy, AI attitude, motivation and CPS (N=24)

The incorporation of intelligent drone technology into STEM education has the potential to enhance students' attitudes towards AI, motivation to learn, self-efficacy, and collaborative problem-solving skills, thereby effectively fostering their interest in STEM education.

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RESEARCH ON THE CONSTRUCTION AND APPLICATION OF STEM INTEGRATED CURRICULUM AROUND BIG IDEAS

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BACKGROUND AND AIMS

STEM curriculum provides a panoramic form of interdisciplinary curricular integration that enables students to think and learn in the wider world, focusing on deeper understanding and broader transfer of applications. (He, 2022)However, the over-rapid development of STEM education has moved STEM curriculum design toward a utilitarian tendency, making it difficult to improve teachers' interdisciplinary understanding. Therefore, designing STEM curricula around big ideas is the best option for practicing this philosophy and facilitating the formation of STEM literacy in learners.

Through an in-depth study of STEM curriculum design around big STEM ideas, this paper aims directly at students' cross-disciplinary synthesizing ability, building bridges of connection among many isolated conceptual monoliths, aiming to provide students with the possibility of understanding the world as a whole, while enhancing teachers' interdisciplinary comprehension.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

Through extensive literature analysis, this study identifies the utilitarian tendency of current STEM curriculum design and proposes recommendations for STEM curriculum design around the Big Idea. It further collected 10 STEM education standards and policy texts from the United States, South Korea, Australia, Ireland, Finland, and China, and conducted cluster analysis to sort out three groups of important concepts that are recurrent and critical in STEM education standards and policy texts. During the research process, we focus on combining theory and practice, guiding practical application through theoretical analysis, and proposing the Twin Towers model of STEM curriculum construction, which provides new perspectives and methods for STEM curriculum research.

RESULTS AND CONCLUSIONS

STEM curriculum around STEM Big Ideas can be constructed according to the Twin Towers model, in which the inverted pyramid points to the screening of STEM Big Ideas (clusters). The core concepts recurring in the various STEM standards documents are first screened to form a core idea bank. Then, experts from the fields of education, psychology, and philosophy screen, integrate, modify, and adjust the concepts to form STEM ideas that are suitable for learning by students in schools and colleges. The orthogonal pyramid points to the design of curriculum and instruction around STEM ideas, with the design process of identifying the ideas, clarifying the sub-ideas, separating the basic issues, linking the STEM contexts and themes, and implementing project-based activities.

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LEARNING TEACHING MATHEMATICS WITH INSTRUCTIONAL TECHNOLOGY: A PRAXEOLOGICAL ANALYSIS OF A GHANAIAN MATHEMATICS TEACHER EDUCATION COURSE

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Abstract

The study used the Anthropological Theory of the Didactic to understand how and what is privileged and for what reasons in a Ghanaian mathematics teacher preparation course that teaches about using instructional technology for teaching mathematics. A mathematics course plan and tasks, video observation and teacher-educator interview were triangulated and analysed using a reference model. The study results show that teaching with instructional technology in transformative ways was privileged. The didactical logos linking the praxis was TPACK. The privileged meta-didactical praxis was the representation of practice with some vague meta-didactical logos discussed. Although the didactical and meta-didactical logos were mentioned in the interview, they were not taken up with the prospective teachers. It is recommended that teacher educators engage prospective teachers in the reasons for what they teach and how they teach it.

Keywords: Instructional technology, anthropological theory of the didactics, mathematics teacher education, didactical praxeology, meta-didactical praxeology

BACKGROUND AND AIMS

In today's increasingly technologically enhanced classrooms, preservice mathematics teachers (PMTs) are expected to possess the requisite professional expertise, pedagogical content knowledge, and technological competencies to facilitate meaningful student learning. However, preparing PMTs for teaching is plagued with ongoing issues of complexity, enactment, and shared language (e.g., Grossman & McDonald, 2008). This raises questions about what is privileged in mathematics teacher education and why. This study draws on the Anthropological Theory of the Didactic (ATD) to examine how and what is privileged and for what reasons in learning teaching mathematics with instructional technology in the context of a Ghanaian teacher preparation course. ATD makes it possible to identify what is privileged as content in educational institutions, embedded within a broader system and culture. The study does so by identifying what is privileged for PMTs to do (didactical praxis) with what reasons (didactical logos), but also how the teacher educator goes about doing this (meta-didactical praxis) and with what motivations (meta-didactical logos) and their relationships.

METHODOLOGY

The study is designed as a single case study grounded in an interpretive paradigm. The study serves as a preliminary analysis for a more extensive study that will include multiple cases. Data collected were a course plan and tasks, video observation, and a semi-structured interview with a mathematics teacher educator. A praxeological analysis was employed,

drawing on a reference model as the analytical framework. A reference model (RM) is a framework researchers use to challenge and address didactical situations in specific institutions (see Wijayanti & Winslow, 2017). In developing the RM (didactical reference model), we made a distinction between pre-didactical praxeologies (planning), didactical praxeologies (implementation) and post-didactical praxeologies (reflection). Using instructional technology in teaching and learning mathematics was classified into transformative and productive use.

Further, we made a distinction according to who would be the agent in using the instructional technology: the teacher or the learner. The study draws on Grossman et al. (2009) pedagogies of the practice of representation, decomposition, and approximation as reference models to analyse the meta-didactical praxis. The didactical and meta-didactical logos component for praxis was determined inductively by looking for justifications for the identified praxis components.

RESULTS AND CONCLUSIONS

The preliminary results show that teaching where instructional technology transformed teaching in substantial ways was privileged as intended learning for the PMTs. The privileged didactical logos linked to the praxis was TPACK. In the discussion, I further address how this form of teaching was modelled for the PMTs. However, PMTs never decomposed the practice nor had opportunities to approximate the practice inside/outside of the school site. The meta-didactical logos was vaguely described in the interview as a means of learning how to teach it. Although the teacher educator mentioned the didactical and meta-didactical logos in an interview, it was not taken up with the PMTs.

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Narrative Engagement in Culturally Sustaining Learning: A Tale of Redesigning the *Forbidden Island* Board Game

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Abstract

This six-month research project engaged teachers and students at a culturally diverse urban Canadian junior high school in redesigning the cooperative board game *Forbidden Island*. The goal was to explore culturally sustaining pedagogy's impact on diverse student populations. Utilizing a tabletop game redesign process, students integrated humanities and science curriculum into their redesigned games while engaging in layers of narrative sharing with teachers and classmates. The study highlighted the significance of narrative in educational game design, suggesting that embedding rich narratives within games and game redesign projects can foster deeper connections and insights, particularly within culturally sustaining pedagogies in the context of interdisciplinary and transdisciplinary learning and STEM education.

Keywords: Culturally sustaining pedagogy, board game design, narrative engagement, interdisciplinary learning, STEM education

BACKGROUND AND AIMS

In a six-month research project, we collaborated with teachers and students at a mid-sized urban Canadian junior high school to redesign the cooperative board game *Forbidden Island.* Our goal was to investigate the impact of culturally sustaining pedagogy on a diverse student population (Paris, 2012, 2019, 2021). Through data analysis including games, artifacts, and video recordings, we discovered unexpected layers of narrative engagement during the redesign process.

METHODOLOGY AND DESIGN

Involving a total of 450 students, we adopted a tabletop game redesign process model (Kim et al., 2024) and consulted with teachers to align the project with their grade 7 curriculum for social studies and science. This interdisciplinary approach opened space for engagement which students made transdisciplinary (Takeuchi, et al., 2020) through their narrative sharing.

Although we appreciated the role narrative might play in development of game backstories, our data revealed that participants engaged in various narratives throughout the project, exploring deeper themes. These narratives helped them understand their relationships with peers, assignment instructions, and the project’s goal of integrating curriculum into their redesigned

games. As students participated in design and testing sessions, they shared personal stories, experiences, and identities, fostering community and exploring meaningful episodes. Even the procedural writing (the 'rules') for their designed games became part of the game's narrative. Narrative sharing and co-creation shaped the learning process.

RESULTS

Narrative exploration (1) provides insight into perspectives and experiences (Goodson, 2013; Goodson and Gill, 2011), (2) allows us to make sense of meaningful moments, (3) considers ethical representation (4) bring order to events, and (5) connects with personal growth (Park, 2005; Richardson & St. Pierre, 2018; Tedlock, 2018).

An illustrative example occurred during a game design discussion among students (Grace, Saabira, and Shaza [pseudonyms]). Grace defended a complex game mechanic involving traversing multiple countries to return home after collecting hidden treasures (see Figure 1). Shaza preferred simpler options like boats or planes.



Figure 1: Grace, Saabira, and Shaza's game illustrating the countries and landmarks players must traverse through to win.

Grace shared a poignant story from a Cameroonian friend, highlighting the significance of walking. Her friend's father and uncle, as migrants, walked through the desert for days to reach a ship and escape to Italy. Tragically, the uncle died and was buried at sea. Grace's narrative shed light on colonization's lingering effects (e.g., warfare, migration, diaspora, climate change), connecting with social studies and STEM themes.

DISCUSSION

While narrative importance in serious games is recognized (Michael & Chen, 2006), many widely used educational games lack a strong narrative context (i.e., narrative and content/rule of the game do not align). *Forbidden Island* stands out—a game with a clear backstory that catalyzes gameplay and fosters inter-player relationships. For researchers exploring culturally sustaining pedagogies, considering our students' narrative capital (Goodson, 2013) in game redesign projects is crucial, especially for those exploring interdisciplinary and transdisciplinary

learning and STEM education. Narrative capital plays a critical role in making educational games more meaningful and engaging for diverse student populations.

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FROM STEM TO STEAM EDUCATION: AN ANALYSIS OF THE ROLE OF THE ARTS

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BACKGROUND AND AIMS

The rapidly changing knowledge and information society of the 21st century is forcing STEM education to shift to STEAM education.And the value of the arts in STEAM education seems to be gradually popularized and recognized. However,in actual STEAM education, educators do not know enough about the educational characteristics and value of the "A" element, the true meaning of STEAM education has not yet been realized. Solving the shortcomings of STEM education and the challenges of STEAM education requires an in-depth analysis of the role of the arts themselves.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

Firstly,through extensive literature review, this paper takes the development of STEAM education to STEM education as the entry point, discusses the development process from STEM education to STEAM education.

Secondly,through an analysis of the origin and development of the concept of STEAM education, we analyzed the content of "A", interpreted the concept of "A", and re-examined the value of "A". It provides the basis for the subsequent exploration from STEM education to STEAM education.

Thirdly,based on the analysis of the concept of STEAM education and the establishment of a framework for analyzing the roles of the arts, we propose a model for integrating the arts in STEAM education, and put forward effective strategies to promote STEAM education.

RESULTS AND CONCLUSIONS

On the one hand, in terms of categorization and understanding of the arts, which can be classified as high arts, humanities, language arts and physical arts.The arts contribute to creativity,and contribute to the development of comprehension, and can help students visualize the content of their learning, helping them to better understand scientific concepts and to explore them,and contribute to the growth of critical thinking as well as to the advancement of learning.On the other hand, effective strategies to promote steam education include the following three points. First, we should emphasize the broad concept of interdisciplinarity to enrich the connotation of the arts;second, the importance of adapting the true integration of the arts in STEAM education lies in the emphasis on arts-based practices; and lastly,we should tap into appropriate educational resources to create an artistic atmosphere.

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BRITISH COLUMBIAN AND BANGLADESHI SECONDARY SCIENCE TEACHERS' VIEWS ON THE ROLE OF PROFESSIONAL LEARNING COMMUNITIES IN THE GROWTH OF THEIR KNOWLEDGE FOR TEACHING

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BACKGROUND AND AIMS

Enhancing teachers' knowledge for teaching (K4T) and implementing evidence-based teaching practices (Milner-Bolotin, 2018) are vital for quality education, requiring continuous professional development. Collaboration in Professional Learning Communities (PLCs) (Senge,1990) fosters effective knowledge sharing and enhances educational practices. Despite over three decades of PLCs and events like the pandemic, gaps remain in understanding PLCs' features and their role in K4T growth (Trust & Whalen, 2021). This study examines secondary science teachers in British Columbia (BC), Canada and Bangladesh (BD) to address these gaps and assess PLCs' impact on K4T growth.

METHODOLOGY

This study employed an explanatory sequential mixed-method design: first surveying 100 participants (50/region) via purposive sampling, second, conducting semi-structured interviews with 10 participants (5/region) through convenience sampling. Data analysis included descriptive statistics (quantitative data) and thematic analysis (qualitative insights).

RESULTS AND CONCLUSIONS

The study revealed varying responses to key PLCs' features in both regions (Figure 1). BD teachers emphasize student focus, shared goals, reflective practices, belonging, resource-sharing, ongoing improvement, open communication, and data-informed decision-making more than their BC counterparts. BC educators place higher value on collaborative problem-solving and mutual respect. The biggest discrepancy is in distributed leadership skills, which are less valued in BC than in BD. Both regions benefit from PLCs through resource sharing, new pedagogies, understanding student needs, technology integration, self-reflection, and staying updated on educational trends for K4T growth. This aligns with literature on PLCs' role in enhancing teacher collaboration, pedagogies, and Pro-D (Ben-David Kolikant, et al, 2020; Vescio et al, 2008). By leveraging the benefits of PLCs, educators can enhance teaching practices, meet diverse learner needs, and embrace modern technology-enhanced pedagogies.

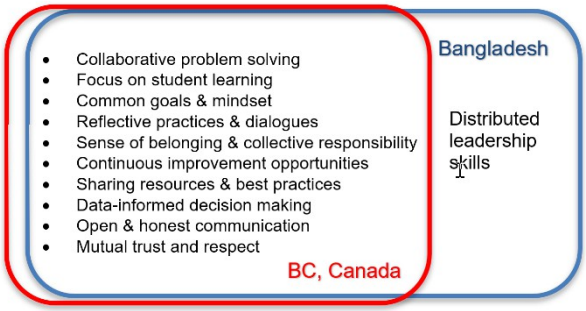


Figure 1: Key PLCs' Features in BC and BD

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JUST PLAYING OR FOUNDATIONAL STEM LEARNING : INTRODUCING STEM PHONICS

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THEME:

STEM education within and across settings (in school, out of school)

BACKGROUND AND AIMS

Children start observing experiencing and learning from birth. The 3 years before preprimary are the foundational basic experiences. The child begins interacting in their immediate surroundings with objects in particular. These STEM-Experiences (E) develop[progressively with practice through problem solving as the child engages developing t an understanding of STEM concepts and effective thinking. Playing is learning . It is children's work (Roth et al.. 2013.) Play moves are STEM in action.. Different play types occur in parallel with STEM-E and STEM which follow the play cycle (Tunnicliffe, 2022).

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

Children aged a few months to preprimary (3 yrs). were observed over 3 years during a weekly (in term time) Toddler Playgroup in S.E. England. Whilst the usual playgroup items were provided , tow low tables of early years toys with a particular STEM focus were provided. - small wooden blocks, stacks with rings oi diminishing thickness to be placed on a central upright rod, stacking beakers, shapes with fit into a holder on a board, a hammer bench of pegs. The actions the child took and the outcome was noted.

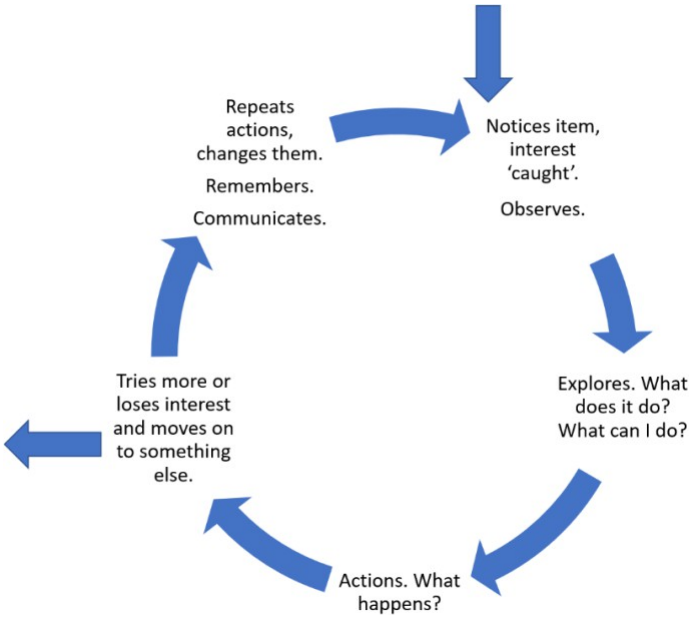


Fig 1 the children had free choice of when and what they played with as they naturally worked through the play cycle (.fig. 1. Tunnicliffe, 2023)). Parents / carers permission enabled photographs of interactions to support field notes of play enabling component action to be identified.

RESULTS AND CONCLUSIONS

Looking at a particular child interacting with a specific toy over a session and subsequent session progression in skill was noticeable as they interacted with that object of interest through the stages of the Play cycle. It was possible to identify small actions as individual components of the child's play, enabling a realization that such interactions are composed of basic units, a ouch, a pull, a lift, a placed precisely. I realized these are the units of a STEM interaction that put together make the resultant outcome. Hence these are equivalent to the phonics used when teaching a child to read, or the basic Maths phonics of learning basic arithmetic, different shapes. Hence these are the science phonics. `We need to compile such to enable practitioners, and parents who are keen on the development of reading to enable practitioners to recognise/ encourage the essential basic Science phonics in action, which also as STEM included basic Maths units such as counting, matching, and engineering, deigning for a purpose, constructing .objects.

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Star storytelling and Astronomy or how to weave Western and Indigenous approaches in Sciences Education

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BACKGROUND AND AIMS

How to infuse Indigenous knowledge and wisdom into science teaching? As educators for future elementary school teachers, we are often faced with this question. In Alberta, teachers have to integrate Indigenous voices in all subjects (Alberta Education, 2023).

In our experience, pre-service teachers are especially uncertain and confused regarding how to integrate Indigenous knowledge in the science and technology teaching practices. These observations corroborate with the literature on the subject (Bartlett et al., 2012; Aikenhead, 2006; Battiste, 2002). This presentation is the result of a collaboration between a professor specialized in intercultural education and a professor specialized in science education, positioning themselves as in solidarity with Indigenous Peoples (Kluttz et al., 2020), in an attempt to decolonize the practices of pre-service teachers at the university level (Gaudry & Lorenz, 2018). In order to bring together Western and Indigenous perspectives into science teaching, and challenge students' epistemic stance on scientific knowledge (Aikenhead, 2006), we have chosen to develop an educational unit on astronomy, in collaboration with an Indigenous Elder.

In the new Alberta science curriculum, Teachers from grades 4 to 6 are expected to teach different astronomical phenomena from a Western perspective as well as with an Indigenous lens. Despite the fact that astronomy has been part of the Canadian Science Education curricula for a few decades, many obstacles to its implementation in class persist. Frède (2017, 2019), Chastenay (2018) mention that the construction of astronomical knowledge in Western countries remains difficult. The lack of material and the abstract nature of the subject as well as the student's cultural perspective are cited as being important hurdles for teachers.

METHODOLOGY

A collaborative practice-led research as guided our methodological approach used in this research project as it provides a foundation to use practice as an integral part of the research design (Candy, 2006). This presentation draws on our journey leading to the creation of a pedagogical unit plan dedicated to teaching astronomy. We will explain our theoretical framework, anchored in a transsystemic approach (Battiste & Henderson, 2021) also referred to as two-eyed seeing (Bartlett *et al.*, 2012).

EXPECTED OUTCOMES

Inspired by the Indigenous ways of learning (Battiste, 2002,), by their holistic and relational dimensions, and inspired by land-based learning (Cajete, 1994; Simpson, 2014; Wildcat et al., 2014) and storytelling (Archibald, 2008), we will report on the challenges we faced in the creation of this unit that aims to teach astronomy from both the Western and Indigenous perspectives. We will explain how we addressed these challenges in order to create an

engaging unit plan for our students, and how it shifted our own practices teaching Science Education.

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"WHY DON'T THEY COUNT THE SPIDERS?" TEACHERS CO-CREATING LESSONS IN TEACHING MATH FOR SOCIAL AND ECOLOGICAL JUSTICE

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BACKGROUND AND AIMS

Facing complex issues including climate-change, geo-political unrest, increasing social divide, and the effects of war and displacement, now more than ever, students need opportunities to explore, critique, and deepen knowledge and understandings to imagine, act, and respond. Increasingly, age-appropriate curriculum materials are available for educators across subject areas and grade levels including the (M)athematics in STEM to address the effects of such social and ecological injustices (e.g., Bartell et al., 2023).

Although these pre-packaged resources provide examples, they lack community context and nuances that teachers value for connecting with their students' lives and interests. Yet, few research-based examples exist of teachers designing mathematics education curriculum to support students in using mathematics to make sense of, imagine, and enact change in the world. We ask: How do teachers design and implement social justice mathematics lessons, and what possibilities and challenges are experienced?

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

Three principles of data feminism (D'Ignazio and Klein, 2020) served as the framework for this collaborative study including examining and challenging power, elevating emotion, and rethinking binaries. Four educators as graduate students and their graduate supervisor drew upon this framework and others including Indigenous Storywork (Archibald, 2008) and ecological perspectives (Greenwood, 2013; Kimmerer, 2013). Over the course of four months educators created, and taught lessons focused on teaching math for social justice [TMfSJ] in their own educational contexts. Lesson topics from K-Gr. 12 involved students in analyzing accessibility by measuring; examining math, consumerism, and the environment; exploring data deficit in terms of what data gets counted; and challenging views and actions of human-supremacy for re-considering what counts as waste.

Data collected included multimedia lessons created by the educators, observations and reflections (field notes), photos and recordings of student engagement, and student feedback. We analyzed the data for similarities and differences in approaches to creating TMfSJ lessons and the challenges experienced.

RESULTS AND CONCLUSION

Our results indicate that teachers can create meaningful curriculum materials for their students to use mathematics to make sense of their worlds. Very young children can engage in issues by examining power: who has it and who doesn't, what gets counted and what

doesn't. For example, after noticing her students were interested in arachnids the Grade 2 teacher designed lessons to explore how arachnids are an integral part of the ecosystem and what is gained/lost in counting/not counting them in world species databases. For youth, social-media TikToks formed appropriate strategies to engage students in using mathematics to challenge dominant economic and ecological practices. One key finding teachers noted was that young children have visceral reactions to unfairness and injustice. And that teachers can channel students' curiosities and emotions into inquiry and action for community good. Another key finding was how mathematics provided the needed background knowledge for students to deepen understandings allowing them to re-imagine issues and move to action. Our study provides examples of teachers co-creating mathematics curriculum with their students, curricula that helps understand and change the world.

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STEM FUTURES DENIED: THE RACIALIZED POLITICS OF EXCLUSION OF NEWCOMER YOUTH OF COLOR IN SCHOOLS AND WORKPLACES

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Abstract

Drawing upon a two-year-long community-engaged project with newcomer youth of color that examined their migration and resettlement experiences in Canada, this paper centers Black and Muslim new immigrant youths' experiences of in/visibility and indignity that in turn are rooted in their experiences of racialized discrimination and othering in-school STEM classrooms, and extends to their temporary, part-time workplaces. Our work makes visible the entanglement of discursive and material conditions under which raced and gendered bodies of Black and Muslim newcomer youth become invisible, hypervisible, and undignified in white-dominant spaces and set them up on a trajectory away from professional futures in STEM disciplines.

Keywords: Racialization, Othering, STEM Education, Workplaces, Schools

BACKGROUND AND AIMS

Our work arises from concerns of disciplinary and systemic marginalization within and beyond STEM classrooms that are disproportionately faced by multilingual, immigrant youth of colour (Kayumova & Sengupta, 2022). Drawing on a two-year-long community-engaged project with newcomer youth of colour, this paper centers Black and Muslim new immigrant youths' experiences of in/visibility and indignity that in turn are rooted in their experiences of racialized discrimination and othering in-school STEM classrooms, and also extends to their temporary, part-time workplaces. In the context of globalized mandates such as "coding for all" (Canada Learning Code, 2018; Obama, 2015; Smith, 2016) and inclusive STEM education (National Academies, 2011) that emphasize access to computing and STEM education for marginalized youth, our work makes visible the entanglement of discursive and material conditions under which raced and gendered bodies of Black and Muslim newcomer youth become invisible, hypervisible, and undignified in white-dominant spaces and set them up on a trajectory away from professional futures in STEM disciplines.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

Our work is grounded in a participatory, community-centered, social design research approach (Bang, 2020; Gutierrez & Jurow, 2016). Over a period of two years, we met with newcomer (refugee) youth of color in weekly co-design workshops in which they co-created culturally responsive narratives of their migration and resettlement experiences (Dutta et al., 2024; Sanyal et al., 2024; Banerjee et al., 2022), and we also visited them in their workplaces. Our data is based on periodic interviews and focus-group conversations with them that highlight their experiences of racialization at the intersection of race, gender, and immigration status both in their classrooms and their workplaces.

