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PROCEEDINGS OF THE

27TH ICMI STUDY CONFERENCE

MATHEMATICS EDUCATION AND

THE SOCIO-ECOLOGICAL

Editors: Kate le Roux, Alf Coles, Armando Solares-Rojas, Arindam Bose, Catherine P. Vistro-Yu, Paola Valero, Nathalie Sinclair, Mariam Makramalla, Rochelle Gutiérrez, Vince Geiger, Marcelo Borba.

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THE 27th ICMI STUDY: MATHEMATICS EDUCATION AND THE SOCIO-ECOLOGICAL

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PREFACE

A five-year International Commission of Mathematics Instruction (ICMI) study is designed to represent 'the state of the art' in an area of mathematics education, but takes a further step: it builds community towards harnessing current knowledge for further knowledge contributions and anticipates new possibilities.

As a named topic in international mathematics education forums, 'Mathematics Education and the Socio-Ecological' is relatively new compared to many others in the field. Yet there is wide recognition of the urgent need for thought leadership to consider what is and might be the role of mathematics and mathematics education in multiple, intersecting, social, political, and ecological issues such as climate change, poverty, inequality, health crises, discrimination, and marginalization. There is also increased attention to how traditions such as critical mathematics education, decoloniality, ethnomathematics, feminist and new materialist thought, Indigenous