RESULTS AND CONCLUSION

We build on critical whiteness theories (Ahmed 2006, 2007; Du Bois, 1935; Puwar, 2004) and racialized emotions (Bonilla-Silva, 2019; Teeger, 2023),and used the constant comparative method (Charmaz, 2014) to identify specific ways in which schools and temporary jobs deny them STEM futures through the following mechanisms: (1)muting and invisibilization of youth in STEM classrooms and workplaces through impositions of hegemonic discourse of English, (2) gendered racialized forms of objectification that genders, sexualizes and criminalizes Black male and female Muslim bodies both in schools and workplaces, and (3) relegating newcomer youth of color to traditionally low-wage, racialized positions in the Canadian labor market. Our work highlights how the politics of racialized exclusion from STEM futures goes beyond the confines of symbolic violence in the classroom (Sengupta et al., 2022) and further needs to be interpreted through the lens of the circulation of these mechanisms of oppression and exclusion in both in-school and out-of- school contexts for Black and Muslim newcomer youth of color.

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STUDENT EXPERIENCES OF MATHEMATICAL INQUIRY THROUGH A 3-ACT-TASK: CHALLENGING THE TEACHER'S ROLE

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BACKGROUND AND AIMS

The 3-Act Task, pioneered by Meyer (2011), has garnered praise from educators for its ability to enhance engagement and collaborative learning (Redmond-Sanogo et al., 2018). The positive reviews of the 3-Act approach have primarily been from the teachers' perspective. We sought to address the question: Do students favor the 3-Act Tasks over conventional methods?

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

A 3-Act Task was created and implemented in two batches of grade 7 students at a Metro Vancouver school for this study. A video clip demonstrated two containers with different dimensions, yet a sheet of paper wrapped around one container exactly covered the other. By pouring liquid into the containers, students observed that although the lateral areas were equal, the volumes differed. In Act 1, students posed the core question: How can the difference in volumes be explained? In Act 2, students received the relevant information to calculate the volumes. After discussing students' answers (Act 3), there was one survey question: Which method of teaching do you prefer: a) Traditional, b) New (3-Act Task), and c) No preference.

RESULTS AND CONCLUSIONS

The students' feedback on the survey question is summarized in Table 1.

Table 1. Summary of Student Preferences for Teaching Methods

Preference	Group 1 students (18)	Group 2 students (21)
Traditional	11	13
3-Act Task	4	3
No Preference	3	5

The majority of students in favor of the traditional method wrote that they found the video interesting. However, they had difficulty with the question of what was needed to solve the problem (Act 2). One student wrote: "I think a mix of both [inquiry and direct instruction] would be the best solution." Another student acknowledged the method's benefits but also expressed concern about the teacher's role, stating: "Through this method it gets your brain to think more but it also defeats the purpose of a teacher because then the student is doing everything."

While the 3-Act task offers a valuable opportunity for engagement, its success requires careful consideration of student preferences and cultural contexts. Additionally, utilizing student engagement is essential to promoting both conceptual understanding and acquiring the procedural skills necessary for mathematical proficiency.

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Applying Complexity Thinking to Exploring Health and Wellness: A Catalyst for Including Health and Physical Education in the Learning Sciences

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Abstract

According to school health promotion proponents, the health and wellness of students and teachers influence academic achievement. The COVID–19 pandemic caused major disruption to K–12 education and compounded existing teacher stress and burnout. This study involved interpretively exploring eight teachers' experiences of health in relation to the pandemic, using a complexity thinking lens. Results from this work include recognizing the complexity of teacher health, teacher burnout as a wicked problem, and applying a trans-systemic approach to better support teachers and students moving forward. This example highlights the potential of including health and physical education within the Learning Sciences as part of a critical, transdisciplinary approach to teaching and learning.

Keywords: complexity thinking, health and physical education, teacher health, wicked problem

BACKGROUND AND AIMS

This work addresses the importance of including the discipline of health and physical education (HPE) in the Learning Sciences as part of a critical, transdisciplinary approach to teaching and learning. According to school health promotion proponents, supporting the health and wellness of teachers and students fosters academic achievement (Canadian Healthy Schools Alliance, 2021). Furthermore, teacher burnout is associated with reduced student achievement and motivation (Madigan & Kim, 2021). This research involved working to understand teachers' experiences of health in relation to the COVID-19 pandemic. The pandemic caused major disruption to K–12 education and resulting stress for teachers, compounding already existing fatigue and burnout. Recognizing teachers as individuals who play a variety of roles (e.g., teacher, parent, partner) fostered a nuanced exploration of teachers' health and how to better support teachers and students moving forward.

METHODOLOGY

An interpretivist philosophical orientation (Creswell, 2003) was used for this work, alongside a complexity thinking theoretical lens that addresses the interconnected nature of and within complex systems (Davis et al., 2015). Eight elementary teachers were recruited from a large school board in western Canada and were engaged in a one-on-one unstructured interview.

Reflexive thematic analysis (Braun & Clarke, 2019) was used to analyze data, which included interview transcripts as well as a researcher journal.

RESULTS AND CONCLUSION

Teachers' health is influenced by complex systems that interact and create circumstances unique to context. Additionally, teachers are suffering and their experiences of health are influenced by the many roles they play, requiring a *trans-systemic* (i.e., multi-system and system-level) approach to care and the use of resources appropriate to respective systems and system-levels. A complexity thinking lens offers an opportunity to understand unique experiences and can be used to address the wicked problem of teacher burnout – to recognize and work to mitigate stressors in interactions within and between systems. Aspects of complexity principles and systems thinking, including emergence, cascading failure, injury, and fitness, are discussed. This thinking can be applied to student health as well. It is important to consider the health and wellness of teachers and students as part of the transdisciplinary approach to fostering teaching and learning. Complexity thinking is one example of how constructs commonly discussed within STEM can be meaningfully applied within HPE to improve education.

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INSIGHTS FROM TALKING CODE ALONGSIDE DATA VISUALIZATIONS OF RACIAL SEGREGATION

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ABSTRACT

This paper renders seeks to render visible, and dis/orient White Innocence (Gotanda, 1994; Gutiérrez, 2005) in computing education by highlighting the role of racialized emotions (Bonilla-Silva, 2019) when immigrant and racially minoritized learners engage with socio-scientific simulations of racial segregation.

Keywords: race, computing education, racialized emotions, ethnocentrism, multi-agent systems

BACKGROUND

Our goal is to make visible the hidden assumptions that underlie computational algorithms of socio-scientific phenomena (Heilweil, 2020; Smith, 2019) through an axiological turn to de-settle Western knowledge systems as the ways of truth-seeking in STEM disciplines (Bang, 2020). Following Sengupta et al. (2022), this research seeks to render visible, and dis/orient White Innocence (Gotanda, 1994; Gutiérrez, 2005) in computing education. White Innocence (Gotanda, 1994; Gutiérrez, 2005) can be understood as the ideological framework of defending and maintaining the innocence of White people that has shaped the legal and constitutional frameworks, as well as public education in North America. Our work highlights the role of racialized emotions (Bonilla-Silva, 2019) in computing education, especially when immigrant and racially minoritized learners engage with socio-scientific simulations of racial segregation.

METHODOLOGY

We invited university students to interact with a computational simulation of ethnocentrism (Figure 1) created in the Netlogo platform and language (Wilensky, 2003; Hostetler et al., 2018) alongside Racial Dot Maps of Canadian cities (https://censusmapper.ca/maps/3675, see Figure 2) in a public walkway in a university in Canada. The racial dot map is a spatialized data visualization of racial segregation in Canadian cities (McPhee, 2022), whereas the ethnocentrism simulation is an instantiation of a generalized algorithm that represents how segregated societies *emerge* over time through individual-level interactions based on Schelling's game theoretical model of imperfect information exchange (Schelling, 1980).

We ask the following research questions:

RQ1) How did participants interpret and critique the underlying algorithm and code of the ethnocentrism simulation in light of their lived experiences of racialization and migration to the Global North?

RQ2) How were their interactions with the simulation and the Racial Dot Map supported by their interactions with the facilitators?

In this paper, we report on five participants who were all post-secondary students of color who migrated to the Global North. During their interactions, we invited them to discuss their lived

experiences, including experiences of migration, that were relevant to the simulation and the Racial Dot Map. Their interactions with the simulation and the map, as well as their conversations with us were video recorded and transcribed. We analyzed the videos and transcripts using the constant comparative method (Charmaz, 2014).

FINDINGS

In our attempts to answer RQ1, we found that participants' racialized emotions (Bonilla-Silva, 2019) shaped their interpretations of the simulation and the Racial Dot Map. Across all participants. In particular, we found that their feelings associated with being racialized immigrants to the Global North shaped their interpretation of the code as well as the emergent patterns of racialized segregation in Canadian cities. Two most prominent examples of such racialized emotions noted in the participants' responses and interactions are their feelings of being excluded and/or invisibilized in a predominantly White Canadian society, and a sense of loss of their language and cultural belongingness. Participants' critique of the race neutrality of Schelling's algorithm were also tied to their racialized emotions, which in turn is tied to RQ2, as we explain next.

In our attempts to answer RQ2, two key themes emerged:

Dignity affirming micro-interactions with facilitators deepened participants' computing experiences: Recognizing and centering participants' affect, and positioning socio-political dimensions of lived experiences of learners of color as central to the critique and refinement of the model can deepen learners' understanding of the code and the model. For example, a few participants noted that that the omission of human memory and feelings, as well as the implicit assumption of agency of all individuals in Scheling's model were dissonant with their experiences of living as racialized immigrants in Canada.

Reflexivity of technical and critical elements deepened participants' engagement the simulation and code: We noticed that participants' engagement with technical elements of the computer code deepened as they engaged in critiques of White Innocence in which the elements of code were entrenched. For participants of colour, this in turn was connected to their own experiences of racialization. Note that this is also related to our finding for RQ1.

CONCLUSION

Our study highlights the importance of centering dignity and affective experiences of immigrant learners of colour in the post-secondary computing education, through recognizing and centering racialized emotions. This is important not only for centring heterogeneity (Sengupta et al., 2021) in computing education, but also for addressing fundamental, ontological critiques of White Innocence and coloniality in computing education that are deeply embedded within algorithms (Sengupta et al., 2022). Finally, while there have been recent calls to orient post-secondary computing education towards social justice (Connolly, 2023), our work further shows how pedagogy in computing education needs to be viewed as inextricably intertwined with fundamental, ontological issues at the heart of algorithms, as well as embodied and affective experiences of learners of colour in the Global North that in turn are tied to colonial and geo-political histories of domination.

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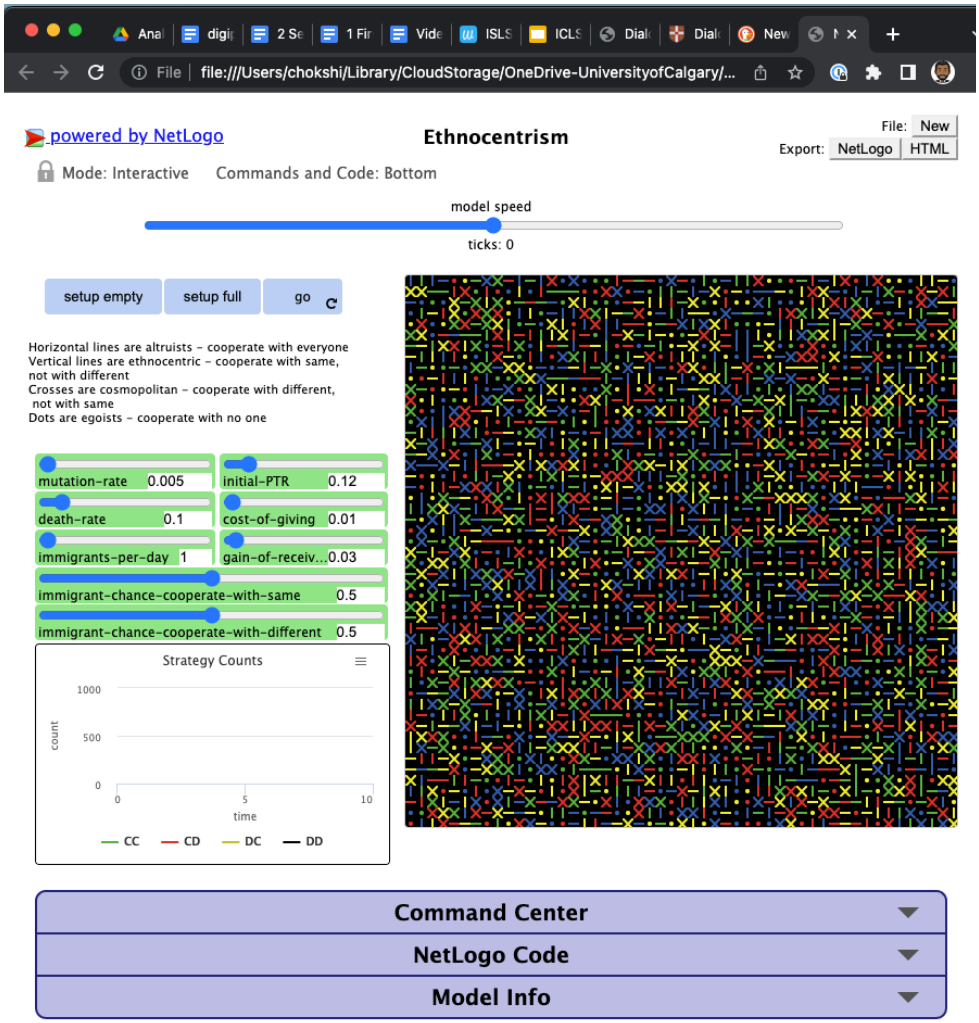


Figure 1: Screenshot of the Netlogo Ethnocentrism simulation used for the study

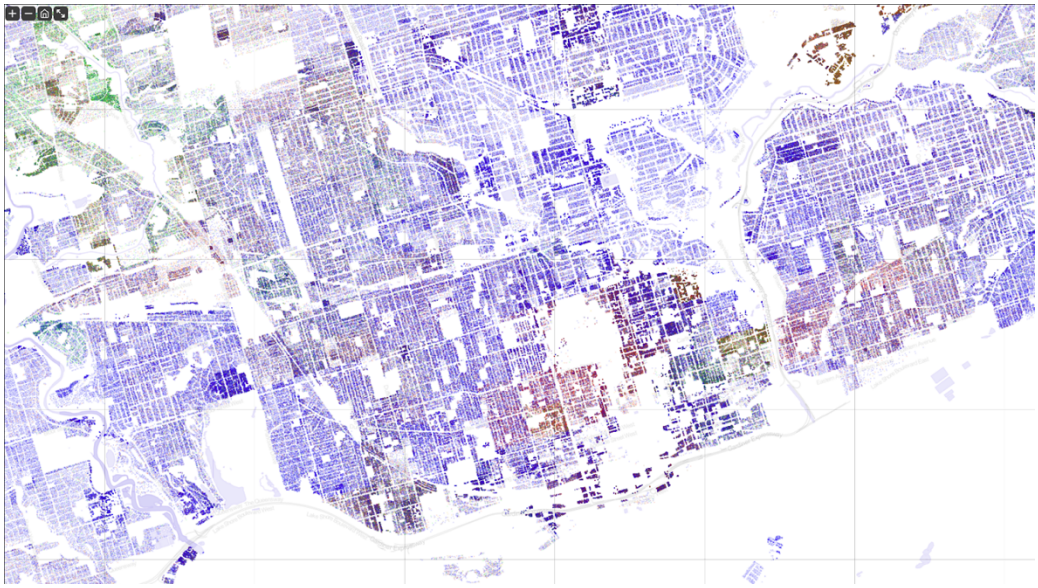


Figure 2: Screenshot of the Racial Dot Map of Toronto used for the study

EXAMINING EFFECTIVE TECHNOLOGY INTEGRATION FOR PROBLEM-BASED LEARNING

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BACKGROUND AND AIMS

Against a rapidly changing landscape of learning technologies, educators are faced with expanding options for engagement, assessment, delivery, and more. The COVID-19 pandemic accelerated development and adoption, furthering hybrid and blended learning within higher education. Many educators seek to increase experiential learning opportunities within their classrooms, working to bridge theoretical knowledge and practical application using techniques such as problem-based learning (Tan & Ng, 2012). While integrating technology, it is important that educators continue with established best practices such as student mindset, motivation, and teacher-directed instruction (Mourshed, et. al, 2017). Though technology may promote experiential learning (Tüchler, 2021; Liberatore, et. al, 2020), it may also introduce challenges including steep learning curves, training requirements, lack of troubleshooting resources, and accessibility hurdles (Hunter, 2015). This study examined integration of a browser-based interactive textbook during active learning sessions within an introductory programming course.

METHODOLOGY UNDERTAKEN

With a yearly cohort of 1000 first-year engineering students, ENDG 233 is a blended format course where syntax and theory are introduced through videos and interactive lectures ahead of active learning studio sessions. An interactive Wiley zyBook has been used since Fall 2021 to supplement student learning. This resource was divided into two separate experiences. The “zyBook textbook” included course notes and detailed practice problems. The other half of the platform, called “zyLabs”, was provided to students through faculty funding. Instructors guided students through weekly formative problem sets that included automated feedback and real-time help for problem-solving and syntax. A survey was conducted in 2021 and 2023 on students’ experience with the zyBook and zyLabs platforms. Results between the two years were consistent and are presented in aggregate (total n = 217, 2021n = 121, 2023n = 96).

RESULTS AND CONCLUSIONS

Overall, students preferred the experiential aspects of live coding with automated feedback, balancing their use of digital tools while interacting directly with an instructor. 94% agreed or strongly agreed that hands-on application helps them learn technical concepts, and 73% said that personal interaction with the instructor is important. Students were more likely to agree that their most effective learning occurred during the active learning sessions (69%) rather than with the online lecture content (38%). Both groups rated the zyLabs and studio sessions as the most useful study tools in the course when compared with the videos, quizzes, zyBook notes, discussion boards, and faculty tutoring supports. 90% agreed that the zyLabs helped support their learning, and that the zyLabs helped them to understand the course content. The

zyBook was a bit more polarizing. Only 58% of survey respondents said they purchased the book and only 51% felt it was a useful purchase. Feedback from this survey will be used to continue refining the course as the experiential components are expanded for 2024.

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DIS/ORIENTING COMPUTING EDUCATION THROUGH CENTRING CAREWORK OF NEWCOMER YOUNG WOMEN SIBLINGS OF COLOR

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Abstract

In this paper, we show how two groups of newcomer young women siblings of color in Canada dis/orient canonical computational simulations and algorithms that are entrenched in white, colonial and masculine ideologies as they center their stories of migration and their lives as racialized and gendered youth in Canada. We conducted co-design workshops with the youth over a period of 10 months. We adopted a grounded theoretical approach and used the constant comparative method (Charmaz, 2014) to identify *ethical-affective design turns* as evident in the epistemic and representational work of the participants. We show how centering the affective, embodied, and relational dimensions of intersectional care between two groups of newcomer siblings of color during their engagement with computational simulations can offer fundamental re-orientations to technocentric theories and design of technoscientific learning spaces that are typically exclusionary to *endarkened bodies* (Philip and Sengupta, 2021; Sengupta et al. 2022).

Keywords: Computing education, care, anti-colonialism, immigrants, technocentrism

BACKGROUND AND AIMS

We present illustrative cases of newcomer immigrant and refugee young girls of color in Canada as they engage in co-design workshops to redesign and reimagine canonical computational simulations that are entrenched in white colonial, imperialist, and masculine ideologies (Sanyal et al., 2024). Participatory research with refugee learners of colour has highlighted the importance of centering play and playfulness (Braden et al., 2023) and cultural contexts (Lee and Worsley, 2019) for supporting disciplinarily rich and personally meaningful learning in makerspaces. In this paper, we show how centering the affective, embodied, and relational dimensions of intersectional care between newcomer siblings of color during their engagement with computational simulations can offer fundamental re-orientations to technocentric theories and design of technoscientific learning spaces that are typically exclusionary to *endarkened bodies* (Philip and Sengupta, 2021; Sengupta et al. 2022).

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

The participants in our study are two groups of sisters. Nezuko and Yasmine are immigrants from a politically disputed region in South Asia. Moon and Dina are refugees from South Asia who have fled religious persecution in their home country also in South Asia. We met the youth once a week over a period of approximately 10 months, with each workshop session being 2-3 hours long. We adopted a grounded theoretical approach and used the constant comparative method (Charmaz, 2014) to identify *ethical-affective design turns* as evident in the epistemic and representational work of the participants. These turns signified significant events, as evident in the conversations and interactions between the participants and the researcher, eventually resulting in representational changes in the code and the simulation interface.

RESULTS AND CONCLUSION

Nezuko and Yasmine primarily engaged with the Lunar Lander simulation hosted on the agent based simulation platform Netlogo (Wilensky, 2005) where the aim is to land a solo spaceship on the surface of the moon while adhering to certain parameters of landing. In their first stage of redesigning the simulation, Nezuko and Yasmine created the “BTS World" based on their favorite Korean pop music band, where they repurposed the code for the existing lander to create two landers which were bringing BTS fans to the BTS world, that was purple in color, for a BTS concert. In the next stage, through a combination of Netlogo code and digital sketching, Nezuko and Yasmine recreated a childhood memory they had of crossing a river valley in their homeland by modeling the flow and movement of the river, their sense- memory of feeling the cold water of the river, and being surrounded by flowers, dandelions, forests and snow-capped mountains.

Moon and Dina worked separately to create two simulations that modeled friendship in their lives. They primarily engaged with the Flocking simulation on Netlogo based on Craig Reynold’s flocking algorithm that was originally developed to model the movement behavior of a large group of birds flying together (Wilensky, 1998). Moon’s redesign of the flocking algorithm modeled the different kinds of friendships she has at different places of importance in her life: the mosque, the school, her home, and the University where she spent time with us. She created algorithms to model repetitive movements in a subset of the agents present to create aesthetically pleasing designs and patterns which reflected the way she interacted with her friends in that location and her feelings for them.

Dina, who is Moon’s elder sister, created a model in the memory of a childhood friend she had lost contact with due to her journey of forced migration. Through the use of agents of different shapes, and using the functionality of links on Netlogo that creates a subset of agents that are connected to each other, Dina modeled the various affective dimensions of losing a dear friend due to her experience of forced migration.

Each of the design turns taken by the youth as they engaged in co-designing simulations that centered their lifeworlds, which we are calling ethical-affective design turns, emphasized their affective and relational histories in various ways: Nezuko and Yasmine engaged in conversations about the direction and the shade of

the flow of the river that they were walking in; Moon carefully decided what kind of designs reflects her feelings about her friends, and Dina explored the functions of links to model her memories of her friend despite of not having physical proximity with her. While Nezuko and Yasmine's design turns offer dis/orientations of the experience of landing from being a futuristic, colonial expedition to recreation of nostalgia in their home country, Moon's and Dina's design turns dis/orient a simulation that has canonically found applicability in modeling movements of drones for militaristic purposes (Olfati-Saber, 2006) towards centering their sense of aesthetics and desires that are founded upon love and care for friends of present and of past. Each of these ethical-affective design turns thus offer crucial dis/orientation to the white colonial and masculine imaginations that underpin the discipline of computing and computational modeling (Ames, 2019; Sengupta et al., 2022).

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MATHEMATICS FOR SUSTAINABLE FUTURE: UNPACKING HIGH SCHOOL TEACHERS' & PRE-SERVICE TEACHERS' EXPERIENCES WITH BIG DATA IN PEDAGOGICAL PRACTICES

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BACKGROUND AND AIMS

Our work is grounded in the critical mathematics education framework, aiming to empower students with the knowledge, skills, and dispositions needed to create democratic communities that embrace social justice (Aslan, Bondy, & Adams, 2011). Critical perspectives in mathematics teaching help identify and analyze critical societal features that may be both global and local. Mathematics problems that combine the mathematical processes of modelling and analysis with judgements and interpretation about contextualized data imply a view of mathematics as a human endeavor (Yaro, Wagner & Amoah, 2020). For this study, big data includes various databases at local or global levels from government or non-profit organizations:

METHODOLOGY

The collaborative project explored innovative ways to teach students the application of mathematical concepts using Big Data resources to address real-world issues related to Sustainable Development Goals (SDG) and social justice. The study involved six high school (Grade 6-9) teachers in Moncton and six secondary pre-service teachers in Edmonton, Canada, who engaged in 12 hours of Teacher Professional Learning (TPL) over 2 days period to create and implement SDP/big-data inspired mathematics tasks in their respective classrooms. This presentation draws on preliminary results from teachers' and pre-service teachers' experiences, gathered through reflective journals and individual/focus group interviews.

RESULTS AND CONCLUSIONS

Findings indicate both possibilities and challenges for creating SDG/big-data inspired math tasks; teachers' initial conceptualization of SDGs evolved during the TPL, seeing SDGs as a context for reimagining interdisciplinary teaching and learning of STEM that foregrounds social justice. Teachers saw TPL as offering safe and collaborative environment to exchange ideas in developing mathematics educational resources that use real data to explore issues related to sustainable development. That's said, teachers' experiences also

show their struggle in creating high cognitive demand tasks that address both the both the curriculum goals and SDGs.

The findings of this study contribute to the literature on critical mathematics education, with special focus on SDG big-data inspired mathematics task design and implementation, that takes into account issues within students' local and global communities.

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Expanding Ethical Horizons in Technological Design: A Systematic Review

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Abstract

This proposal outlines a systematic review aimed at exploring emerging perspectives on ethics in technological design and engineering education, with a focus on the need for a paradigm shift towards socially, politically, and environmentally conscious design practices. It underscores the inadequacy of educational frameworks that emphasize depoliticization and overlook the complex interrelations between technology, society, and the environment. By incorporating both qualitative and quantitative studies, the review seeks to identify key themes through thematic analysis. Preliminary findings suggest three main areas for future exploration: the integration of macro-ethics in engineering education to address broader societal and ecological impacts, the exploration of collective narratives and designers' positions to foster critical and inclusive viewpoints, and the support of learners' systems view of design and engineering practices to enhance ethical and environmental awareness. This research aims to contribute to the development of a more critical and reflective approach to technological design and engineering education.

> *"... and hardly less marvelous has been the capacity of industry to design, and of labor to operate, the machines and methods to do things never done before…What has been done is the greatest achievement of organized science in history."* (Truman after dropping the atomic bomb on Hiroshima, committing an instant mass killing)

PURPOSE

Technological design stands at a crucial juncture, particularly in the context of evolving AI technologies and their social-environmental impacts, including concerns for AI-enabled mass surveillance and weaponization. Design and engineering education has been critiqued for its emphasis on depoliticization and technical/social dualism. Critics advocate a paradigm shift towards socially, politically and environmentally aware practices (Cech, 2014; Steen, 2015). These concerns have been addressed through a macro-ethics perspective in design and engineering education (Leydens & Lucena 2017; Herkert, 2005). While this literature provides profound insights, a systems approach could further include the extended and delayed social, political and environmental effects of technological design (Mashayekhi et al., 2010; Whiteley, 1993). We see design processes as intentional reflective human acts, and design as a field that could reinforce criticality through producing artifacts for human-social-environmental well-being (Bastani et al., 2023; Nathan, 2017; Sengupta et al., 2019). Our review addresses the question:

what are the emerging perspectives on ethics in technological design and engineering education and what do they implicate for curriculum design?

SYSTEMATIC REVIEW

This systematic review includes qualitative and quantitative studies within design and engineering education. We locate studies searching keywords, including “design education”, “engineering education”, “macro-ethics”, and “systems thinking”. Studies are selected using PRISMA principles for screening the papers to meet the inclusion criteria and coding (Page et al, 2021; Steel et. al, 2023). The final review will provide a thematic analysis of the selected studies.

PRILIMINARY FINDINGS

Our on-going review has identified three preliminary research streams, which we propose as key areas for future exploration:

Macro-Ethics in Design Education. This stream criticizes traditional engineering curricula predominantly addressing micro-ethics, e.g., clients’ rights and workplace behaviour. They argue for pedagogies that integrate macro-ethics, concerning the broader societal, environmental, and political impacts of technological design (Herkert et. al, 2020; Son, 2000).

Collective Narratives and Designers’ Position Taking. The interplay between societal dynamics, collective narratives (e.g., nationalism, gender and race discourses) and technological advancements could hinder designers’ critical perspective -- one that considers the broader, long-term social and ecological implications (Gupta et al. 2019). This stream argues for re-politicizing the science/engineering curriculum and delving into ideological values and underlying assumptions to enrich educators’ and students’ ethical and societal understanding of design practices (Gupta et al., 2023; Takeuchi et al, 2020).

Systems Views on Design Practices. This stream uses various systems views. Nathan (2017) argued that design thinking, with its emphasis on human-centered design and empathy, is critical for embedding ethical considerations into technological innovation. An ethics-based systems approach highlights the interplay of defining ethical principles for sustainable practices and developing a systems view for addressing environmental and socio-economic issues through design (Peet & Bossel, 2000). Yoon (2008) also demonstrated complex systems curricula could foster ethical and environmental awareness among engineers and designers.

CONTRIBUTIONS

We aim to uncover barriers towards developing a critical systems perspective of long-term effects of technological design. Our findings contribute to curricula with critical and ethical insights, helping students navigate how technology shapes the current and future human and more-than-human worlds.

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STUDENTS' CONCEPTIONS OF THE DERIVATIVE IN THE AREAS OF MATHEMATICS AND SCIENCE

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Abstract

This research is a result of an investigation into the difficulties students have in learning the derivative concept and working on unveiling several origins that hinder the process of conceptualization. We identified the constraints that prevent them from understanding the concept definition of a derivative at a point and from having adequate concept images of this complex notion. These difficulties have several origins, they are of epistemological origin, they originate from the mathematical objects themselves and from the ways of presenting them in textbooks. In this article, we provide a glimpse into how this concept is introduced in textbook used in the third-year secondary school and how students (17-18 years) articulate their knowledge of mathematics and physical sciences when confronted with it. The most prominent claim around which our study revolves is concerned with the fact that: the interpretation of the derivative as an instantaneous rate of change to the students plays an essential role in strengthening their concept images.

Keywords: derivative concept, mathematics, physics, instantaneous rate of change

BACKGROUND AND AIMS

Indeed, the concept of derivative holds an important place in calculus courses in high school and at the university. Many researches have been conducted to comprehend the cognitive process when learning derivative. Biza & Zachariades (2010) reported students' perspectives about tangent line and classified it into three categories; analytical local perspectives, geometrical global perspectives, intermediate perspectives. The results highlighted students' difficulties to manage covariational thinking about the rate of change and its link to the slope of the tangent as well as the limit notion (for an overview see Bressoud et al., 2016). Indeed, we discovered that the research on the derivative concept remained untapped in Tunisia; this lack of this area of research in the Tunisian context made us decide to take it as our subject of interest. In the Tunisian context, the concept of derivative is introduced as an instantaneous speed for the first time in the third year of secondary school (17-18 years). This concept is introduced by the instantaneous speed which is already known by students in courses of physics. We considered that this introduction does not help Tunisian students understand the derivative at a point (Bouguerra, 2019). Indeed, there is no doubt that this approach is closely related to the subject being taught (i.e. derivative concept) but is there really nothing that prevents students from understanding it through this approach? From this perspective, we wonder whether this approach is sufficient to make a strong conception for the students or not? Do they really properly understand the meaning of the instantaneous speed? Are they really aware of the relationship between the rate of change and the derivative at a point? Do they know that derivative is an instantaneous rate of change? Thought on the epistemological aspects of the derivative concept and the various notions associated with it raises a number of inquiries that must be addressed, including the ways of presenting this concept in textbooks

as well as the students' conceptualizations of the derivative and the notions related to it. Indeed, we wanted to analyse institution choices in introducing derivative at a point and their relationship to students' understanding of derivatives. Therefore, we relied on Praxeology (Chevallard, 1999) and images frame (Tall &Vinner, 1981) to model derivative institutional organisation into several mathematical activities and analyse concept images that students have in regards to the notion of the derivative and some other related terms. By using these frames, we know the different difficulties learners have and the origins of these difficulties occurring when learning this concept.

METHODOLOGY

In this research, the textbook is a vital source of data as we relied on it to conduct the praxeological model. In the first step, we studied the official program's text and the official textbook used in the third-year secondary school. Institutionally, the textbook of mathematics, is the only reliable medium in the teaching/learning process and the Tunisian Ministry of Education offers only one textbook for each grade level. This step plays a significant role because it enables us to work out the praxeological models for each activity related to the derivative notion. Thus, it gives a general idea about the Tunisian learners' probable practices. At a later stage, to gather complement information illustrating the problem, we conducted an interview and a questionnaire highlighting the images about derivative concept of third-year secondary students (17-18 years) in the mathematics section in a Tunisian public school. Believing that the students' difficulties arise when moving from repetitive calculations to functional thinking and that they cannot get rid of the abstract aspect, in which the formal definition is formulated, is the main reason to make us conducting a specific questionnaire to clarify this issue. Its structure is far from numerical and direct applications as we only need to figure out how they have conceptualized the notion of derivative. An interview with 30 students from Pilote School Kairouan and 166 secondary students belonging to different secondary schools filled this questionnaire. The data derived from the questionnaire involves information about how and why a conceptualisation issue may occur.

RESULTS AND CONCLUSIONS

When launching our journey into reviewing the official program text of Mathematics for the third-year secondary school, we found that one of the primary guidelines in the curriculum is for students to grasp that the derivative at a point is the slope of the tangent to the curve. There is also a note stating that the instantaneous velocity notion could be used as an example for introducing the derivative. However, the national textbook that follows this curriculum, starts the derivative chapter with two activities concerning the concepts of speed and instantaneous speed. These activities contain the formal definitions of these notions as previously defined in physics courses: average speed is defined as a distance divided by time, and instantaneous speed is defined as the limit of the average speed. These concepts are treated as straightforward calculations rather than specific instances of the rate of change. Indeed, these first two activities are followed by an activity related to the geometric interpretation of the derivative concept. These three successive activities are followed by the definition of the derivative concept and the equation of the tangent to the curve as a consequence of the differentiability of the function at a point, without any further explanation.

By reviewing the national textbook of physics, we found that the average speed is introduced through the notion of ‘rapidity’ to compare the speed of two movements, by identifying as follows: “the rapidity notion is characterized by a quantity depending on the length of the path traveled and the duration of the path; this quantity is called average speed. Then the average speed of a mobile is equal to the ‘quotient’ of the distance ‘d’ travelled by the mobile by the duration ‘t’ of the journey, $V_{moy} = d/t$”.

It is important to note that the introduction of the derivative in the textbooks does not emphasize a precise or formal definition of the rate of change; only its algebraic expression is used to talk about derivative notion. It is worth mentioning here that the formal definition of

the rate of change is not consistently included in high school textbooks (both mathematics and physics) across grade levels. Only the algebraic expression of this concept is indicated whenever it must be used without presenting it as an independent concept. For instance, in the chapter on the derivative of a function, one exercise touches upon the notions of production rate and instantaneous rate of production, giving their definitions to calculate them and determine the behavior of the function. Thus, the rate of change notion loses its meaning and this would hinder students to visualize all aspects of the concept of the derivative.

Then, we extracted all the type of tasks, which are in work in the curriculum (table 1). The praxeological analysis proves that mathematical activities related to the derivative in the Tunisian curriculum mostly entail algebraic and algorithmic activities, rule applications, or well-known techniques. As a result, the research demonstrates that the institution's purpose is to assist students in learning algebraic abilities with the derivative concept. Students should learn techniques, algorithms, and procedures for solving tasks, thus achieving the objectives of the curriculum.

Type of task T1	Calculate the derivative of a given function f in a given point 'a'
Type of task T2	Determine the equation of the tangent line to a function in a point 'a'
Type of task T3	Calculate the limit of the function f at a point a, by using the derivative at a point 'a' of a function that we have to determine.
Type of task T4	Draw the tangent.
Type of task T5	Determine the points on a curve where the tangent T is parallel to another line noted.
Type of task T6	Deduce that the tangent line T to the curve of function 'f' and the tangent T' to the curve of function 'g' are perpendicular lines.
Type of task T7	Demonstrate that the tangent T to the curve C and the tangent T' to the curve C', at the point x=a, are parallel.
Type of task T8	Demonstrate that the tangents to the curve C respectively at the points A and B are parallel.
Type of task T9	Demonstrate that C is above T (or C is in below T).
Type of task T10	Estimate the value of a function

Table 1: The type of tasks about derivative

Obviously, the lack of familiarity with the notion of the rate of change in physics and mathematics courses would be the gap and the constraint that prevents students from understanding the derivative concept. The instantaneous speed is considered a direct application of the derivative concept, both of which are defined abstractly.

A pressing question lies at the heart of this part: what follows from these institution choices? Is the way of presenting the notion of the derivative in the textbook a reason for the cognitive problem that students have? Recognizing the significance of the initial introduction of new knowledge and the substantial impact of textbooks on the teaching and learning process, we think that the content of the textbook has a detrimental effect on students' understanding of this concept. We anticipate that students will encounter challenges in integrating knowledge from physical sciences and mathematics. The way of presenting this concept in the textbook would cause learning difficulties for the students of high school. Indeed, the textbook cannot be sufficient for assessment and we cannot anticipate everything about learners' understanding and what is related to their conceptualization. For this reason, we activate the frame of concept image and concept definition to know how they conceptualize this concept and answer the networking question.

So to gather complement information illustrating the problem, we conducted an interview (with 30 students from Pilote School Kairouan) and a questionnaire highlighting students' images (the questionnaire was completed by 166 students of the third year of secondary school

from various secondary schools) about derivative notion. The structure of questionnaire is far from numerical and direct applications as we only need to figure out how they have conceptualized the notion of derivative and we need to focus on the functional thinking of students about it.

In the first question, we tried to put the student in the general frame with a theoretical question as we asked for the formal definition of the derivative at a point 'a'. The majority of participants knew the formal definition and only a small minority did not answer this question. 76% provided us with the formal definition (which involved the symbolic representation). 8% of participants gave us the formal definition to which they added the graphical representation of this concept. The reliance on graphical representation as a definition accounted for 12% of answers. The result suggests that the formal definition of this concept is known and the participants relied on graphical representation as a definition of the concept.

Then, we asked them about what comes to their mind when they hear the word derivative at a point. We found that many respondents provided more than one answer whereas others provided no response. The following table (Table 2) shows the responses of some students, which were different and had many significations. The respondents mentioned many things in their answers: slope, formula, max/min, the monotonicity, the differential equation, linear approximation, translation (i.e. they translated the word 'derivative'), and specific courses in which they applied this concept.

	A
1	Signification_of_derivative
2	slope+monotonicity of functions+max/min+instantaneous speed+approx
3	formula+instantaneous speed+acceleration
4	monotonicity of functions + derivative of particular functions
5	slope + formula + monotonicity of functions + tangent + derivative of particular functions
6	slope + max/min
7	monotonicity of functions + tangent
8	slope + monotonicity of functions
9	monotonicity of functions + max/min
10	monotonicity of functions + antiderivative
11	slope + instantaneous speed + monotonicity of functions
12	tangent + slope
13	translation + derivative of particular functions
14	tangent + dpp + speed + accelaration
15	
16	
17	
18	derivative of particular function + formula
19	translation
20	slope + max/min + business evolution
21	formula + tangent + derivative of particular functions
22	tangent + derivative of particular functions + antidenivative + monotonicity of functions
23	slope
24	monotonicity of functions
25	tangent
26	formula
27	instantaneous speed + acceleration
28	
29	dpp
30	monotonicity of functions + tangent
31	slope + derivative of particular functions + monotonicity of functions
32	monotonicity of functions + derivative of particular functions

Table 2 : Some participants' responses

The result reinforces the idea that the concept image is a dynamic entity that develops differentially over students. Each response shows a particular aspect of this concept. Indeed, these responses reflect the institution's choices, and what was taught and learned. It also gives us a general idea about the students' practices and their relation with the derivative.

After that, we tried to gather all the responses of the participants to this question in R to find out what is the most main representation in their concept images (figure 1). The students mentioned five main representations in regards to the notion of the derivative in their answers: the graphical representation, the formal definition, the derivative of particular function, the monotonicity and the extremum of function. More than one-third of the answers showed the slope and tangent as the most main things that come to the students' minds, and the formula was the second. The instantaneous speed and acceleration accounted for 5% of responses. Hence, the graphical representation represents their most main representation of this concept. While the instantaneous speed and the acceleration account for only a very small minority of the answers.

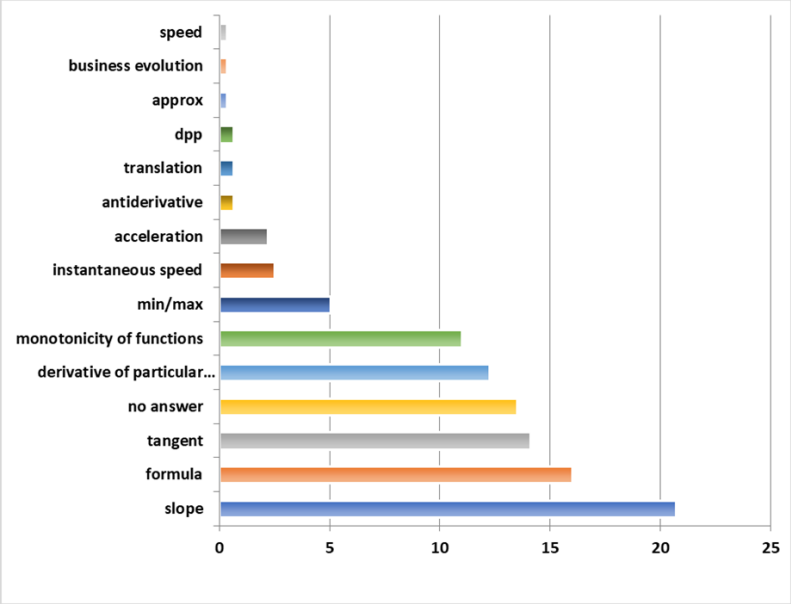


Figure 1: Signification of derivative at a point

The results show that the graphical representation, the formal definition, the derivative of particular function, the monotonicity and the extremum of function are the main representations in regards to the notion of the derivative. Furthermore, it shows that the graphical representation represents their most main representation of this concept. While the instantaneous speed and the acceleration account for only a very small minority of the answers. These outcomes reflect the standpoint of the curriculum that the emphasis should be on understanding the derivative at a point as the slope of the tangent.

Then, we asked them about whether they have something in mind that links the concept of the derivative to any object in real life (figure 2). Forty-seven percent of respondents had no idea about it and fourteen percent said that there is not a link between this notion and real life. While the instantaneous speed and average speed accounted for eighteen percent of responses and we found that both the acceleration and some formula available in the electrical course presented five percent of answers. Only a small minority of participants identified the courses of mechanics and chemistry and other courses as areas in which they applied this concept.

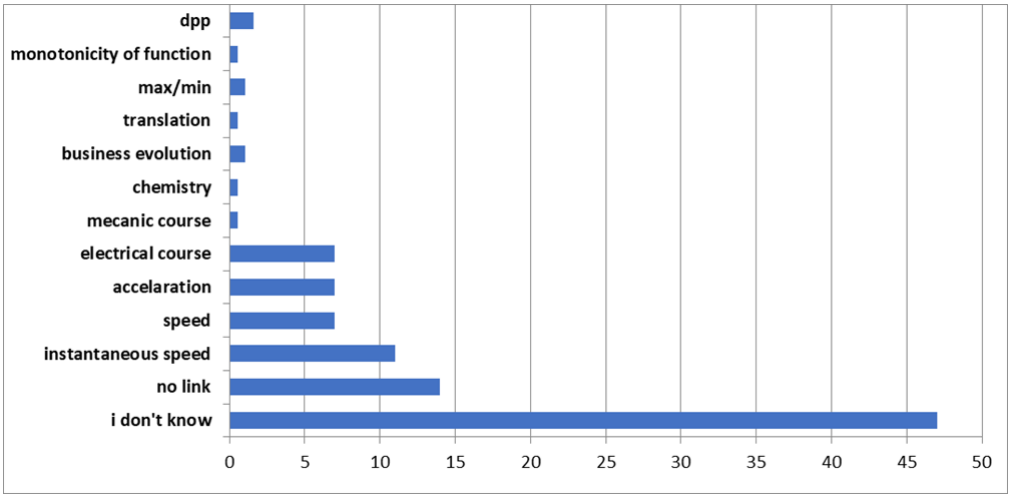


Figure 2: link between derivative and real life

The results suggest that a small minority of participants identify the instantaneous speed and average speed along with identifying the courses of mechanics and chemistry and other courses as areas in which they applied this concept. As for sixteen percent of participant stated that they have no idea and others stated that there is no link between this concept and real life and this result reflects the misunderstanding of students about this concept and their uses of it are limited to mere direct applications.

Following that, we asked students what is the rate of change of a function defined on an interval I, and the results suggest that the majority of students do not know the definition of the rate of change of a function over an interval although they know the definition of the derivative at a point. We discovered that 9% of them believed that the rate of change of a function 'f' between two input values is the difference between two function's output values, so they confused the rate of change of a function 'f' with the amount of change of the function values (the change in the output values).

We followed this question by an exercise containing two interlinked questions on Hooke's Law. This situation is well known by the students, they have already studied it in mechanics courses, and they used it before in mathematics courses. We gave them the force-deformation curve which is a straight line passing through the origin in order to solve the questions and we asked them in the first question to determine the rate of change from the graph of the applied force F as a function of displacement x. Just 9 students recognized that the rate of change had to be interpreted as the slope, using the short specific formula for computing the slope of a proportional function, and they were among those who already knew what rate of change definition. Then we ask a subordinate question about the spring constant k. Only five percent of the participants linked this question with the first question. Eighty-three percent of students responded to this question but they did not connect the two questions and all of them used the particular short formula of computing the slope of proportional function.

These results suggest that the majority of students (ninety-five percent) fail in making a correspondence between the rate of change and the slope. The results insure that the students know that the constant 'k' is the slope of the linear graph and this means that in terms of the law of physics and direct application of slope of proportional function they have no problems but the problem lies in making the correspondence between the rate of change and the slope. This means that they are already familiar with the concept of slope but it is not the case with the concept of rate of change. This result assures that the notion of rate of change is not well-assimilated and the students cannot interpret the rate of change graphically.

By looking at a car's speedometer at any instant, one can know the instantaneous speed of a car, and this idea should be adopted by all the students but the survey found that the majority of students answered by the average speed. The result suggests that the students

Confuse the instantaneous speed with the notion of the speed and not all students have access to the fact that the speedometer is an instrument that measures and displays the instantaneous speed of a car. The results of the question, which is about the connection between the rate of change and the speed, indicated that only one-third of students understand that the speed is a special case of the rate of change interpretation. This misunderstanding is due by and large to the lack of familiarity with the notion of the rate of change. As well as, they get used to define speed as a distance divided by time and they do not get used to define it as a rate of change. Thus, this result also assures that the notion of the rate of change is not well- understood.

The interview also allows us to conclude that students do not have a strong concept image of the concept of the derivative. It shows the fragmented image they have about it. They only can relate it to direct applications on physics or mechanics. This accounts for the fact that the student regards the derivative as a tool they can work within the other discipline. Even when the students were asked what does the speedometer in a car measure, they were reluctant and hesitant between whether the measure was instantaneous velocity or average velocity and they were unable to justify their answers in both cases. In this case, we intervened with an insight about the derivative and the rate of change and asked about what connection they have between each other and how we would use them in relation to velocity. But even with this insight, they remained clueless as, from the beginning, they cannot think of these terms as puzzles of a greater image but think of them as independent terms with no connection between each other; which again accounts for the distorted image they have in their minds about the derivative concept and the terms that relate to it.

Thus, the results assure that the notion of the rate of change, which is closely related to the notion of the derivative is not well-assimilated and well-understood. Not only that, due to this misunderstanding, we can conclude that the notion of the derivative at a point is not well understood either and the students have not a strong concept image about the physical notions which are closely related to the concept of the derivative. This misunderstanding begins with the formal definition of the derivative at a point. They cannot get rid of the abstract aspect in which the formal definition is formulated. Their difficulties in using the rate of change to interpret definition of derivative at a point are the cornerstone issue. The results assure that their uses of it are limited to direct applications only and the difficulties of students are of several origins and that the way of presenting this concept in the textbook is one of the reasons that enabled them to comprehend the meaning of this notion.

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EMBODIED LEARNING THROUGH ART: ENHANCING INTERDISCIPLINARY APPROAHCES IN STEM EDUCATION

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Abstract

This study explores the integration of embodied learning through art into STEM education, aimed at enhancing interdisciplinarity and addressing the pedagogical needs of future complexities. Employing a Design-Based Research approach, we conducted outdoor art workshops to examine how experiential art-based learning fosters critical thinking, problem-solving, and interdisciplinary insights among pre/in-service teachers and university students. Our findings indicate that art production not only boosts creativity and understanding of STEM concepts but also enables participants, to demystify and articulate complex disciplinary, such as engineering, principles creatively. This approach not only broadens the educational perspective but also promotes a more inclusive, equitable access to learning, thereby preparing educators and students for a dynamically evolving educational environment.

Keywords: Embodied Learning, Interdisciplinary Education, STEM Integration, Experiential Learning, Art in Education

BACKGROUND AND AIMS

In this study, we explored the impact of integrating embodied learning through art into STEM education, with a focus on enhancing interdisciplinary approaches and inclusivity. The research was conducted in response to the growing demand for innovative and transformative teaching methodologies (Ahad et al., 2022; Freeman et al., 2017). The primary aim was to investigate how experiential learning facilitated through art could foster critical thinking, problem-solving skills, and an interdisciplinary mindset. Participants, including pre-service and in-service teachers along with university students, engaged in outdoor art workshops where they created kinetic sculptures. These activities were specifically designed to enhance their understanding of STEM concepts through artistic expression, ultimately promoting creativity and offering new perspectives on interdisciplinary education (Grace et al., 2021). This study responds to the need for educational models that promote social equity and deeper understanding across disciplines, thereby contributing significantly to the broader goals of fostering holistic education and social justice.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

This Design-Based Research focused on the iterative design, implementation, and rigorous evaluation of outdoor art workshops (Cohen et al., 2011) designed to integrate artistic processes with STEM education frameworks. Seven participants, including pre-service and in-service teachers, along with university students residing in Toronto, Ontario, actively engaged in creating kinetic sculptures to explore and embody physical and engineering principles. Inspired by the foundational work of Lave & Wenger (1991), our methodology engages participants in innovative educational practices that recognize the value of integrating diverse disciplines. Data collection was comprehensive, using observational techniques,

participant feedback, and reflective journals. This qualitative data was subsequently analyzed using thematic analysis to systematically dissect and understand the influence of artistic activities on STEM learning, thereby establishing a robust pedagogical framework that supports the integration of these disciplines.

RESULTS AND CONCLUSIONS

Our findings suggest that engaging in art production fosters creativity and deepens the understanding of STEM disciplines in diverse educational contexts (Kolb & Kolb, 2005; Powell, 2020). Participants reported a heightened sense of creativity, improved problem- solving skills, and a broader perspective on how STEM can intersect with other fields for transdisciplinary understanding (Adams et al., 2017). A notable example is a master's degree engineering student, Minyoung, who initially struggled to see the relevance of art to his field. He said: "After creating a kinetic sculpture in the workshop, it helped me visualize and articulate ideas about movement and balance in a way I hadn't considered before, bridging my understanding of engineering with creative expression." Through the process of creating a kinetic sculpture, he discovered a way to visualize and explain complex engineering principles related to movement and balance, thus enhancing his discipline- specific knowledge and ability to communicate these concepts to others (Bremmer, 2005; Mayer & Moreno, 2003).

These outcomes demonstrate how integrating embodied learning through art can help deepen participants' comprehension of STEM disciplines and democratize access to these fields, making them more inclusive and engaging for a diverse range of learners (Eisner, 2002).

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Experiences and Challenges of Canadian and American Women Faculty Members in one Striving University in the Heart of Central Asia

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BACKGROUND AND AIMS

This research examines gender-based challenges and experiences of Canadian and American women faculty in a research-intensive university in Kazakhstan. Acker's gendered organizations theory (Acker, 2006) and Eagly's (2002) social role theories were used as the theoretical framework, which highlight consistent gender inequities in organizations and the impact of culture and society on a woman's role in academia. The findings showed that the masculine culture in the university reinforces the institutional structures that marginalize women scientists and academics, limiting their opportunities to contribute to research and knowledge creation in STEM in Kazakhstan.

METHOD

The study implemented a qualitative narrative research design to explore and understand participants' lived experiences in depth (Golsteijn & Wright, 2013). The study used non-probabilistic, purposive sampling for a specific group of information rich people (Suri, 2011; Palinkas et al., 2013; Etikan et al., 2016). Eleven women faculty members were recruited for this research and some of them were among the few foreign founders of the university's policies, gender mainstreaming strategies and curriculum. In alignment with one of the conference's themes "Social justice in STEM education", this study addresses the issue of gender inequities in STEM education, given the context that more than 90 % of leadership positions in STEM disciplines at the participating university were occupied by men.

It was also challenging to recruit women scientists to participate in this research because there is a severe lack of women academics employed in STEM at the participating university. Nevertheless, the recruited participants, few of whom are employed in STEM, helped explore the reasons of this significant gender disparity through the Western lens and provides recommendations for the generation of emerging scholars as well as encouragement and support for the existing community of female scholars in STEM.

FINDINGS

Findings from this study offers insights into the ways to achieve gender equity in STEM disciplines. Furthermore, given that the government of Canada guided by a feminist foreign policy, supports efforts in Kazakhstan to enhance the effectiveness of its policies by making them more inclusive and gender-responsive, (Government of Canada, 2020), my research can potentially inform such policy-level engagement by illustrating specific mechanisms of othering and gender-based discrimination, as well as acts of resistance by women. Future work along these lines can support solidarity between scholars from the Global North and Global South and can facilitate a deeper understanding through transnational perspectives on centering women and gender minorities in STEM disciplines.

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STEM Inclusiveness In Action: Embrace Vulnerable Children Towards Achieving Sustainable Development Goal-4 In Nigeria

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BACKGROUND AND AIMS

The attainment of Sustainable Development Goal 4 "Ensuring inclusive and equitable quality education and promote lifelong learning opportunities for all" as stated in Sustainable Development Agenda by the year 2030 is hinged on an inclusive education with regards to Science, Technology, Engineering, Mathematics (STEM). STEM is the bedrock of qualitative education at early years (FRN 2012). According to United Nations Convention on the Rights of the Child (UNCRC,1989) which includes right of children to education (Articles 29) without discrimination based on disability makes it mandatory for children of all categories to be exposed to basic concepts of STEM, especially with respect to vulnerable children. Vulnerable children are at a disadvantage, with their rights being violated and denied, hence adoption of strategies to break barriers hindering their access to education. (CRIN, 2018).This paper presents some steps taken in imparting the principles of STEM to these children, highlighting the roles of a Non-Governmental Organization in presenting STEM as fun.

METHODOLOGY

Theoretical Framework used involves a non-formal, community-linked, and integrated approaches to teaching and learning (Ogunlade and Odewale, 2023) and STEM Play Cycle (Tunnicliffe, 2021) for the vulnerable children (11 months to 5 years) housed at MOSADOLUWA Childcare Home at a rural-urban setting of Ado-Ekit, Nigeria. This includes science songs, poems, plays and interactive sessions with the children and their handlers.

RESULTS AND CONCLUSIONS

The results showed that the children responded positively to some of the STEM concepts such as motion, counting, building blocks and identifying shapes. Observatory skills and art of team spirit, inquisitiveness, reading, and numeracy are acquired.

It is hoped that utilization of these non-conventional, innovative methods and out-of-school activities will go a long way in disseminating knowledge, develop other needed skills and foster the frontiers of STEM education especially among the children of different categories at early years.

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Contextual Science Learning And Student Motivation: The Case Of Grade 11 Girls In A Kenyan Secondary School

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Abstract

Student motivation is essential for engagement in meaningful learning, particularly when it involves connection to their local context/environment. In this way, science and STEM (Science, Technology, Engineering and Mathematics) based subjects benefit from continued student interest, engagement and motivation. Meaningful learning can thus be about grounding understanding in daily life experiences. Thus, the more students continue with STEM based subjects, the more promising that there is a future of STEM based workforce. Informed by Hull's (1995) contextual learning theory, the study employed an investigative case study approach where Form three (Grade 11) students from a mixed day secondary school, experienced contextual science learning that involved a full day interaction with *Jua Kali*[1] artisans at a local *Jua Kali* shade/workshop. While in the workshop, the students interacted freely with the artisans and asked questions related to production activities and products. Back in school, groups were interviewed as a way to discern their understanding of the science imbedded in the Jua Kali production activities and products. The girls, who often are minority in the STEM field and often drop out from science classes at this stage in education, were able to participate in discussions even with teachers for the first time. They freely discussed any activities or production related to cooking e.g. cooking ovens/charcoal stoves. Thus, for the first time, the mixed day secondary school saw the girls' performance in KCSE improve. In two subsequent years, a total of 41 and 36 female students sat for the Kenya Certificate of Secondary Education (KCSE) in the years Y1 and Y2 respectively. The mean scores for science subjects were Mathematics (4.1±1.9), Physics (4.0±0.8), Chemistry (4.4±0.3) and Biology (4.4±1.4) in Y1. In Y2, the mean scores were Mathematics (5.0±2.5), Physics (6.0±0.4), Chemistry (5.2±0.3) and Biology (5.8±1.8). The difference in performance of the girls in KCSE between Y1 and Y2 was statistically significant (all $p<0.05$). The outcomes of this study point to the need to change and employ teaching strategies that involve students' local environment and cultural practices as these do enhance motivation and positive attitude towards learning of STEM subjects.

Keywords; Jua Kali, contextual, curricula, Positive attitude, motivation

INTRODUCTION

In Kenya, student performance in STEM subjects is still low compared to Arts oriented disciplines. The poor performance has affected not only the Girl child's interest in these disciplines but also the number of girls that take STEM-oriented programs at tertiary levels (Mbirianjau, Chege & Oanda, 2019). Several mitigating measures have been enacted although the situation has not changed much (Onsongo, 2006; Hooker, 2017). This paper reports on an aspect that involved removing students from classrooms and having them investigate scientific phenomena imbedded in the local *Jua Kali.* In this study we report on the case of Girls' participation in STEM education in a grade 11 Kenyan secondary school and how they engaged in the science learning discourse in a local Jua Kali. Students understand science concepts better when these are explained with connections to their local context. Our previous research (Nashon et al. 2021) has indicated that girls get motivated and engaged whenever science learning and teaching activities are linked to events in their local context and especially activities that connect their daily home chores to the imbedded science concepts. While girls tend to outperform boys in reading skills in most regions, they continue to be under-represented amongst top performers in STEM subjects. Thus women continue to be under-represented in the STEM workforce, a phenomenon deeply rooted in unequal gender norms that falsely portray girls as not capable of succeeding in subjects that involve problem solving minds (Mbirianjau, Chege & Oanda. 2019). Girls deserve to access an education that prepares them for the jobs of the future and to be ready and equipped to participate in the Fourth Industrial Revolution. There is therefore need to reimagine an education system where gender-responsive STEM learning happens in every classroom. Girls need an education that goes beyond literacy and numeracy that equips them with the tools to equally and actively participate in solving the complex challenges our world faces (UNESCO, 2016). With technological change accelerating and economies rapidly changing to face the effects of the recent COVID-19 global pandemic, failure to invest in girls' STEM education, and to empower them to participate in the digital revolution, will not only undermine the economic potential of half the population, but also exclude girls and women from world-class digital learning solutions and a whole range of new occupations that require STEM-related skills.

STATEMENT OF THE PROBLEM

Kenya, like other African countries, is currently facing poverty, unemployment, poor infrastructure, destruction of the environment and many health issues (GoK 2005b; ILO, 2006) To combat these challenges Kenya needs its own experts including engineers and biotechnology specialists as well as properly educated public in science and technology. Kenyan schools are struggling to get basic science teaching equipment and text books when there is an overwhelming opportunity to teach hands on science using contextualized science learning and student motivation through exposure to local jua kali artisans. The problem is further aggravated by the abysmal quality of teaching noticeable in foundational subjects such as Mathematics, where teaching in Kenyan schools is more abstract than functional (Asiago, et al; 2018). The underrepresentation of women in STEM fields raises two significant concerns:
(a) women's lack of participation in highly influential and well-paid careers threatens to perpetuate and exacerbate existing socioeconomic disparities for women; (b) women will have little say when it comes to inventing the technologies of the future and determining how the world will be shaped by technology. There is a need to enhance equitable, access and performance of the girl child to STEM education in order for Kenya to realize sustainable development. Attempts to address this need have encountered challenges including female learners staying away from STEM subjects and even dropping out altogether (Wajngurt & Sloan, 2019). As has been demonstrated in case studies elsewhere (e.g., Nashon & Anderson, 2013; Nashon & Madera, 2013; Nashon et.al., 2021) contextualizing teaching and learning consistent with Hull's (1993) theory of learning discussed later in this paper, can be an enabling approach to achieving girl child participation and success in STEM education in Kenya.

AIM OF THE STUDY

The main aim of this study was to investigate the impact of contextualized science learning and teaching on student motivation, engagement and performance.

This was guided by the following research questions:

a) To what extent do students connect classroom learning of science to events in a Jua Kali context?
b) How does this way of learning science affect their performance in science?

THEORETICAL FRAMEWORK

Our research is grounded in Hull's contextual learning theory which says that learning occurs only when students process new information or knowledge in such a way that it makes sense in their frame of reference (Hull, 1995, p.23). According to Hull, "learning and teaching assumes that the mind naturally seeks meaning in context and does so by searching for relationships that make sense and appear useful" (Hull, 1995, p.24). This approach is premised on the fact that the brain searches for the meaning of specific relationships with our surroundings (Johnson, 2002). Based on these Contextual Learning (CL) activities not only can be done in the classroom, but also in laboratories, and in the future in the workplace (jua kali). Educators have to be smart to design learning environments that can be easily related to real life. In this type of environment students can find connection between not realistic ideas and everyday submissions in real world context.

METHODOLOGY

Research Approach and design

This is a case study (Stake, 1995; Merriam, 1998) that employed both qualitative and quantitative data collection methods that included Likert scale questionnaires, interviews and non-participant observation of student engagement with Jua kali artisans as they asked questions on their products, production activities and processes in general (Bryman, 2006; Bryman, 2016; Creswell et al., 2011). Nonparticipant observation was necessitated by the need to be immersed in the activities of the group being studied (Kumekpor, 2002). Prior to data collection, preliminary field visits were made to all the schools. The aim was to have firsthand information on certain key issues relevant to the study through unofficial interactions with the heads of science and math department and all the science teachers in school including those teaching senior classes.

Context of the study

The study involved form three (grade 11) students from one multi ethnic mixed secondary school in western Kenya. Form 3 is the secondary school class (grade 11), when students select subjects to study for the Kenya Certificate of Secondary Education (KCSE) examinations taken at the end of Form 4 (grade 12). Therefore, it was hoped that better understanding of contextualized science, would motivate them to study it in Form 4 (last class in high school). It was also clear to them that decisions about their proceeding to University/College in Kenya or end up in the Jua Kali centers were based on their performance in KCSE examinations. Typically, schools in Kenya are highly exam centered and teaching strategies that contextualize science learning are not valued. Thus, offering to expose the students to a contextualized science local setting (Jua Kali) was excellent fodder for understanding and motivating students towards science learning.

ANALYSIS AND FINDINGS

The data were analyzed using both quantitative and qualitative methods and revealed that:

1) Lesson development that connected science concepts to activities in the local context motivated and improved girl child's participation and performance in contextualized learning activities. This is exemplified from the interview discussions from the students as below:

   - Student 2: "I can see the connection between jua kali and the forest when they improve the jikos so that they can use little charcoal from the forest. So in a way they are helping in the conservation of the forest".

   - Student 1: "Yes, like in agriculture I have learnt about spacing for plants and also management of trees in the nursery beds and also geometry in mathematics, trigonometry and matrices. As they said you can calculate the number of trees using matrices and angles".

   - Student 4: "When they design boxes they used a topic in math called trigonometry they measure at an angle and in physics a topic called the measurements/ Also painting of those boxes there is a topic in chemistry on preventing rusting maybe coating galvanization, electroplating".

2) Familiarity with the materials and tools used in planning and implementing contextualized learning activities evoked the girl child's enthusiasm and courage to exchange knowledge and to ask more focused questions:

   - Student 2: "On my side, why are you interested so much on this side of environment that is the juakali and the forest?"

   - Student 1: "In the juakali I think it's the best because it requires application of most of the learning in class like mounding circular objects. So a lot of knowledge to mathematics they are approximating most of their measurements that we are being taught in class so I believe jua kali is the best for learning experience"

   - Student 5: Seeing scientific concepts in action (juakali) reinforced what I learnt in classroom bridging the gap between theoretical knowledge and practical application".

Literature showed that science learning carried out in a contextualized environment, highly motivates students (Zemelman et al 1998). Students will learn from what they do, and from their experience (Schelecty, 1997).

In this study, a total of 41 and 36 female students sat for the Kenya Certificate of Secondary Education in the years 2012 and 2013 respectively. The mean scores for science subjects were Mathematics (4.1±1.9), Physics (4.0±0.8), Chemistry (4.4±0.3) and Biology (4.4±1.4) in year before the contextual learning experience or year Y1. In year Y2, after the contextual learning experience, the mean scores were Mathematics (5.0±2.5), Physics (6.0±0.4), Chemistry (5.2±0.3) and Biology (5.8±1.8) as in figure 1

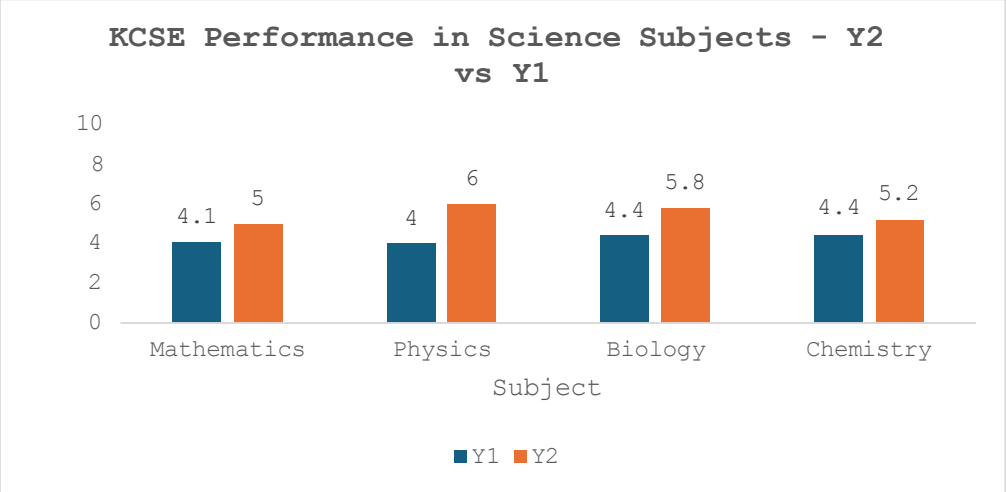


Figure 1:Mean performance in science subjects between Y1 and Y2

The difference in performance between Y1 and Y2 was statistically significant (all $p<0.05$) as indicated in table 1.

Subject	Y1	Y2	t-value	p-value
Physics	4.0±0.8	6.0±0.9	3.266	0.016
Chemistry	4.4±0.3	5.2±0.3	1.924	0.029
Biology	4.4±1.4	5.8±1.8	3.84	0.001
Mathematics	4.1±1.9	5.0±2.5	1.76	0.041

Table 1:Mean performance in science subjects between Y1 and Y2

CONCLUSIONS

Girls who are more confident in their abilities to engage in math and science curriculum are more likely to pursue challenging courses in math and science in high school. Teachers should avoid any negative stereotypes when working with female students in math and science.

Instead, they should encourage them to enter science fairs, join math competitions or robotic teams, and choose activities that spark inquiry learning and interest in math and science. In addition, teachers can engage female students in STEM experiences that are transformative, such as hands-on science activities, exploratory trips and field experiences, and positive interactions with female role models. There is continued need to reduce the gender gap in STEM education, and to put in place STEM interventions to demystify STEM and ignite interest in girls. Also, there is the need to adopt a storytelling approach to elicit interest in the girl-child participation in STEM-related courses. Scholarships should target girls to pursue STEM programs, including online education and nano courses (short courses) to increase accessibility of young women to STEM related courses training of teachers on gender-sensitive instruction and how to engage girls in STEM. The studies' findings point to the need for Educators to do more to encourage girls to enroll in STEM classes so that they can build their self-confidence in STEM subjects and develop a love for advanced technology, math, and engineering skills.

IMPLICATIONS

In terms of theory, this study's findings exemplify Hull's contextual learning theory. It validates this theory in its demonstration that the students were more engaged including those who would ordinarily not participate in classroom science learning. In terms of practice, the study demonstrated that learning is genuinely active when it takes place in students' local contexts. From a research perspective, the study recommended more creative and innovative teacher training programs that help teachers to focus on contextual and gender-related related learning activities that enable more robust girl child participation in science learning to result in better performance in STEM education. Also, the study demonstrated the need to carry out similar studies in different contexts to determine whether student motivation can be improved through this method.

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INTEGRATING ICT INTO STEM EDUCATION IN CHINA: THE ROLE OF STEM TEACHERS' ICT COMPETENCY

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BACKGROUND AND AIMS

Information and Communication Technology (ICT) is an important component of STEM education and an essential teaching method in STEM education (Bybee, 2013). Existing literature proved that STEM teachers' ICT competency is the key to promoting the deep integration of ICT in STEM education (Tunc & Bagceci, 2021). The stakeholders in China attach great importance to the implementation and development of ICT in STEM education as it provides a new direction for teaching and sets higher requirements for STEM teachers' ICT competency (Dong et al., 2020). Therefore, it is necessary to investigate and study the current situation and level of STEM teachers' ICT competency in China to provide a basis for further training and development.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

The Technological Pedagogical Content Knowledge (TPACK) framework is commonly used to evaluate teachers' ICT competency as it can reflect better in the knowledge/ability dimension (Mishra & Koehler, 2006). Therefore, this study mainly adopts a quantitative research method based on the TPACK framework to investigate and research the level of STEM teachers' ICT competency in China. The questionnaire scores on the overall situation of STEM teachers' ICT competency through a 5-point Likert scale and then analyzes the specifics of STEM teachers' ICT competency in the TPACK dimensions.

RESULTS AND CONCLUSIONS

Preliminary analysis based on the data from the pre-survey found that the overall scores of Chinese STEM teachers' ICT competency is at a relatively good level. However, there are apparent differences in the TPACK dimensions. A follow-up survey with a larger sample will be conducted to obtain more comprehensive data and supplement and correct the preliminary survey results. The research results hope to provide innovative and practical suggestions for the targeted cultivation and enhancement of STEM teachers' ICT competency.

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Game (Re)Design, Fictional Worlds, and Exploring STEM Across Disciplines in Formal and Informal Learning Spaces.

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BACKGROUND AND AIMS

Analog game redesign and its ability to engage a variety of learners in STEM has been demonstrated by multiple research projects (*Bastani & Kim, 2022).* One aspect that has not been highlighted is impact of the transmedia nature of games. Analog games are amalgamations of their physical realities, texts, player experiences and expectations (Kamm, 2020). The ease of changing any or all aspects gives these games the representational fluidity that is leveraged in transmedia storytelling (Wolf 2012; Schier et al., 2018). This fluidity allows learners redesigning games to apply STEM and Humanities lessons to the world-building of fictional spaces. This has a particular benefit for engaging those learners who already participate in existing fictional worlds.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

This paper is based on data collected between 2020 and 2023 over two different board game redesign studies. The data set includes video interviews with participants, video of participants engaged in redesign, transcripts, the games, and their rules. The first study was focused on game redesign as a tool for culturally sustaining pedagogy in informal learning environments. It was conducted with several intergenerational families, of different cultural backgrounds, redesigning games in their own homes (Bastani, et al., 2023). The second study was designed to investigate the utility of game redesign to support culturally sustaining pedagogy in a formal learning environment (Kim et al., 2024). It involved the teachers and grade seven students at a Western Canadian junior high school utilizing a single game redesign group project for both Humanities and STEM throughout the year. While reviewing the data we found several instances of study participants intentionally engaging in transmedia worldbuilding with their game redesigns.

RESULTS AND CONCLUSIONS

Playing and modding games allow one to share, explore, and expand on fictional worlds (Grouling, 2021). We observed this taking place as learners created secondary fictional worlds modeled on the real world as part of their game redesign. The modeling was particularly explicit when realism needed to support the willing suspension of disbelief. This practice of reconciling the mundane-world with their fictional-world required participants to look to physical sciences for laws and rules and the humanities to express them through narrative and aesthetic representation (Wolf).

In the formal space, one participant redesigned *Forbidden Island* by drawing from the *How to Train Your Dragon* fictional world. They created fictional ecologies that followed more

normal biological systems, reflecting the student's STEM knowledge. In the informal learning setting, a participant created a game that let players experience the world of the *Warriors* book series by redesigning the card game *Love Letter* by leveraging their Humanities learnings in composition and reading comprehension. Throughout the studies when participants brought fictional world building into their game redesign, they showed high levels of engagement and commitment to the project. Their passion for engaging with a fictional world motivated their engagement with real world STEM and Humanities content.

This suggests that for learners the representational fluidity of analog games presents an opportunity to use game redesign to increase the depth and breadth of their engagement with STEM and Humanities course content by giving it additional meaning and application.

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Effectiveness of mixed reality in stem education: A meta-analysis

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BACKGROUND AND AIMS

With the advancements and innovations in digital technology, mixed reality (MR) has increasingly penetrated into the Science, Technology, Engineering, Arts, and Math (STEM/STEAM) education field. In this study, STEM refers to learning within a single STEM discipline and the integration between two or more disciplines. Mediated Reality, proposed by Professor Steve Mann from the University of Toronto, and mixed reality are collectively referred to as MR. This study adopts the definition provided by Paul Milgram and Fumio Kishino in 1994: A fully real world and a fully virtual visualization environment are situated at the extreme left and right ends, and the realm in between these two extremes constitutes mixed reality (Milgram & Kishino, 1994). MR is a combination of both augmented reality (AR) and virtual reality (VR).

Mastering STEM skills is crucial for students' future development (Togou et al., 2020). Students' experience with STEM learning influences whether they will continue to choose to learn STEM. The creative use of technology in education can stimulate students' interest in learning, as learners prefer interesting and technology-oriented education. MR expands the way humans interact with the digital world, providing users with an infinite and interactive virtual experience. These technologies can fundamentally improve the way students experience STEM content (Onime, 2021).

On one hand, MR can significantly improve students' understanding of STEM concepts and academic performance. Studies have shown that combining physical and virtual laboratories can help students learn scientific concepts (Birt & Cowling, 2017; Wan et al., 2023). Researchers introduced Mursion into primary school mathematics classrooms, allowing students to create virtual classrooms and play virtual roles. After the course, students' understanding of scientific knowledge has significantly improved (Dahn et al., 2021; Tu et al., 2021). Some researchers introduced a multimedia art learning laboratory into high school chemistry classrooms. And students' content learning and spatial reasoning abilities have significantly improved, with the progress of top-performing students being significantly higher than that of average students (Wolski & Jagodziński, 2019). Some MR systems also offer tactile interaction and collaborative functions. For instance, during the global COVID-19 pandemic in 2019, MR effectively remedied the inability to conduct certain experimental courses offline(Barrett et al., 2018).

Secondly, MR can also improve students' non-cognitive abilities. Study findings indicated that the MR learning environment significantly promotes problem-solving success rates for both novices and experts, particularly in experimental courses (Sonntag & Bodensiek, 2022). Specifically, Embodied Mixed Reality Learning Environments foster collaboration among students more effectively than conventional environments (Martínez-Cerdá et al., 2018). Students showed significant improvements in computational thinking, critical thinking, leadership skills, as well as comfort and self-efficacy in STEM (Azhar et al., 2023; Cindioglu et al., 2022). The integration of Fab Lab into the curriculum can help students reduce absenteeism and dropout rates. Using MR demonstrations in digital presentation software during reading can significantly enhance the engagement of adult scientists (Kong et al., 2019). MR simulators were found to enhance teachers' management skills, address autistic students' learning issues, reduce behavioral problems, and aid in preventing and responding to bullying in STEM education(Pas et al., 2016; Pas et al., 2019).

On the other hand, some researches have reached opposite conclusions. There are limitations in the device and functionality of MR (Uhomoibhi et al., 2019). MR primarily stimulates students' vision, while other senses are rarely stimulated. Sometimes, MR can distract students and increase their cognitive load. MR is currently more suitable for small-scale (Keifert et al., 2020). Some studies have found that students prefer operating in traditional laboratories. Graduate teaching assistants participating in MR simulator training did not have a significant impact on undergraduate students' understanding of physics concepts. In college biology courses, traditional textbook-based teaching was found to be more effective in imparting biomedical knowledge and resulted in higher test scores compared to MR. Even researchers have found that among emerging technologies, MR is one of the least popular (Veer et al., 2022).

In conclusion, MR plays a crucial role in the implementation of STEM education. However, different studies have yielded inconsistent and even contradictory conclusions, and no definitive conclusion has been reached. Therefore, this study conducts the meta-analysis to evaluate the effectiveness of mixed reality in STEM education. Based on this, the following research questions are proposed:

(1) Can mixed reality significantly promote the effectiveness of STEM education compared to non-MR environments?

(2) What are the moderating variables that affect the effectiveness of mixed reality in STEM education?

METHODOLOGY

Ten English databases such as IEEE were selected for this study. The search keywords included "mixed reality" and "STEM" or "STEAM." To obtain a more comprehensive set of literature, a 'snowballing' approach was employed, which involved further searching the references cited in the selected literature. The criteria for literature screening mainly include the following points: the research environment is STEM education, the intervention is MR. The control measures are traditional teaching methods. English journal articles with a sample size greater than 10, complete experimental data, and accessibility were selected. Duplicate and ineligible literature were excluded. After the above-mentioned retrieval and screening, a total of 23 studies, with 41 independent effect sizes, met the criteria for meta-analysis. The original literature encoding information is shown in Table 1.

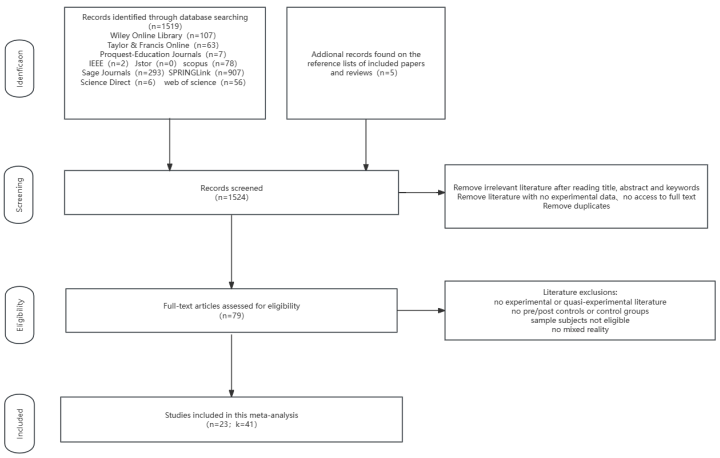
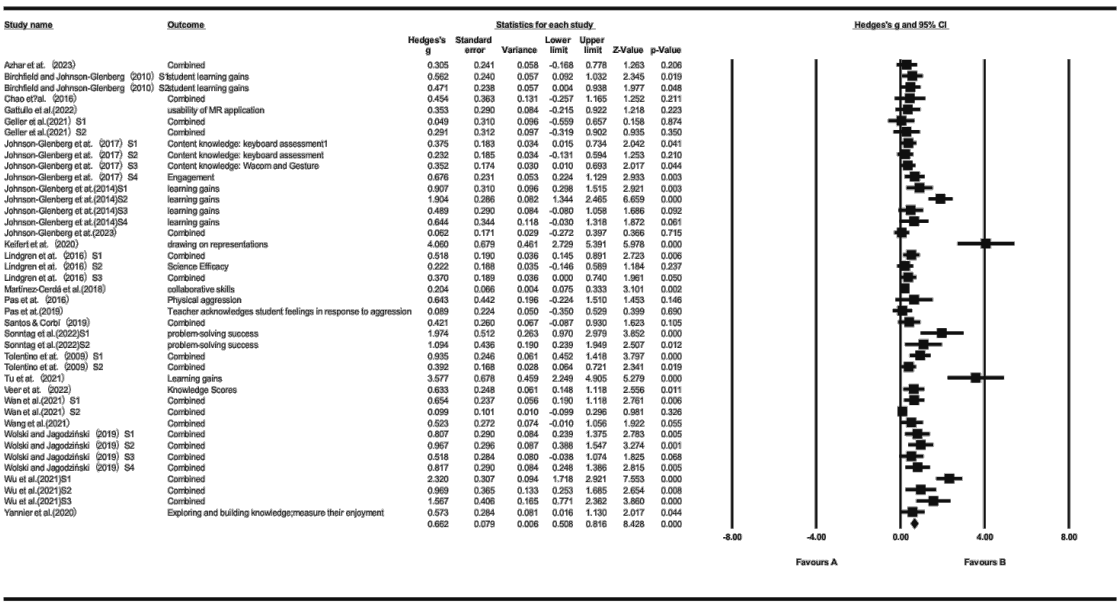


FIGURE 1 PRISMA flowchart.

Heterogeneity and Overall effect size

This study uses the Comprehensive Meta-analysis V3.0 software to analyze 41 selected experiments or quasi-experiments concerning the effectiveness of MR in STEM education. Because Hedges' g corrects the bias of small-sample studies to some extent, Hedges' g was used as the effect size in this study. According to Higgins et al. (2003), 25%, 50%, and 75% are used to indicate low, moderate, and high levels of heterogeneity, respectively. In this study, $Q=188.160$, $I^2=78.741$, $p<0.001$, showing high heterogeneity. So the random effect model was adopted in this study to ensure its reliability.

The absolute values of Hedges' g (hereinafter referred to as g) are interpreted as representing small, medium, and large effect sizes when they reach 0.2, 0.5, and 0.8, respectively (Cohen, 1988). The overall effectiveness of MR in STEM education, as summarized in Table 2, revealed a significant positive effect with a combined effect size of 0.662 ($p<0.001$) across 41 independent studies. The sensitivity analysis results showed that after excluding any one study, the overall effect size ranged from 0.606 to 0.687. This indicates that the results of the meta-analysis are robust and the results are not affected by extreme values.



Study name	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Azhar et al. (2023)	Combined	0.305	0.241	0.058	-0.168	0.778	1.263	0.206
Birchfield and Johnson-Glenberg (2010) S1	student learning gains	0.562	0.240	0.057	0.092	1.032	2.345	0.019
Birchfield and Johnson-Glenberg (2010) S2	student learning gains	0.471	0.238	0.057	0.004	0.938	1.977	0.048
Chao et?al. (2016)	Combined	0.454	0.363	0.131	-0.257	1.165	1.252	0.211
Gattullo et al.(2022)	usability of MR application	0.353	0.290	0.084	-0.215	0.922	1.218	0.223
Geller et al.(2021) S1	Combined	0.049	0.310	0.096	-0.559	0.657	0.158	0.874
Geller et al.(2021) S2	Combined	0.291	0.312	0.097	-0.319	0.902	0.935	0.350
Johnson-Glenberg et al. (2017) S1	Content knowledge: keyboard assessment1	0.375	0.183	0.034	0.015	0.734	2.042	0.041
Johnson-Glenberg et al. (2017) S2	Content knowledge: keyboard assessment	0.232	0.185	0.034	-0.131	0.594	1.253	0.210
Johnson-Glenberg et al. (2017) S3	Content knowledge: Wacom and Gesture	0.352	0.174	0.030	0.010	0.693	2.017	0.044
Johnson-Glenberg et al. (2017) S4	Engagement	0.676	0.231	0.053	0.224	1.129	2.933	0.003
Johnson-Glenberg et al.(2014)S1	learning gains	0.907	0.310	0.096	0.298	1.515	2.921	0.003
Johnson-Glenberg et al.(2014)S2	learning gains	1.904	0.286	0.082	1.344	2.465	6.659	0.000
Johnson-Glenberg et al.(2014)S3	learning gains	0.489	0.290	0.084	-0.080	1.058	1.686	0.092
Johnson-Glenberg et al.(2014)S4	learning gains	0.644	0.344	0.118	-0.030	1.318	1.872	0.061
Johnson-Glenberg et al.(2023)	Combined	0.062	0.171	0.029	-0.272	0.397	0.366	0.715
Keifert et al. (2020)	drawing on representations	4.060	0.679	0.461	2.729	5.391	5.978	0.000
Lindgren et al. (2016) S1	Combined	0.518	0.190	0.036	0.145	0.891	2.723	0.006
Lindgren et al. (2016) S2	Science Efficacy	0.222	0.188	0.035	-0.146	0.589	1.184	0.237
Lindgren et al. (2016) S3	Combined	0.370	0.189	0.036	0.000	0.740	1.961	0.050
Martinez-Cerdá et al.(2018)	collaborative skills	0.204	0.068	0.004	0.075	0.333	3.101	0.002
Pas et al. (2016)	Physical aggression	0.643	0.442	0.196	-0.224	1.510	1.453	0.146
Pas et al.(2019)	Teacher acknowledges student feelings in response to aggression	0.089	0.224	0.050	-0.350	0.529	0.399	0.690
Santos & Corbí (2019)	Combined	0.421	0.260	0.067	-0.087	0.930	1.623	0.105
Sonntag et al.(2022)S1	problem-solving success	1.974	0.512	0.263	0.970	2.979	3.852	0.000
Sonntag et al.(2022)S2	problem-solving success	1.094	0.436	0.190	0.239	1.949	2.507	0.012
Tolentino et al. (2009) S1	Combined	0.935	0.246	0.061	0.452	1.418	3.797	0.000
Tolentino et al. (2009) S2	Combined	0.392	0.168	0.028	0.064	0.721	2.341	0.019
Tu et al. (2021)	Learning gains	3.577	0.678	0.459	2.249	4.905	5.279	0.000
Veer et al. (2022)	Knowledge Scores	0.633	0.248	0.061	0.148	1.118	2.556	0.011
Wan et al.(2021) S1	Combined	0.654	0.237	0.056	0.190	1.118	2.761	0.006
Wan et al.(2021) S2	Combined	0.099	0.101	0.010	-0.099	0.296	0.981	0.326
Wang et al.(2021)	Combined	0.523	0.272	0.074	-0.010	1.056	1.922	0.055
Wolski and Jagodziński (2019) S1	Combined	0.807	0.290	0.084	0.239	1.375	2.783	0.005
Wolski and Jagodziński (2019) S2	Combined	0.967	0.296	0.087	0.388	1.547	3.274	0.001
Wolski and Jagodziński (2019) S3	Combined	0.518	0.284	0.080	-0.038	1.074	1.825	0.068
Wolski and Jagodziński (2019) S4	Combined	0.817	0.290	0.084	0.248	1.386	2.815	0.005
Wu et al.(2021)S1	Combined	2.320	0.307	0.094	1.718	2.921	7.553	0.000
Wu et al.(2021)S2	Combined	0.969	0.365	0.133	0.253	1.685	2.654	0.008
Wu et al.(2021)S3	Combined	1.567	0.406	0.165	0.771	2.362	3.860	0.000
Yannier et al.(2020)	Exploring and building knowledge;measure their enjoyment	0.573	0.284	0.081	0.016	1.130	2.017	0.044
		0.662	0.079	0.006	0.508	0.816	8.428	0.000

FIGURE 2 Forest plot of the 41 effect sizes.

Publication bias

Meta-analysis can derive a combined effect size from multiple studies, but these studies may be a biased sample of all relevant research. In this study, small sample sizes appeared at the bottom of the funnel plot, indicating greater sampling errors in small-sample studies. The points on Figure 1 did not symmetrically scatter around the effect size of 0.662, initially suggesting a possible publication bias in this study. However, judgments based on the funnel plot are subjective, and visual inspection alone is insufficient. Quantitative Egger regression analysis also revealed the existence of publication bias (P<0.05). If the fail-safe N is greater than "5k + 10", it indicates that unpublished articles in this field have no impact on the meta-analysis results (Rothstein et al., 2006). In this study, N=2673, K=41, and 2673>5*41+10, indicating no publication bias. Lastly, the trim and fill analysis indicated a non-significant impact on the results, suggesting the absence of publication bias.

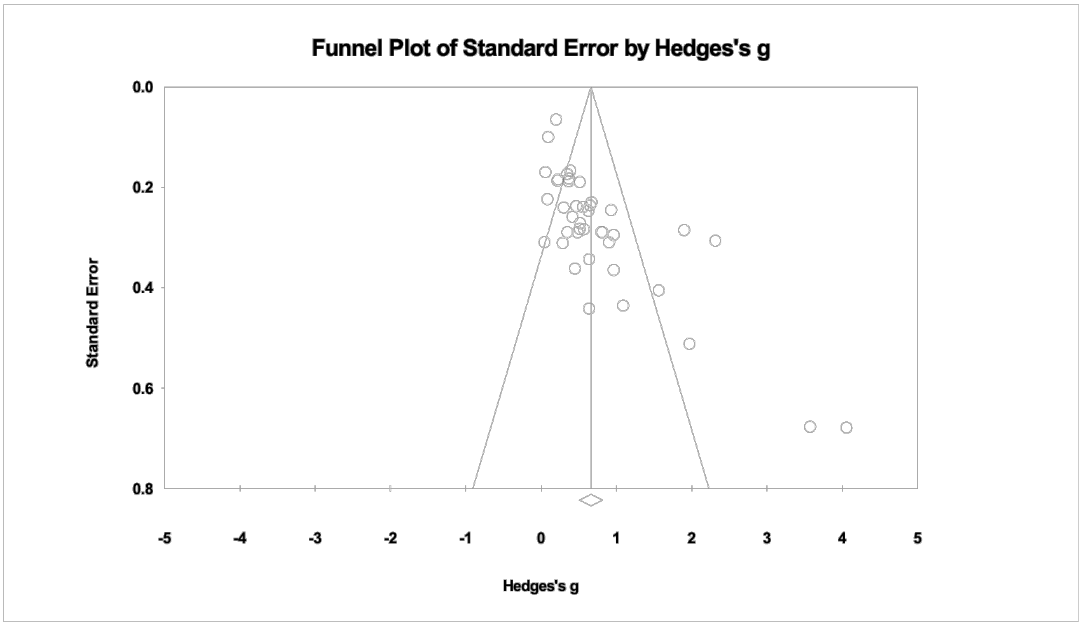


FIGURE 3 Funnel plot of publication bias.

Moderator analysis

Different country and region: The combined effect sizes for different educational country and region are presented in Table 3. Among them, Hong Kong, China, Poland, and the USA have achieved significant levels in their combined effect sizes, while Germany and China did not reach significant levels. This may be attributed to the fact that developed countries tend to adopt and utilize MR in STEM education earlier and more frequently than developing countries. Intergroup comparisons ($Q = 19.456$, $p < 0.001$) indicated a significant difference in the effectiveness of MR among different countries and regions.

Different educational level: The combined effect sizes for different educational levels are presented in Table 4. The effect size decreases with the increase in educational level, indicating that MR has a greater impact on students in lower educational levels for STEM learning. This may be attributed to the lower academic pressure, greater curiosity, and more exploration time for emerging technologies among students in lower educational levels. Furthermore, intergroup comparisons ($Q = 49.520$, $p < 0.001$) indicated a significant difference in the effectiveness of MR among different educational levels.

Different course types: The 82 data were divided into seven course types. STEP curriculum (g=3.818) achieved a significant combined effect size, while chemistry (g=0.732) reached a large combined effect size. Assembly training task (g=0.514), physics (g=0.412), and science (g=0.467) all achieved near-medium combined effect sizes. Interdisciplinary (g=0.315) and biology (g=0.296) exhibited smaller combined effect sizes. Intergroup comparisons (Q =

61.691, p < 0.001) indicated a significant difference in the effectiveness of MR among different courses. These differences may be attributed to various factors such as research design, experimental conditions, and sample selection.

Different measurement method: The combined effect sizes for different measurement method are presented in Table 6. Among these, the test measurement was the most commonly chosen, followed by questionnaires. Both of these measurement methods were significant at the 0.001 level (P<0.001). Time did not reach a significant level, while test and questionnaires, classroom observations, eye-tracking analyses, and test were significant at the 0.05 level (p<0.05). Eyetracking analyses and test (g = 1.493) achieved a substantial combined effect size, possibly due to students' familiarity with testing and their greater interest in the novel eye-tracking analysis method. Intergroup comparisons (Q = 8.901, p = 0.113) did not indicate a significant difference in the effectiveness of MR among different measurement methods.

Different gender groups: The combined effect sizes for different gender groups are presented in Table 7. When the number of males and females was equal, a large effect size of g=0.958 was observed. When there were more males than females, the effect size approached a medium level at g=0.493. Conversely, when there were more females than males, a smaller effect size of g=0.322 was noted. This may be attributed to the technical nature of MR used in STEM education, which males tend to prefer and are more inclined to explore. However, both genders have equal learning potential and equal opportunities to use MR. Intergroup comparisons (Q = 16.682, P < 0.001) indicated a significant difference in the effectiveness of MR among different gender groups. And the meta-regression results indicated that sample size has a significant impact on the effect size (coefficient < 0.01, p < 0.01).

Different experimental duration: The study classified the experimental durations into four types in Table 8. Each type of experimental duration reached a significant level, and intergroup comparisons (Q = 11.733, P=0.008) indicated a significant difference in the effectiveness of MR among different experimental durations. It can be seen that as the experimental duration increases, the combined effect size also gradually grows. Education is characterized by its long-term nature and latency, and similarly, the effectiveness of MR in STEM education also possesses a long-term impact.

The effectiveness of different types of outcomes: The dependent variables involved in the 84 data are classified into six outcomes in Table 9. The largest number is related to STEM knowledge. Problem-solving success (g=1.493) achieved an extremely large combined effect size. Engagement (g=0.929) reached a large combined effect size. While overall time spent (g=0.176) had a small combined effect size and did not reach a significant level. This may be because students' interest in technology is concentrated in the initial learning phase, and as learning time increases, students' sense of fatigue also increases. Intergroup comparisons (Q = 10.613, p = 0.06) did not indicate a significant difference in the effectiveness of MR among different types of outcomes.

RESULTS AND CONCLUSIONS

This study conducted a meta-analysis of 41 experiments and quasi-experiments of MR in STEM education. MR can significantly promote the effectiveness of STEM education, with a comprehensive effect size of up to 0.662. All the MR technologies involved in this study have positive promoting effects in STEM education. Furthermore, different types of MR have significant promoting effects on students' problem-solving skills, engagement, GTA instructional style, STEM knowledge, preference, and usability of MR applications. The results revealed that country and region, educational level, course, MR device, male/female ratio, and experimental duration showed moderating effects in STEM education, while variables such as sample size, measurement method, and outcome did not show moderating effects.

In this study, the effect size continuously decreases as the educational level increases. Therefore, it is necessary to design MR specifically based on the characteristics of students at different levels (Chng et al., 2023). Regarding sample size, the optimal outcome occurs when the number of males and females is equal. Additionally, some researches have found that females experience greater improvements in engagement, interest, and boredom reduction in science classes compared to males; however, they also experience less reduction in boredom than males. Moreover, certain special groups, such as individuals prone to migraines, may not be able to use these IVR devices, and females are more prone to motion sickness and migraines (Miller et al., 2021). As the experimental duration increases, the effectiveness of MR in STEM education becomes more pronounced. When students first encounter MR devices, they tend to focus on the technology itself due to curiosity; however, as they gain more understanding of the experimental device, they gradually shift their attention to the learning content (Tolentino et al., 2009). Therefore, Johnson-Glenberg et al. provided teaching suggestions to teachers: teachers can arrange for students who are less proficient in existing knowledge to undergo scaffolding learning on common devices. Once they become more familiar with the knowledge, teachers can transition them to more novel devices, such as 3D printing with haptic MR (Johnson-Glenberg et al., 2023).

This study concluded that the combined use of MR and other technologies yields the best results, with the effectiveness of the integrated MR being the greatest. Among different measurement methods, the combined effect size is also the largest. Wan et al. emphasize the use of multiple comprehensive methods to measure research results to ensure accuracy (Wan et al., 2021). The comprehensive learning effect based on MR is better than the single learning effect based on MR (Wu et al., 2021). To enhance learning effectiveness while providing an additional sense of learning stimulus, Yannier et al. propose integrating MR into traditional text-based teaching, which is conducive to improving STEM education (Yannier et al., 2020). Other studies have shown that 3D MR environments can be used in both online and face-to-face STEM learning in the future to enhance learning benefits (Geller et al., 2021).

Researches suggested that the order of introducing MR technology versus conventional teaching affects learning outcomes, with initial conventional teaching followed by MR yielding better results (Birchfield & Johnson-Glenberg et al., 2010). However, other studies indicated that the order does not impact test scores (Johnson-Glenberg et al., 2014). The effects of different MR also vary in different regions, for instance, the role of 3D printing device is more pronounced in rural or low SES communities (Johnson-Glenberg et al., 2023). Lastly,

emerging technologies should not be misused. This study also identified some potential limitations and challenges, such as the cost and difficulty of technology development, and the resistance of teachers and students to MR. Merely allowing students to use educational software or technology alone cannot bring significant learning outcomes. Based on this, some requirements for designing MR learning tools are proposed. Firstly, the needs of teachers and students should be taken into consideration to enhance engagement. Secondly, when designing the layout and content presentation, it is crucial not to increase users' cognitive load, ensuring that the graphics are simple and non-distracting. Finally, incorporating novel experiences can aid learning and maintain attention (Gattullo et al., 2022).

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Appendix

TABLE 1 Coding table of the 41 combined effect sizes.

Author (year)	Country and region	Sample size		Educational level	Course types	MR	Intervention Duration	Measurement method	Outcomes	Hedges's g
		experimental	control							
Azhar et at. (2023)	USA	34	34	university	interdisciplinary course	Virtual Hackathon	1 day	questionnaires	knowledge	0.305
Birchfield and Johnson-Glenberg (2010) S1	USA	37	34	high school	earth science	SMALLab	3 days	test	knowledge	0.562
Birchfield and Johnson-Glenberg (2010) S2	USA	34	37	high School	earth science	SMALLab	6 days	test	knowledge	0.471
Chao et al. (2016)	USA	16	14	high school	chemistry	the Gas Frame activity	90 mins	test	knowledge	0.454
Gattullo et al.(2022)	Italy	20	28	university	Remote lab course	MR application		questionnaires	usability of MR application	0.353
Geller et al.(2021) S1	USA	20	20	university	Biomedical Engineering	Zyndo platform		test and questionnaires	engagement	0.049

Geller et al.(2021) S2	USA	20	20	university	Immunology disciplines	Zyndo platform		test and questionnaires	engagement	0.291
Johnson-Glenberg and Megowan-Romanowicz (2017) S1	USA	127	39	university	Physics	Wacom large tablet	75 mins	test	knowledge	0.375
Johnson-Glenberg and Megowan-Romanowicz (2017) S2	USA	82	45	university	Physics	Wacom large tablet	75 mins	test	knowledge	0.232
Johnson-Glenberg and Megowan-Romanowicz (2017) S3	USA	75	59	university	Physics	Wacom large tablet	75 mins	test	knowledge	0.352
Johnson-Glenberg and Megowan-Romanowicz (2017) S4	USA	39	39	university	Physics	Wacom large tablet	75 mins	questionnaires	engagement	0.676
Johnson-Glenberg et at.(2014) S1	USA	16	35	high school	chemistry	EMRELE	3 days	test	knowledge	0.907

Johnson-Glenberg et at.(2014) S2	USA	35	35	high school	chemistry	EMRELE	3 days	test	knowledge	1.904
Johnson-Glenberg et at.(2014) S3	USA	39	17	high school	biology	EMRELE	3 days	test	knowledge	0.489
Johnson-Glenberg et at.(2014) S4	USA	17	17	high school	biology	EMRELE	3 days	test	knowledge	0.644
Johnson-Glenberg et at.(2023)	USA	68	68	university	chemistry	haptic MR	90 mins	test	knowledge	0.062
Keifert et at. (2020)	USA	13	13	elementary school	STEP curriculum	Tracing bodies through liminal blends	270mins	Video of classroom	Overall performance	4.060
Lindgren et at. (2016) S1	USA	58	55	secondary schools	physics	a simulation called MEteor	60 mins	test	knowledge	0.518
Lindgren et at. (2016) S2	USA	58	55	secondary schools	physics	a simulation called MEteor	60 mins	questionnaires	Science Efficacy	0.222
Lindgren et at. (2016) S3	USA	58	55	secondary schools	physics	a simulation called MEteor	60 mins	questionnaires	Overall performance	0.370

Martínez-Cerdá et al.(2018)	Spain	465	465	online university	E-learning	MR application	two months	questionnaires	collaborative skills	0.204
Pas et at.（2016）	USA	11	9	5-21 岁	TeachLivE™ course	TeachLivE™	10 weeks	questionnaires	knowledge	0.643
Pas et at.(2019)	USA	39	39	middle school	interdisciplinary course	TeachLive© MR simulator	4 months	observations	Overall performance	0.089
Santos & Corbí（2019）	Spanin	30	30	high school	summer camp	wearable technology	four hours	questionnaires	knowledge	0.421
Sonntag et al.(2022) S1	Germany	13	9	university	Physics	MR-HMD		eyetracking and questionnaires	problem solving skills	1.974
Sonntag et al.(2022) S2	Germany	13	10	university	Physics	MR-HMD		eyetracking and questionnaires	problem solving skills	1.094
Tolentino et at.（2009）S1	USA	37	37	high school	chemistry	Multimedia Learning Laboratory	6 weeks	test	knowledge	0.935
Tolentino et at.（2009）S2	USA	60	99	high school	chemistry	Multimedia Learning Laboratory	6 weeks	test	knowledge	0.392

Tu et at. (2021)	USA	11	11	elementary school	STEP particle curriculum	Microsoft Kinect cameras	30 mins	test	knowledge	3.577
Veer et at. (2022)	Australian	33	34	university	Interdisciplinary	three-dimensional MR HoloLens	2 weeks	test and questionnaires	knowledge	0.633
Wan et al.(2021) S1	USA	39	33	university	physics	MR simulator	1 semester	classroom observations	GTA instructional style	0.654
Wan et al.(2021) S2	USA	163	165	university	physics	MR simulator	3 semesters	test	knowledge	0.099
Wang et al.(2021)	China	28	28	university	assembly training task	MR remote collaboration system	50 mins	questionnaires	Satisfaction with MR	0.523
Wolski and Jagodziński (2019) S1	Poland	25	25	middle school	chemistry	Kinect sensor from Microsoft	4 months	test	knowledge	0.807
Wolski and Jagodziński (2019) S2	Poland	25	25	middle school	chemistry	Kinect sensor from Microsoft	4 months	test	knowledge	0.967
Wolski and Jagodziński (2019) S3	Poland	25	25	high School	chemistry	Kinect sensor from Microsoft	4 months	test	knowledge	0.518

Wolski and Jagodziński (2019) S4	Poland	25	25	high School	chemistry	Kinect sensor from Microsoft	4 months	test	knowledge	0.817
Wu et al.(2021) S1	Hong Kong	35	35	university	RFID course	the integration of SSM and MR	13 weeks	questionnaires	knowledge	2.320
Wu et al.(2021) S2	Hong Kong	18	18	university	RFID course	the integration of SSM and MR	13 weeks	questionnaires	knowledge	0.969
Wu et al.(2021) S3	Hong Kong	18	18	university	RFID course	the integration of SSM and MR	13 weeks	questionnaires	overall improvement	1.567
Yannier et al.(2020)	USA	25	25	secondary schools	Practiced tower building	AI computer vision algorithm		test and survey	Knowledge and engagement	0.573

TABLE 2 Overall effect size.

Model	Number Studies	Effect size and 95% confidence interval			Test of null (2-Tail)		Heterogeneity			
		Hedges' g	Upper limit	Lower limit	Z-value	P-value	Q-value	df (Q)	P-value	I^2
Fixed effects model	41	0.425	0.489	0.360	12.960	<0.001	188.160	40	<0.001	78.741
Random effects model	41	0.662	0.816	0.508	8.428	<0.001				

TABLE 3 Different country and region.

Moderator variables	Country and region	K	Effect size (Hedges's g)	95% confidence interval		Test of null (2-tail)		Test of heterogeneity
				Upper limit	Lower limit	Z-value	p-value	Q = 19.456 p = 0.001 df = 4
Different country and region	China	3	0.514	1.164	-0.136	1.549	0.121	
	Germany	2	0.973	2.831	-0.885	1.026	0.305	
	Hong Kong, China	6	1.603	2.578	0.627	3.219	0.001	
	Poland	16	0.769	0.911	0.627	10.616	<0.001	
	USA	56	0.431	0.529	0.333	8.624	<0.001	

TABLE 4 Different educational level.

Moderator variables	Educational level	K	Effect size (Hedges's g)	95% confidence interval		Test of null (2-tail)		Test of heterogeneity
				Upper limit	Lower limit	Z-value	p-value	Q=49.520 (p < 0.001) df = 3
Different educational level	Primary school	2	3.956	4.930	2.982	7.961	<0.001	
	Middle school	9	0.780	1.021	0.540	6.355	<0.001	
	High school	39	0.557	0.662	0.453	10.482	<0.001	
	University	35	0.512	0.676	0.347	6.110	<0.001	

TABLE 5 Different course types.

Moderator variables	Course types	K	Effect size (Hedges's g)	95% confidence interval		Test of null (2-tail)		Test of heterogeneity
				Upper limit	Lower limit	Z-value	p-value	Q = 61.691 p < 0.001 df = 6
Different course types	assembly training task	3	0.514	1.164	-0.136	1.549	0.121	
	biology	6	0.296	0.545	0.046	2.325	0.020	
	chemistry	42	0.732	0.917	0.547	7.760	<0.001	
	interdisciplinary	6	0.315	0.506	0.123	3.224	0.001	
	physics	19	0.412	0.535	0.288	6.517	<0.001	
	science	4	0.467	0.742	0.193	3.336	0.001	
	STEP curriculum	2	3.818	4.758	2.878	7.959	<0.001	

TABLE 6 Different measurement method.

Moderator variables	Measurement method	K	Effect size (Hedges's g)	95% confidence interval		Test of null (2-tail)		Test of heterogeneity
				Upper limit	Lower limit	Z-value	p-value	Q = 8.901 p = 0.113 df = 5
Different measurement method	test and questionnaires	4	0.421	0.700	0.142	2.958	0.003	
	classroom observations	3	0.459	0.834	0.084	2.398	0.016	
	eyetracking analyses and test	2	1.493	2.352	0.634	3.406	0.001	
	questionnaires	25	0.614	0.834	0.393	5.459	<0.001	
	test	49	0.561	0.678	0.445	9.444	<0.001	

	time	2	0.176	0.607	-0.254	0.802	0.423	

TABLE 7 Different gender groups.

Moderator variables	Gender groups	K	Effect size (Hedges's g)	95% confidence interval		Test of null (2-tail)		Test of heterogeneity
				Upper limit	Lower limit	Z-value	p-value	Q=16.682 (p < 0.001) df = 2
Different gender groups	equal number of men and women	4	0.958	1.247	0.668	6.488	<0.001	
	females are more	23	0.322	0.445	0.199	5.137	<0.001	
	males are more	35	0.493	0.586	0.399	10.324	<0.001	

TABLE 8 Different experimental duration.

Moderator variables	Experimental duration	K	Effect size (Hedges's g)	95% confidence interval		Test of null (2-tail)		Test of heterogeneity
				Upper limit	Lower limit	Z-value	p-value	Q=11.733 P=0.008 df = 3
Different experimental duration	one day or less	38	0.402	0.523	0.280	6.475	<0.001	
	more than one day to within two months	12	0.673	0.933	0.412	5.068	<0.001	
	more than two months	28	0.831	1.065	0.596	6.942	0.005	

	absent	8	0.482	0.822	0.142	2.778	<0.001	

TABLE 9 Different outcome.

Moderator variables	Outcome	K	Effect size (Hedges's g)	95% confidence interval		Test of null (2-tail)		Test of heterogeneity
				Upper limit	Lower limit	Z-value	p-value	Q = 10.613 p = 0.06 df = 5
Different outcome	engagement	4	0.929	1.748	0.111	2.225	0.026	
	GTA instructional style	2	0.654	0.982	0.326	3.907	<0.001	
	overall Time Spent	2	0.176	0.607	-0.254	0.802	0.423	
	preference and usability of MR application	10	0.454	0.646	0.263	4.660	<0.001	
	problem-solving success	2	1.493	2.352	0.634	3.406	0.001	
	stem Knowledge	64	0.619	0.745	0.493	9.627	<0.001	

Province-wide STEM Network: Outreach Collaboration across British Columbia

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ABSTRACT

This study describes a STEM action research project aimed at improving access to high-quality STEM education throughout British Columbia (BC), Canada. This project is a timely response to the current demands for teacher-researcher-practitioner STEM collaborations ranging from K-16 education to teacher training and community outreach. Moreover, the challenge posed by the surge in online graduate programs underscores the necessity of adopting research-informed pedagogies and effectively engaging diverse students, including refugees and Indigenous students. The project's key objective was the expansion and transformation of the UBC-based David Robitaille International STEM Network (https://dfr.stemnetwork.educ.ubc.ca/) into a comprehensive provincial STEM education network. This expansion involves the process of identifying and building connections with a variety of STEM education entities within BC, including post-secondary institutions, museums, outreach programs, and community organizations.

To facilitate this collaboration, two virtual symposiums were organized. The first symposium laid the groundwork for collaborative engagement among these diverse stakeholders. It provided a platform for discussing community needs, challenges in STEM education, and joint funding opportunities. This event significantly contributed to promoting mutual understanding and commitment towards enriching STEM education province-wide. A post-symposium survey revealed a few key concerns that included: limited STEM outreach funding, difficulties in assessing the impact of STEM activities, and time constraints faced by educators in implementing STEM curricula. Identifying ‘Assessment and Evaluation of STEM Activities' Impact" as an area requiring immediate focus, the second symposium was dedicated to brainstorming potential collaborative research initiatives on this particular aspect. The collaboration aided in refining the potential projects into three key research arenas that crystallized into three primary research topics: Sustainable Community Engagement for Enhanced STEM Assessment, Assessment Strategies for Enhanced STEM Education, and Capacity Building for STEM Outreach Professionals for Advanced Practices in STEM

Assessment. The overarching goal of this initiative was not only to identify immediate concerns but also establish a foundation for sustainable and impactful solutions through collaborative initiatives. The next phase of the project is targeted towards setting up lasting province-wide collaborations to secure grants for the identified research areas. This involves connecting potential collaborators and aligning their interests and expertise with the proposed research themes, thereby

cultivating a collaborative action research ecosystem. Each participant's unique insights and skills are crucial in forming a holistic strategy to tackle the challenges in STEM education. However, since the identified issues are so big, none of the individual participants can solve them in isolation. By nurturing relationships with diverse STEM education communities, the project aspires to create a vibrant network that fosters innovation and generates meaningful outcomes. This multifaceted approach ensures that the proposed research endeavors not only address pressing issues but also contribute substantially to the future progress of STEM education in BC. Through sustained collaboration, the BC STEM education network aims to become a driving force for positive transformation, advocating for quality, equality, and excellence in STEM education across the province.

Keywords: David Robitaille International STEM Network, STEM education outreach, sustainable community engagement, assessment and evaluation, province-wide collaboration, grant application

THE INFLUENCE OF STEM ACTIVITIES IN MIDDLE SCHOOL ON CHINESE ENGINEERING STUDENTS IN COLLEGE

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BACKGROUND AND AIMS

STEM education refers to education in the four subject areas of science, technology, engineering and mathematics. First, STEM is interdisciplinary, representing four separate subject areas of science, technology, engineering and mathematics. Secondly, STEM is integrated, which is not limited to four separate disciplines, but emphasizes the cross-integration of multiple disciplines.[1]China also tries to localize STEM education, so that it not only needs to adapt to the improvement of China's general environment in the form of implementation, but also needs to make reasonable adjustments to its educational value in line with the needs of China's education reform, so as to better develop students' core literacy.[2]

Students' participation in a variety of STEM extracurricular learning activities during primary and secondary school is conducive to developing their interest and skills in engineering and deepening their understanding of engineering. A variety of extracurricular learning activities have been carried out for primary and secondary school students at home and abroad, and most of these activities are concentrated in STEM fields, integrating interdisciplinary concepts, scientific inquiry elements in science education and other aspects of content.[3]

This study focuses on STEM extra-curricular activities in middle school, aiming to explore the influence of STEM extra-curricular activities in middle school on engineering students' various aspects (including interest, ability, recognition and identity) in high school and college, so as to put forward suggestions for improving STEM education in middle schools in China.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

This study is a qualitative study, aiming to understand the experiences and feelings of first-year engineering students through face-to-face interviews, so as to explore the specific impact of STEM extracurricular activities on their then and now. Based on this, this study designed the interview outline from the three dimensions of interest, performance/ability, recognition and the overall situation of engineering identity, collected data in the form of one-to-half structured interview, recorded the

whole process with the permission of the author, and conducted subsequent data collation. The duration of each interview was controlled from 30 minutes to 60 minutes. The survey subjects were 7 freshmen majoring in engineering in class 2023 of Shanghai Jiao Tong University, including 5 males and 2 females, 6 students from the School of Mechanical and Power Engineering and 1 student from the School of Shipbuilding, Oceanology and Architectural Engineering. The respondents' information is shown in Table 1.

Table 1

ID	Name(Pseudonym)	Gender	Major	Location of secondary school
1	Wu	Male	Mechanical major	Zhejiang, China
2	Zhong	Male	Mechanical major	Hubei, China
3	Li	Male	Mechanical major	Henan, China
4	Zhe	Male	Mechanical major	Shanghai, China
5	Qi	Female	Mechanical major	Shanghai, China
6	Wang	Female	Mechanical major	Shanghai, China
7	Ma	Male	Ship engineering major	Jiangsu, China

RESULTS AND CONCLUSIONS

First of all, STEM activities in middle school can give students a clearer understanding of engineering, and the influence on students' interest may be enhanced or suppressed, depending on students' feelings after contact, which is indeed conducive to students' choice of major intention after this. In terms of ability, in addition to the subject competition may be helpful to the study at that time, in most cases, the STEM activities that students are exposed to are hardly helpful to the academic performance of students at that time or after entering the university, but they can improve students' ability in other aspects, such as self-learning ability, teamwork, hands-on ability, etc. In terms of recognition and engineering identity, respondents said that there is no significant impact, because China's current STEM extracurricular activities for middle school students do not go into engineering deeply.

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THE EFFECT OF PROJECT-BASED LEARNING ON STUDENTS' CREATIVITY: A META-ANALYSIS

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BACKGROUND AND AIMS

In the 21st century, with rapid socio-economic development and the rise of the knowledge-based economy, there is an increasing demand for individuals to acquire diverse skills, especially in innovative talents, in order to maintain global competitiveness and enhance national innovation capacity. Of these, creativity, defined as the ability to generate novel ideas and solutions, is of paramount importance for personal adaptation and societal progress (Florida, 2002). Consequently, the fostering of creativity in education has become a matter of paramount importance.

Project-based learning has been identified as an effective strategy for fostering creativity in students (Khoiri et al., 2013). project-based learning represents an optimal framework for integrating creativity training into the curriculum and stimulating individual creativity through project tasks(Duke et al., 2021; Saimon et al., 2022). The objective of this study is to provide a comprehensive summary of the impact of project-based learning on creativity, and to enumerate the effects of relevant moderating variables.

LITERATURE REVIEW

Creativity is a multifaceted concept that encompasses various human capabilities and processes. Scholars have acknowledged the multidimensional nature of creativity(Almulla, 2020; Amabile, 1995). It encompasses the generation of novel solutions, which are influenced by intrinsic motivation and domain-related knowledge (Sternberg, 2003; Amabile, 1995). In the 21st century, creativity is of vital importance for economic growth and national competitiveness (Almulla, 2020; Cummings & Blatherwick, 2017).

Project-based learning is a systematic teaching approach that facilitates deep student exploration of complex topics (Mergendoller et al., 2006). It places a strong emphasis on tasks such as problem-solving and fostering innovation (Lu et al., 2021). PBL has been identified as a potential avenue for fostering creativity by researchers (Barak & Yuan, 2021; Isabekov & Sadyrova, 2018).

Furthermore, a number of variables affect the impact of project-based learning on creativity. Barak and Yuan (2021) drew attention to the influence of cultural factors on the impact of PBL on creativity, while Mustapha (2020) highlighted the role of the learning stage, particularly for younger students. Kuo (2019) demonstrated that the use of challenging project topics can enhance creative thinking, while Chang (2022) emphasised the significance of teamwork and collaboration in fostering creativity. Teacher guidance also has a positive influence on the development of creativity (Kingston, 2018).

In conclusion, it can be said that PBL has a positive impact on the development of students' creativity, which is influenced by factors such as cultural background, learningnstage, complexity of the project and teacher guidance. Nevertheless, further investigation is required to gain a comprehensive understanding of the factors that influence creativity within PBL. This study employs meta-analysis to summarize the effectiveness of PBL on creativity and to analyze the influence of moderating variables.

METHODOLOGY

Database search

In this study, literature screening was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, with the selection process (Moher et al, 2009).Two sources were used to search for relevant literature on "project- based learning" and "creativity," including 10 databases: Science Direct, IEEE, JSTOR, ProQuest, SAGE Journals, Scopus, Springer Link, Taylor & Francis, Web of Science, and Wiley Online Library. A total of 5793 articles published before March 2023 were retrieved.

The preliminary literature screening involved the evaluation of titles, abstracts, and keywords of the retrieved literature, leading to the exclusion of 5590 articles based on three criteria: non-journal articles (n=3434), non-English articles (n= 345), and irrelevant articles (n= 2104). This left 203 articles for further consideration. Next, 37 duplicate studies were identified and removed, resulting in 166 articles for full-text assessment. The eligibility of these remaining articles was assessed according to four exclusion criteria based on relevant guidelines (Higgins & Green, 2008). Ultimately, twenty-five articles with high impact factors and quality were included for the meta-analysis.

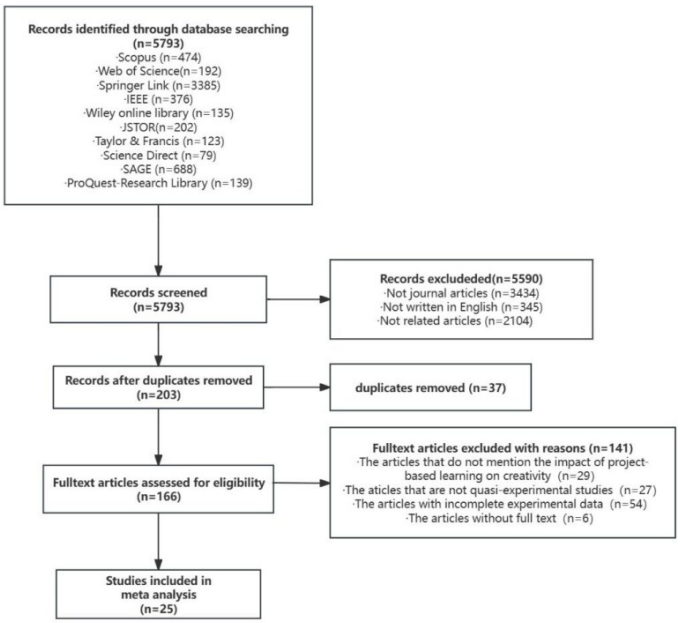


FIGURE 1 The PRISMA flow chart.

Coding

Two researchers extracted and coded data from 25 studies, and where there was disagreement, a third researcher was involved in the discussion to reach a consensus conclusion. Information such as author (year), country, level, curriculum, sample size, mean of experimental group, standard deviation of experimental group, mean of control group and t-value in the data of experimental studies were extracted from the articles.

Data analysis

Effect value is an indicator used to measure the strength of an experimental effect or the strength of association of a variable, which is less affected by the size of the sample size. In pedagogy, effect sizes can be categorized into difference, correlation, and group overlap based on their statistical significance. Difference category effect values are usually used in experimental studies comparing the means of two or more groups, and commonly include Cohen's d, Glass' Δ (or Glass coefficient) and Hedges' g.

Due to the small sample size and number of studies in this study, Hedges's g was used as the final effect size. The procedure for calculating the effect size g value is as follows: first calculate the standardized mean difference (d) and then multiply it by the correction factor (J). The Comprehensive Meta-Analysis 2.0 software was used to calculate the effect size in this study.

RESULTS AND CONCLUSIONS

Main conclusions arising from the study should be substantiated by evidence/results and/or literature. Implications for policy, practice and/or theory should be noted. Instructions to authors in this template should be deleted before submitting.

RESULTS

Heterogeneity

From the results of this study, the Q-tests of the outcome variables were all significant ($Q=84.540$), $P<0.001$, indicating that the effect sizes of the meta-analysis of the impact of project-based learning on students' creativity were heterogeneous. For the I^2 test, the formula for I^2 is as follows: $I^2= Q-(K-1)Q\times100\%$, when $0< I^2<40$, there is low heterogeneity; when $40< I^2<60$, there is moderate heterogeneity; when $60< I^2<75$, there is large heterogeneity; and when $75< I^2<100$, there is large heterogeneity. The I^2 of this study is 68.573, which has a large heterogeneity, and based on this result, this study uses a random effects model to combine the effect values to ensure the reliability of the results.

Publication bias

Researchers may assess bias in study results by visually inspecting the funnel plot or employing quantitative methods such as Begg's rank correlation test, particularly in the context of small sample studies. The Begg test determines bias based on the Z-score and P-value. A Z-score greater than 1.96 and a P-value less than 0.05 indicate a potential for bias, whereas a Z-score less than 1.96 and a P-value greater than 0.05 suggest the absence of bias. The centre line of the funnel plot represents the mean effect value, with the area between the lines indicating the confidence interval. The circles represent the studies, with smaller sample sizes tending to have less precise effect sizes, which are typically dispersed at the plot's lower end. The uneven distribution of studies around the total effect size, particularly skewed to one side, may indicate the presence of publication bias. In this analysis, Begg's test ($Z=1.052$, $P=0.106$) indicates that there is no publication bias, thereby confirming the robustness of the combined effect size.

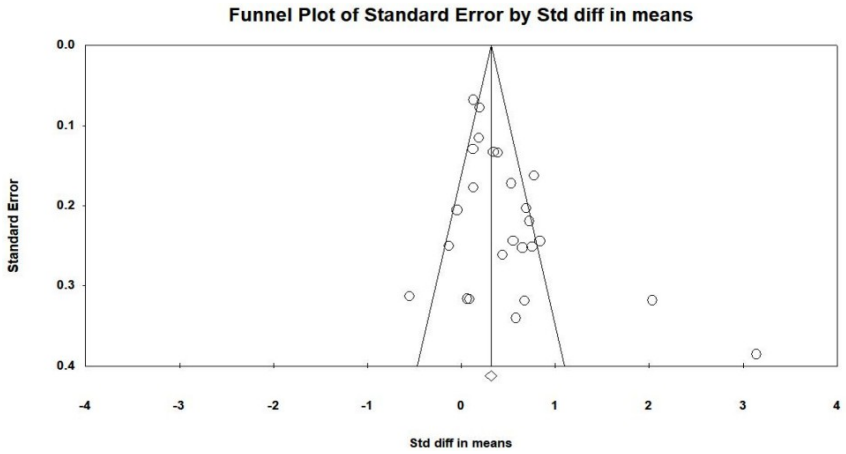


FIGURE 2 Publication bias funnel plot.

Overall effect size and sensitivity analysis

The combined effect values were Hedges's g = 0.492, Standard error = 0.088, Variance = 0.008, Lower limit = 0.319, and Upper limit = 0.665, and reached statistically significant levels (p< 0.001).The combined effect value of this study is Hedges's g = 0.492, indicating that project-based learning has a positive impact effect on creativity that is close to moderate. When the absolute value of the effect value g reaches 0.1, 0.2, 0.5, 0.8, 1.2 and 2.0, it represents different levels of effect size: 0.1 is classified as very small, 0.2 as small, 0.5 as medium, 0.8 as large, 1.2 as very large and 2.0 as huge. A positive effect value g indicates that the impact of the experimental group is better than that of the control group, while a negative effect value g indicates that the impact of the experimental group is worse than that of the control group (Cohen, 1992).

In addition, this study examined the stability of the findings through sensitivity analyses. The results of the sensitivity analysis showed that the overall effect value obtained after excluding any of the studies ranged between 0.271 and 0.428, indicating that the meta-analytic estimates were not affected by the extreme values and had a high degree of stability.

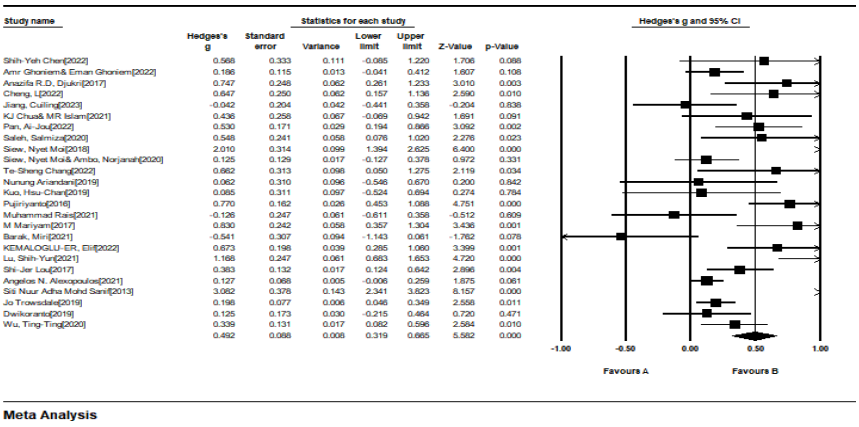


FIGURE 3 Forest plot.

Moderator analysis

This study assessed the overall effectiveness and specific effects of project-based learning on creativity. Given the heterogeneity of effect size, we conducted moderating effects analysis to explore how other factors influence creativity. Drawing on previous literature, we hypothesised that contextual factors such as country prosperity (developed/developing countries), learning stages, and type of curriculum would have a moderating effect on

creativity. We analysed these factors as moderating variables and came up with the following key findings.

Countries

Table 2 Economic development level

Economic development level	N	Effect size and 95% confidence interval			Test of null (2-Tail)		Heterogeneity
		g-value	Upper limit	Lower limit	Z-value	P-value	
Developed country	4	0.390	0.554	0.226	4.661	0.000	Q=1.211 df (Q)=1 P=0.027
Developing country	21	0.618	0.898	0.338	4.328	0.000	

In this study, countries were identified based on the country in which the study was implemented and experiments were conducted, rather than the nationality of the first author. The countries included in the 25 experimental studies were China, USA, Indonesia, United Kingdom, Italy, Israel, Turkish, Malaysia. categorized based on the list of developing countries published by OECD in 2021, these countries and the corresponding measurements were classified for moderated effect analysis and obtained as shown in the table.

Out of 25 studies, there are 4 developed countries with effect value g=0.390, p<0.05, which indicates that gender equality interventions in developed countries reached a significant effect close to medium (Medium), and 21 developing countries with effect value g=0.618, p<0.05, which indicates that gender equality interventions in developing countries reached a significant effect above medium (Medium). The between-group P=0.027<0.05 for developed and developing countries indicates that there is a significant difference in the effect of the intervention between the two. However, overall, the effect of project-based learning on students' creativity is better in developing countries.

Learning stages

Table 3 Different learning stages

Learning stages	N	Effect size and 95% confidence interval			Test of null (2-Tail)		Heterogeneity
		g-value	Upper limit	Lower limit	Z-value	P-value	
Primary school	6	0.185	0.248	0.400	2.213	0.002	Q=4.672 df (Q)=2 P=0.097
High school	6	0.341	0.576	0.136	4.040	0.000	
University	13	0.429	0.653	0.289	5.075	0.000	

In order to further investigate the impact of project-based learning on the creativity of students in different school years, we divided the included literature into three groups according to school years: university, High school and Primary school, and the combined effect values of each group are shown in the table. The combined effect value of university is 0.429, High school is 0.341, and Primary school is 0.185, and the combined effect value of the three

groups reaches a statistically significant level, with university and High school being significant at the 0.001 level (P<0.001), and Primary school at the 0.01 level (P<0.01), indicating that project-based learning has a significant impact on the creativity of students in universities and high schools, indicating that project-based learning has a moderate positive impact on creativity of students at both university and high school levels.

Curriculum

Table 4 Different Curriculum

Different Curriculum	N	Effect size and 95% confidence interval			Test of null (2-Tail)		Heterogeneity
		g-value	Upper limit	Lower limit	Z-value	P-value	
Structured Curriculum	17	0.576	0.898	0.368	4.328	0.000	Q=3.381 df (Q)=1 P=0.017
Informal Learning	8	0.338	0.480	0.197	4.677	0.000	

In this study, the type of curriculum was used as one of the moderating variables. Project-based learning was classified into structured curriculum or informal learning based on whether it was carried out in the school's formal curriculum as a basis for judgment. The effect value of 0.576 for formal courses and 0.338 for secondary schools, both of which reached the significant level, indicates that project-based learning has a moderate positive impact on students' creativity both in structured curriculum or informal learning. The positive impact of project-based learning on students' creativity is greater in the structured curriculum than in the informal learning, and the between-group effect, Q=3.381, p=0.017<0.05, suggests that there is a significant difference between the implementation of project-based learning in the structured curriculum or informal learning.

Findings and conclusions

This study employs meta-analysis to examine the impact of project-based learning (PBL) on students' creativity and identify influencing factors. The findings indicate a significant positive effect of PBL on creativity, with variations observed based on country and curriculum type. Specifically, PBL in developing countries and structured curriculum settings shows a more favourable impact on creativity. Although no significant differences were found across learning stages, PBL appears to have a particularly positive effect on university students' creativity. These insights provide insight into the nuanced dynamics of PBL's influence on student creativity, informing educational practices for enhanced outcomes.

Barak & Yuan (2021) emphasised the importance of cultural diversity in project-based learning outcomes, which is consistent with our research findings. The researchers also observed that students from different cultural backgrounds may exhibit distinctive patterns of creative thinking during PBL engagement. This highlights the necessity of considering national contexts and values when designing PBL initiatives in order to effectively stimulate creative potential. Furthermore, the composition of teams within PBL settings has been identified as a crucial factor in fostering creativity. When teams are composed of members with different cultural backgrounds and expertise, they can share their unique perspectives and ideas, and this diversity can facilitate the generation of ideas (Hsiao et al., 2022), which in turn can lead to collaborative solutions that are more creative and practical(Sterne et al., 2001).

Mustapha(2020) also further revealed that there are differences in the impact of project-based learning on creativity at different learning stages.Therefore, for students of different ages, the design and implementation of project-based learning courses need to be tailored to their needs, and instructors should flexibly adjust their teaching strategies to ensure their effectiveness and applicability, and maximize students' creative potential.

In project-based learning, students are confronted with real-world problems and tasks that are challenging and complex and require them to use creative thinking and innovative approaches to find solutions(Albar&Southcott, 2021). The support that project-based learning may receive is more diverse and has a more significant impact on creativity compared to informal courses. In addition, the curriculum and topic selection of project-based learning can also have an impact on students' creativity. It has also been found that challenging project topics or courses can better stimulate students' creative thinking and problem-solving skills (Kuo, 2020; Li et al., 2022).

It is no doubt that the factors affecting creativity in project-based learning are complex. This study only analyzed the above moderating variables on creativity impact. Overall, in the last decade or so, many researchers have studied the impact of project-based learning on students' creativity, and a variety of research methods have been used, involving different sample sizes of learning stage, countries, and the type of curriculum.

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Appendix

Table1 Coding table for the 25 effect sizes

Author (year)	Country	Learning stage	Curriculum	Experimental period	Sample size	Hedges's g
Shih-Yeh Chen et al.(2022)	China	University	Structured Curriculum	18 weeks	36	0.22
Amr Ghoniem& Eman	Egypt	University	Informal Learning	3 months	300	0.19

Ghoniem(2022)						
Anazifa R.D, Djukri et al.(2017)	Malaysia	High school	Structured Curriculum	1 month	68	0.75
Cheng, L et al.(2022)	China	University	Structured Curriculum	3 weeks	66	0.65
Jiang, Cuiling et al. (2023)	China	University	Informal Learning	32 hours	95	0.80
K, J Chua& MR Islam et al. (2021)	China	University	Structured Curriculum	3 months	60	0.44
Pan, Ai-Jou(2022)	China	High school	Structured Curriculum	7 weeks	140	0.53
Saleh, Salmiza et al. (2020)	Malaysia	Primary school	Informal Learning	2 weeks	70	0.58
Siew, Nyet Moi et al.(2018)	Malaysia	Primary school	Informal Learning	12 weeks	60	0.55
Siew, Nyet Moi& Ambo, Norjanah(2020)	Malaysia	Primary school	Structured Curriculum	2 months	240	2.01
Te-Sheng Chang et al.(2022)	China	University	Structured Curriculum	17 weeks	42	0.13
Nunung Ariandani et al. (2019)	Malaysia	Primary school	Structured Curriculum	3 weeks	40	0.91

Kuo, Hsu-Chan et al.(2019)	China	University	Structured Curriculum	18 weeks	45	1.97
Pujiriyanto et al.(2016)	Indonesia	University	Structured Curriculum	8 weeks	162	0.74
Muhammad Rais et al.(2021)	Italy	University	Structured Curriculum	3 months	64	0.31
M Mariyam et al.(2017)	Tanggamus	High school	Informal Learning	3 months	73	-0.13
Barak, Mir et al.(2021)	Israel	University	Structured Curriculum	6 months	43	0.83
KEMALOGLU-ER, Elif et al.(2022)	Turkish	University	Informal Learning	3 weeks	30	-0.54
Lu, Shih-Yun et al.(2021)	China	Primary school	Structured Curriculum	2 weeks	21	0.68
Shi-Jer Lou et al.(2017)	China	High school	Structured Curriculum	6 weeks	60	1.92
Angelos N. Alexopoulos et al.(2021)	Italy	High school	Structured Curriculum	16 months	175	0.34
Siti Nuur Adha Mohd Sanif et al.(2013)	Malaysia	High school	Structured Curriculum	3 weeks	40	0.13
Jo Trowsdale et al.(2019)	United Kingdom	Primary school	Informal Learning	10 weeks	135	0.20
Dwikoranto et al.(2019)	Indonesia	University	Informal Learning	3 months	32	0.12
Wu Ting-Ting（2020）	China	University	Structured Curriculum	3 years	60	0.34

AN INCLUSIVE PEDAGOGICAL FRAMEWORK TO FOSTER EDIA PRACTICES IN THE STEM EDUCATION

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Abstract

There is an increasing attention to the concept of EDIA (equity, diversity, inclusion, and accessibility) in university agendas, policies, and learning practices (Moriña, 2017), while many scholars have emphasized the importance of EDIA in STEM (McGee, 2020; Ramiah et al., 2022; Takkouch et al., 2023). Although EDIA is receiving much attention, STEM classrooms frequently fail to include diverse learners equally, which is affecting their sense of belonging, active participation, and equal contribution in the classroom and workplace (Valdez & Kelp, 2023; Xie & Ferguson, 2022). The paper proposes an inclusive pedagogical framework based on the principles of Universal Design for Learning (UDL) and Culturally Relevant Pedagogy (CRP). The framework will help integrate EDIA into instructional practices, curriculum design, and governance structures to foster an equitable and accessible STEM environment for learners from all different backgrounds.

Keywords: EDIA, Inclusive Framework, STEM Teaching, Culturally Relevant Pedagogy, Universal Design for Learning

BACKGROUND AND AIMS

The growing internationalization of post-secondary institutions, particularly in STEM (science, technology, engineering, and mathematics) classrooms, is bringing language diversity, cultural differences, and varied learning needs into the university classroom full of diverse learners (De Wit, 2019). Learners of different ages, genders, races, ethnicities, cultures, and physical challenges often feel less confident in STEM and report feeling excluded in the STEM classroom and laboratories (Batty & Reilly, 2023). Teachers often lack the required expertise and skills to support them, which causes inequity and exclusion in STEM education as well as the STEM workplace (Valdez & Kelp, 2023; Xie & Ferguson, 2022). In their critical review, Takeuchi et al. (2020) showed how bodies of learners are conceptualized in both tacit and explicit ways that are often reduced to a set of attributes or variables (e.g., gender, race, ethnicity, and socioeconomic status) in STEM. The main goal of this research is to propose a pedagogical framework to address the systematic barriers associated with EDIA in STEM.

PROCESS(ES) UNDERTAKEN

UDL (CAST, 2018a) and CRP frameworks (Ladson-Billings, 1995) are two commonly used approaches to grapple with the core principles and objectives of EDIA in social settings, classrooms, and teacher preparation (Courts et al., 2023; Super et al., 2020). However, these methods often fall short of addressing the issues of EDIA by undermining curriculum rigor and perpetuating stereotypes (Holland, 2022; Sewell et al., 2022). In this paper, a framework has been developed by considering the key principles of UDL and CRP to bring meaningful and

transformative improvements to STEM that could facilitate EDIA practices (Chita-Tegmark et al., 2012). Utilizing the framework across the classroom and institutional culture can address demographic performance gaps and enhance student retention and active participation. Faculties must consider redesigning course syllabuses, teaching strategies, and statements to best suit the diverse learners where the framework will guide them thoroughly (Fuentes et al., 2021).

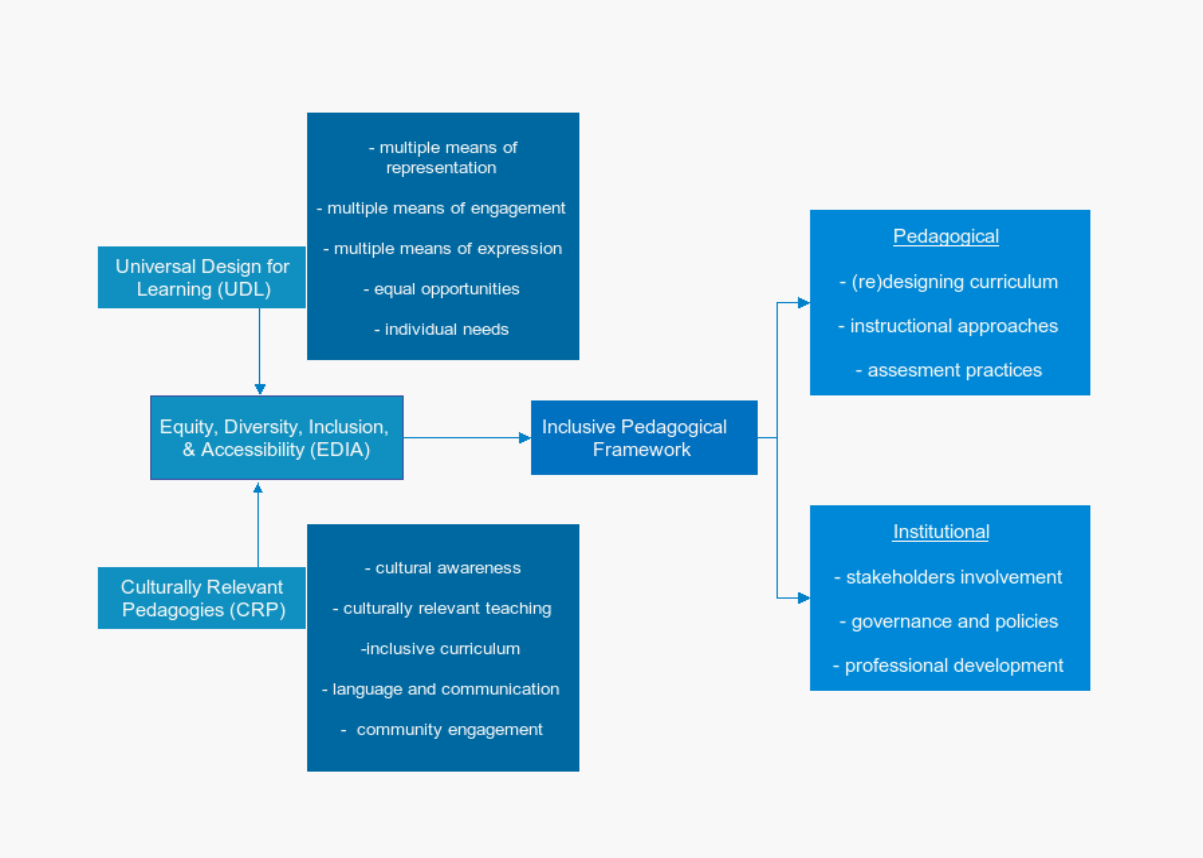


Figure 1: An inclusive pedagogical framework for STEM Education.

RESULTS AND CONCLUSIONS

STEM must persistently empower and develop from ontological heterogeneity reflective of students' lived experiences, especially those historically deprived and dominated (Bang & Marin, 2015). This conceptual framework (Fig. 1) outlines key elements of UDL/CRP frameworks that resonate with EDIA principles while establishing focus areas (pedagogical and institutional) for effective implementation of STEM equity and diversity. From a pedagogical perspective, teachers must implement changes in the areas described (e.g., curriculum, pedagogy, assessment). Similarly, institutional support must be ensured through stakeholders' engagement, policies, and professional training. UDL can foster EDIA opportunities for those with distinguished learning needs, and CRP will guide faculties to engage culturally diverse students in STEM. When designing course materials or professional development sessions, the provided features of UDL/CRP must be considered and incorporated. By implementing these approaches in teaching and institutional endeavors, lack of representation and academic disparities in STEM could be mitigated (Fuentes et al., 2021). This framework would be more effective with continuous readjustment and refinement through an iterative process and engaging learners, teachers, and other stakeholders to receive feedback upon implementation.

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SYMPOSIUM: MIGRANT AND REFUGEE DIS/ORIENTATIONS FOR MAKER EDUCATION

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BACKGROUND AND AIMS

A growing body of literature suggests that informal learning environments such as makerspaces can offer personally meaningful and culturally responsive educational opportunities to refugee learners of color (Desportes et al., 2021; Woodrow, 2016; Braden et al., 2023; Tan & Faircloth, 2023). Maker activities have been used to deepen refugee youths' engagement with disciplinary practices in STEM disciplines (Tan & Faircloth, 2023; Desportes et al., 2021) and literacy (Castrillo & Sedano, 2022). In such spaces, multimodal storytelling and documentary making have been shown to be powerful learning activities, because through participating in such activities, immigrant and racially minoritized learners can center voices of their communities (Lam et al., 2021) and create counter-models of systemic oppression through representing AI based surveillance of marginalized communities (Vakil et al., 2020).

In this paper, drawing upon a two-year, community centered, design-based research study (Bang, 2020; Guttierez & Jurow, 2016), we offer contrapuntal dis/orientations for maker education rooted in voices of refguee and migrant learners of color who are newcomers to Canada. Contrapuntality (Said, 1991) serves as a reminder that the sufferings of *endarkened* peoples are often silenced and invisiblized in technoscientific disciplines, including in educational contexts (Philip & Sengupta, 2021). While the extant literature (as briefly reviewed in the previous paragraph) has primarily focused on engaging refugee learners in STEM, computing, and literacy education in makerspaces, here we offer a *counter-point* and ask the following question: What can maker education look like when refugee and migrant voices are centred through co- designing counter-narratives of migration and refugeehood, using practices such as computational modeling, animation filmmaking, murals, etc.?

OVERVIEW OF PAPERS

We report four studies (papers) as part of this symposium. Paper 1 reports how newcomer youth siblings of color designed computational counter-models of migration and landing through centring carework. Paper 2 reports a study of how two Black youth subverted an animated model of climate change through designing speculative insects to represent colonial violence due to ivory trade on elephants in Ivory Coast. Paper 3 reports how Muslim youth women of color represented moral and affective dimensions of forced migration using cinematic animations. Paper 4 reports how Black and Muslim youth women of color represented gender-based harassment and marginalization using embodied art as part of a collective mural exhibition. Collectively, these papers offer a necessary dis/orientation to technocentrism (Sengupta et al., 2021) in maker education by illustrating how moral, intersectional and political dimensions of experiences of refugeehood and migration can be centered in makerspaces.

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PAPER 1: CENTERING DEEP CARE AMONG NEWCOMER SIBLINGS OF COLOR THROUGH CO-DESIGNING COMPUTATIONAL COUNTER-MODELS OF MIGRATION AND RESETTLEMENT

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BACKGROUND AND AIMS

In this paper, we investigate the axiological dimensions of epistemic and representational work in the context of newcomer youth of color co-designing computational counter-models (Sengupta et al., 2022) of migration and resettlement. We illustrate ways in which they supported and cared for each other in technoscientific spaces that are typically exclusionary to *endarkened bodies* (Philip and Sengupta, 2021). Using Banerjee et al. 's (2022) theoretical framework of *deep care*, which argues that centring marginalized voices entails the inextricable intertwinement of care ethics and care labor, we illustrate how collaborative re-design of hegemonic computational simulations as counter-stories of migration and resettlement can serve as a site for recognizing and centring deep care among newcomer youth siblings of color in an informal makerspace.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

The data that we present in this paper is from a co-design workshop where newcomer immigrant and refugee youth of color in Canada were engaged in redesigning and re-imagining computational simulation (e.g. Lunar Lander) that were entrenched in colonial and masculine ideologies (Wilensky, 2005). For this paper, we focus on 4 of the youth: Nezuko and Yasmine, two young women siblings who migrated from South Asia, and DK and EK, two young men in their teens, also siblings, who migrated from Ivory Coast. We conducted interaction analysis (Jordan and Henderson, 1995) of the audio and video recordings of workshop sessions. This involved coding gestures, bodily movements, and discourse between the siblings and in their interactions with the facilitators, to develop a deeper understanding of the ways in which the participants provided care and support to each other while engaging with the tasks at hand in the co-design process. While doing this analysis, we also engaged in contrapuntal listening (Gilligan and Eddy, 2017), so that we could make visible our own theoretical slips we made as researchers and facilitators.

RESULTS AND CONCLUSIONS

We present two key findings that reveal how deep care was enacted in the representational and epistemic work of computational counter-modeling (Finding 1), and how listening contrapuntally to the participants oriented us to the work of deep care that would otherwise remain invisibilized due to hegemonic lenses of co-design that the researchers brought to the table during facilitation and analysis (Finding 2). Central to Finding 1 was the recognition of reflexivity between epistemic and representational work of dis/orienting colonist models of moon landing and the carework that the participants performed to support each other through ethical micro-interactions, such as turning the focus on each other during design conversations, encouraging each other to remember sense-memories from their childhoods

in Azad Kashmir and recreating them computationally, and offering verbal and non-verbal affirmations that would amplify each other's voice in larger group settings. An illustration of Finding 2 could be found in our (researchers') initial sanctioning of playful physical squabbling and arguing between DK and EK in fears of them getting racially profiled as "troublemakers" based on institutional norms of polite behavior. Our initial framing of their interactions as a form of Black masculinity impeded our recognition of their care work. As we reoriented ourselves towards the Southern framework of *deep care* their interactions revealed care for each other where their recurrent banter and squabbles would ensure that the quieter younger brother felt included and centred in the work. The continuum of deep care as performed by the siblings for each other offer potential insights into how youth of color can resist the "device-centered discourse of control" that has come to define computing education (Sengupta et al., 2021, p. 24) and is also responsible for devaluing care and emotion work in technoscientific spaces (Fletcher, 2001).

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PAPER 2: SUBVERSIVE REPRESENTATIONS OF COLONIZATION IN NEWCOMER YOUTHS' ANIMATIONS OF CLIMATE CHANGE

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BACKGROUND AND AIMS

This paper builds on the critical scholarship on centering refugee children and youth in makerspaces (Tan & Faircloth, 2023; Woodrow, 2016) and illustrates the ways in which migrant subaltern imaginaries can dis/orient (Ahmed, 2010) the White Gaze (Morrison, 1998; Baldwin, 1963) in scientific representations (Sengupta et al., 2022). We offer an illustrative account of how two Black, migrant, refugee youth brothers subversively represented colonial histories of ivory trade in their homeland in Africa as part of an animated model of climate change that they co-designed with our team of researchers, including a climate scientist. State the main aims addressed in the abstract and/or research questions, if appropriate.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

Our study is part of the YARI-collective project, which is a community-centered, co-design research project focused on centering experiences of newcomer youth of color settled in Calgary, Canada. As part of this project, refugee youth of color from several countries in Asia, Middle East and Africa have been meeting weekly in co-design workshops over weekends, where they iteratively work on various creative projects to represent their counter-stories of migration and resettlement using computer simulations, animations, documentaries, photography, etc. As part of this project, two participants (DK and EK) collaborated with STEM education, climate science, and social science researchers to co-design a stop-motion and digital animation film "Red Skies and Forests Burning" to represent both their felt-impact and underlying causes of Canadian wildfires in 2023, which burned the largest area of land in North American history. Our data includes video recordings of the co-design workshops over a period of six months, as well as the media created during the process. However, besides the work of co-creating climate data visualizations of rising temperatures and risks of wildfires across Canada, DK and EK also created a subversive representation of colonial extraction of natural life. This is the focus of our analysis in this paper. We used the constant comparative method (Charmaz, 2014) to analyze our conversations with EK and DK, as well as their representational work, and our findings reveal how DK and EK both unsilenced their embodied histories of colonization through subversive representations, and resisted the work of making this public.

RESULTS AND CONCLUSIONS

While histories of coloniality are traditionally excluded from "scientific" narrativization of climate change, DK subverted expectations of depoliticisation in STEM by drawing an imaginary insect for his film, inspired by Côte d'Ivoire's elephants, that markedly embodied histories of Ivorian ecologies under French colonial rule. DL's elephant insect, which was named by the group as Elephantus Adimani, became a species born out of resilience against colonial violence inflicted upon elephants in the Republic of Côte d'Ivoire. They are neither mammal, nor insect, rather, they sit squarely outside the ambit of scientific classification. These insects made subliminal appearances in the animation, and were not integrated with the narrative explicitly (Figure 1). They also became part of a larger mural exhibit in a separate space during a public installation (Figure 2). In our conversations, DK also conveyed he does not wish to educate anyone interacting with his artifacts; rather, the fictive nature of his "insect" was meant to encourage audiences of his movie to do their own research into Côte d'Ivoire's history



Figure 1. Screenshot from the film "Red Skies and Forests Burning" co-designed by DK and EK

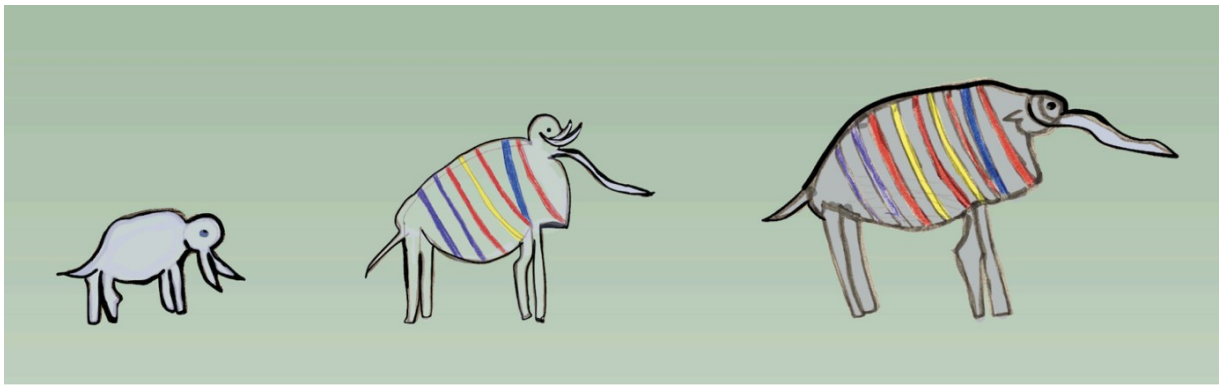


Figure 2. Life cycle of *Elephantus Adimani* as depicted in DK's mural

Our analysis illustrates two essential dis/orientations (Ahmed, 2010) that both reveal and resist symbolic violence (Bourdieu & Passeron, 1990) in academic spaces endured by youth and

learners of color (Sengupta et al., 2022). Firstly, the subversive positioning of DK's fantastical insects challenged normative models of climate change that silence histories of colonization. Secondly, by refusing to take on the sole responsibility of representing his country's history of violent, European colonialism for an unfamiliar audience in the Global North, DK and EK also offer an account of moral resistance, reminding us that the work of decolonizing the academy should not be rested on the shoulders of erstwhile, forcibly colonized people of color.

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PAPER 3: "MAKING" ANIMATED FILMS AS COUNTER STORYTELLING BY YOUNG MUSLIM REFUGEE WOMEN

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BACKGROUND AND AIMS

Scholars have argued for centering educational dignities of marginalized learners in informal makerspaces (Kayumova & Sengupta, 2022; Sengupta-Irving et al., 2022; Vossoughi et al, 2016). To this call, this paper advances a contrapuntal (Philip & Sengupta, 2021; Said, 1991) view of "making" through centering the complex work of representing the often silenced affective realm of experiencing displacement by Muslim, women refugee youth of color who voice a critique of imperial violence, global displacement, and refugee resettlement that structure the lives of racialized and marginalized immigrant and refugee learners globally. Our work is part of an ongoing community-centered, anti-racist research project focused on co-designing youth-centered learning activities for newcomer youth in Canada (Banerjee et al., 2023). Through a series of co-design workshops adopting a design-based research methodology (Cobb et al., 2003), 26 newcomer youth of color, many of whom were victims of forced migration, co-designed multimodal and proleptic artifacts of their experiences of migration, refugeehood and resettlement.

METHODOLOGY OR PROCESS(ES) UNDERTAKEN

In this paper, we present a grounded theoretical analysis (Corbin & Strauss, 1998) of how two groups of refugee Muslim young women of color centered dignity and personhood in making films of their stories of displacement. Our data includes youth participants' constructed artifacts, oral and written reflections, and video recordings of small group work in the weekly workshops. We used the constant comparative method (Charmaz, 2014) to iteratively code the data and compare the emergent codes with relevant theoretical perspectives, resulting in the refinement of both (i.e., codes and theoretical perspectives). In our analysis, we build on the dignity-affirming, ethical-political approaches in makerspaces, such as emphasizing the relationship between affect and ethical trails of micro-interactions between learners (Vossoughi et al., 2020), and centring embodied, multimodal and multilingual interactions between immigrant learners of color (Kayumova & Tippins, 2022), and offer two illustrative cases of the youths' counter-storytelling through the creation of animated movies: centering domesticity and familial life in Central and South Asian migrant homes, and amplification of moral and affective realms of experiences of escaping war.

RESULTS AND CONCLUSIONS

Our analysis reveals the following findings:

Filmmaking served as a way of counter-storytelling: The youths' motivation in making the films was two-fold: (a) to retell the experiences of atrocities and violence they have individually faced that affected their life chances and educational opportunities; (b) to counter the pervasive racialization and indignity due to misrecognition of their communal and ethnic histories in the Canadian institutional settings and muting of their spoken languages in

mainstream educational institutions (schools and higher education institutions that they are involuntarily consigned to).

Filmmaking served as way to make visible the hidden moral dimensions of refugeehood: As part of the film plotlines, one group explored the ethicality of abandoning the dead bodies in a zone of violence by foregrounding choices between honoring the dead alongside survival of those living. Another group, through a film about aliens visiting Earth, highlighted how trust of newcomers, rather than prejudiced beliefs of harm and hate, helps build love among all.

Our work shows what counts as meaningful making by the historically marginalized youth in makerspaces needs to center the heterogenous voices of the learners, "valuing their ways of knowing and being, self-determination, and self-expressions" (Kayumova & Sengupta, 2022, p.227), rather than being determined by technocentric and hegemonic approaches that have traditionally defined STEM and computing education (Takeuchi et al., 2020; Sengupta et al., 2021).

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PAPER 4: LOVE AND PROTEST: REIMAGINING MAKING THROUGH INTERSECTIONALITY

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BACKGROUND AND AIMS

The scholarship on gender in maker education has predominantly focused on broadening participation of women and girls in disciplinary practices in computing and STEM disciplines (Kafai, 2018; Litts et al., 2019). In this paper, we offer a contrasting orientation to maker education through centering intersectional voices and experiences of gender-based oppression of migrant and refugee young women of color in Canada. Rather than immersing them in discipline-based practices in STEM and computing education, we ask the following question: how can making activities render visible gendered and racialized, intersectional harms inflicted on newcomer refugee and migrant, young women of color in Canada?

Intersectional theorists have historically centered embodied expressions of gendered, raced, classed and sexual oppression as a form of resistance to hegemonic erasures of bodies of colour (Lorde 1984, Collins 1990). Black feminist scholars like Collins (1990) contended that one mechanism of maintaining white dominance over bodies of colour was through controlling images that homogenized bodies of colour, especially feminized bodies of colour into stereotypical tropes that cast these bodies as social relegates. In this paper, we demonstrate how three newcomer women high school students of color articulated deeply felt gendered and racial pain by representing the embodiment of this pain through mural art.

METHODS

The three young women centered in this paper are Rosanna, Queztal and Lou, who are all high school students. Rosanna is Black, Queztal is Latina and Lou is South Asian. In weekly co-design workshops with the researchers held over six months, they shared through various forms of storytelling how they had been othered, invisibilized, and hypervisiblized (Lorde 1984) in institutions and public places through gendering and racialization of their bodies. In co-designing artifacts for the mural they gave representational form to the othering (Said, 1991) experienced by them. The data for this paper includes video and audio recordings of conversations and interactions between the youth and research team members during the co-design workshops, that took place over a period of 6 months in the form of weekend meetings. The data was then transcribed and analysed using constant comparative methods (Charmaz, 2014). Our findings are presented in the form of illustrative cases, which reveal how the participants' artistic representations made visible the intersectional forms of oppression that they had to endure on a daily basis as marginalized, young women of color in the Global North.

FINDINGS

Quetzal designed thick red lips by cutting a silk red fabric and pinning it to a blue silk fabric that was proxy for a feminine dress with the words “very exotic to behold but not as important as be taken care of.” The lip on the dress represents the objectification of women and women of colour as their selves are reduced to being sexual other meant for consumption (as the lips suggest) both in her home country and in Canada. In Canada, the exoticization Quetzal impresses in her making is what Collins (2004) has called racial sexual politics of othering feminized bodies of color.

Lou’s illustration of thick, overflowing hair, made of multiple words/utterances like “wild”, “bleak”, “dejected,” “devastated”, “passionate” that express emotions she felt every time her long, wavy, unruly hair became the conduit for her gendered, racialized bullying. She commented that the mural became a form of embodied resistance to her experiences of being gendered and racialized. The piecemeal nature of Lou’s representations of the body parts is similar to Lorde’s (1984) observation of how Black and racialized women’s bodies of color are objectified and invisiblized by piecing them into projected parts offered up for violation.

Rosanna represented her racialized emotions (Bonilla-Silva 2019) by making of a self-portrait. The self-portrait features her face as two faces that are joined but looking away from each other, expressing joy and pain simultaneously, capturing her emotional duality. The portrait illuminates the paradoxes of her emotional worlds as she navigates misogynoir (Ray, 2022) in her everyday life in Canada. She centers joy even as she contends with depths or racism in the form of misogynoir in her school as a form of resistance to re-making the landscape of her racialized emotions that she reclaims through this representation. While critical scholars have viewed controlling images as a way to understand embodied oppression, Cohen (2001) explored the radical potential in the politics of owning these images as a form of embodied resistance to heteronormativity. The movement toward wearing natural hair among Black girls in school where their natural hair had been historically weaponized as a way of resisting the controlling image of unruly Black girlhood is an example of such resistance (Miles 2023).

DISCUSSION

This paper offers a necessary dis/orientation to technocentrism (Sengupta et al., 2021) in maker education by illustrating how moral, intersectional and political dimensions of experiences of refugeehood and migration can be centered in makerspaces through foregrounding voices of refugee and migrant young women of color. Making did not become a context for engaging the participants in computing or STEM activities – rather, they transformed making into a truly aesthetic (Dewey, 1934) activity in which they were able to express their intersectional experiences of gender and racialized oppressions that are otherwise muted and invisiblized in their institutional and disciplined lives.

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Symposium: A Logic-based Approach of Integrating STEM Subjects

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SYMPOSIUM OVERVIEW

There is an urgent need for a well-prepared workforce in STEM and Computing in this century (President's Council, 2010; Smith, 2016). There is consensus that computing should be an important part of the K-12 curriculum (White House 2017). Computing is not only a STEM discipline in its own right but also a discipline integral to the practice of all other STEM disciplines (STEM education act, 2015). It is a very challenging problem on how best we can teach Computational Thinking (CT) and how to integrate it with STEM disciplines to improve STEM learning (National Research Council, 2011).

One interesting line of research is on finding a systematic approach to integrate the teaching and learning of STEM subjects. One representative is the work by Sengupta and colleagues (2013) that employs agent-based computation to integrate STEM subjects. Motivated by this line of work, we studied the STEM subject integration problem. Our rationale can be best summarized below:

- Thousands of years of effort to understand how thinking works leads to the birth of *mathematical logic*, a formal form of logic. The greats contributed to this work include Aristotle, Boole, Frege, Cantor and Russel among others. Einstein has a good summary of the role of logic in science: *"Development of Western science is based on two great achievements: the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, …*"
- There are many decades of practice by computer scientists and AI researchers in solving problems across all kinds of application domains. In this process, logic has been expanded and methodologies developed to solve problems using logic.

Building on the work in AI (knowledge representation and reasoning) and the nature of STEM subjects, we developed a logic-based approach to integrating the teaching and learning of STEM subjects including computing and AI themselves.

The logic-based approach has proven to be effective when we develop integrated curriculum in the context of science at middle school level (called LPK12), data science at high school level (called LogicDS), and chemistry at college level (called iChemistry).

We have carried out a preliminary study of the impact of LPK12 and LogicDS on students' learning and on professional development (PD). Our integrated curriculum has been used by hundreds of students, and in PD for tens of in-service and pre-service teachers.

Although logic has been universal and, together with grammar and rhetoric, was essential to a classical education, logic in its modern form is rarely covered in the current curriculum. As a result, it is new for us on how to measure students' learning of computing and STEM subjects through logic. A significant effort of ours is to study the development of assessment and to validate it.

In this symposium, we will report on the design of logic-based approach, an example data science curriculum based on this approach, a study of the impact of LPK12 on students' learning and the development and validation of an assessment for logic-based abstraction.

Paper 1: The Logic-based Integration Framework

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FRAMEWORK

The logic-based approach consists of the follow components

- Central task: develop a program for computers to answer questions automatically.
- The method of the development of such a program.

The development method consists of three components. The first is abstraction which consists of the following components. a) Questions. The questions can be from any STEM subject. b) Language. For any abstraction (whose definition is in the next bullet), we need a language. One of the most universal languages is *mathematical logic*. c) Abstraction. Once we have a language, we are able to use the language to *abstract* information relevant to our questions. The result is called *abstraction* (or a model). The questions are supposed to be answered from the abstraction through logical reasoning. d) Methodologies. When facing STEM problems, the abstraction is not always straightforward. Methodologies have been developed in STEM areas and explicated in Computer Science and Artificial Intelligence. Examples include:

- object-relation methodology to mode information for most questions about this world interesting to people,
- problem decomposition (or divide and conquer), and
- iterative refinement (of the abstraction).

The second is Programming. Abstraction forms a base for programming. By programming, we obtain a program from an abstraction using a particular programming language. Programs are executable by computers automatically. As a result, the program (and the associated abstraction) can be tested effectively (e.g., compared with an abstraction on paper). Computers also provide convenience for debugging the program (and the associated abstraction).

The final component is that the program/abstraction is iteratively refined based on tests (experiments) and debugging.

How does the logic-based approach integrate computing and a STEM subject? Logic describes the world by objects and relations among them. For any STEM subject, logic is the study of objects and their relationships. These objects and relations can be handily represented by the logic language. A logic-based approach provides a straightforward connection between underlying STEM abstractions, and programs, and the programming usually makes the learning engaging.

By consensus and standards on STEM subjects, we can also make an argument that logic based approach supports students' learning. In the well-known K-12 Computer Science Framework (National Research Council, 2012), the learning of science and engineering involves 8 practices: SP1. Asking questions and defining problems, SP2. Developing and using models, SP3. Planning and carrying out investigations, SP4. Analyzing and interpreting data, SP5. Using mathematics and CT, SP6. Constructing explanations and designing solutions, SP7. Engaging in argument from evidence, and SP8. Obtaining, evaluating, and communicating information. Our approach provides direct support of all of them except SP3. For mathematics, our approach covers its core practices as identified in the Common Core State Standards for Mathematics (Common Core State Standards Initiative, 2011): MP2. Reason abstractly and quantitatively, MP3. Construct viable arguments and critique the reasoning of others, and MP6. Attend to precision.

Paper 2: Develop a curriculum for data science using the logic-based approach

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APPROACH

Data science is revolutionizing science and industries, and the current job market has shown a strong demand for a workforce fluent in data science (NASEM, 2018; NSTCC-STEM, 2018). As an interdisciplinary subject, data science has its foundations in computing, math, and statistics among others by (NASEM, 2018), providing excellent opportunities for high school students to develop college-ready STEM competencies and prepare their future careers. However, developing an introductory data science course for high school students is challenging due to its foundations in multiple areas. This challenge provides an opportunity to apply our logic-based approach to developing an introductory data science course.

Data in data can be taken as objects and their relations that are interesting to human beings, and are amenable to be represented by logic. The concepts of statistics, a major discipline for studying data, can be precisely defined using logic. For example, population and variables can be defined by basic logic concepts of sets and functions: a *population* is a *set* of objects, and *variables* are functions mapping the population to values. The frequency of a value of a variable can also be represented logically. Let P be the population and $x: P \rightarrow V$ be a variable. The *frequency* of a value a in V is the number of individuals of P whose value is a under function x. This can be expressed using *set builder* notation as $len(\{b \in P: x(b) = a\})$ where *len* is a function from sets to their sizes. This representation can be easily translated into a program in programming languages such as R. We have shown how math, computer science, and statistics are unified by logic.

To develop a logic-based curriculum for data science, we gathered math, computing and statistics concepts from sources including *Introduction to Data Science (IDS)*, *Bootstrap Data Science curriculum*, *AP Statistics*, *GAISE II*, and *Data 8*: *The Foundations of Data Science*. We then wrote *precise definitions* for these concepts using mathematical logic. Next, we arranged these concepts in a logical sequence, reflecting their progression and interdependencies. We then identified necessary constructs for the mathematical logic language. We next connect statistics and logic to programming in a particular programming language. Each curriculum lesson began with a motivating example (for a concept, logic, statistics or programming) and a question(s) to engage students' curiosity, followed by the concept's precise definition. Examples and exercises were provided to reinforce the understanding. The lesson will end with programming practices.

The initial curriculum was piloted in classrooms and refined by working with teachers and findings from the analysis of the data collected from classroom implementation.

Paper 3: The impact of a logic-based integration of computing and science on middle school students' learning

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DATA AND RESULTS

To evaluate the impact of our developed curriculum using a logic-based approach, studies were conducted over two separate periods in 2018 and 2020, in a classroom of a STEM elective course at a middle school in the USA. Middle school students aged 11 to 15 were chosen for the study due to their demonstrated ability to employ logical symbols in relation to abstract concepts, as supported by research by Piaget (1972) and Vygotsky (1987). In 2020, with one teacher leading 317 students ranging from 6th to 8th grade through an 8-week module comprising two 50-minute sessions per week, the experiment encompassed activities including video-based lessons, quizzes, and an online post-test assessing computational and science content. In 2018 the participants were 167 students from grade 6th and 7th with one teacher.

Results from both studies revealed significant improvements in computational thinking among middle school students. The 2018 study shows us that both the 6th- and 7th-grade students showed significant development in their computational thinking skills, particularly in abstraction. The effect sizes, measured by Cohen's d, were large, and the normalized gains were medium. This indicates that the modules effectively helped most of the participating students make considerable progress in abstraction skills. Students were given questions that were specifically developed and validated to measure their abstraction skills. From the student responses of 6th grade students, the effect size index (Cohen's d) is 1.36, and their normalized gain is 0.48. For 7th grade students, Cohen's d is 0.82 and their normalized gain is 0.39. In the 2020 study, we explored different levels of abstraction and programming to better understand how well students learn these skills. Our data and analysis provide a detailed understanding of students' learning of abstraction and programming within the LPK12 framework. Students performed well at the basic level of abstraction. For example, they effectively represented knowledge as LP facts and asked questions using LP queries, both with and without variables. We found that students could build their reasoning process to predict the expected answers from queries. Most students had positive experiences with programming and showed debugging skills, demonstrating their ability to identify and fix errors.

These studies also revealed a significant increase in science knowledge among middle school students in the 2018 study. Most interviewees found the modules interesting, and nearly all believed that computing positively impacted their science learning. Integrating computing tools into the science curriculum made topics more interesting and fostered professionalism and engagement, as confirmed by positive feedback from interviewees.

Paper 4: Developing and validating an assessment to measure students' learning of logic-based abstraction

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ASSESSMENT

We are using a logic-based approach to integrate computing with STEM subjects for K-12. However, rigorous instruments measuring students' learning of abstraction are still rare. We developed our assessment tools to measure students' learning of abstraction. Our assessment tools included pre- post-tests, surveys, and interviews. The claim is our developed assessment can measure the student learning of abstraction. We validated our assessment tools using the argument-based validation approach proposed by Kane (2013).

The first step is making the interpretative argument which involves defining abstraction, creating a hypothetical learning progression to guide test development and developing a test according to the progression. Three major assumptions were made in this step, that the definition of abstraction aligned with existing literature, the hypothetical learning progression facilitated student understanding, and test scores accurately reflected understanding of learning progression components. We proved our assumptions using theoretical validation and empirical validation which are other two steps of argument-based validation. Our definition of abstraction agrees with the description of abstraction by Aho and Ullman (1992), Wing (2006), Sherman and Martin (2015). Our hypothetical learning progression is grounded in constructivism and aligned with NGSS standards.

Empirical validity was supported by data from 317 students, 11 of whom were interviewed, and 118 who responded to an online test. Face validity was confirmed by experts, while reliability was assessed through inter-rater consistency, item-rest correlation, item difficulty, and discrimination. Protocol analysis-based validation through interviews and modern test theory-based validation via Confirmatory Factor Analysis further bolstered the assessment's validity. Overall, the results from both theoretical and empirical perspectives were positive, affirming the effectiveness of the assessment tool in measuring students' understanding of abstraction.

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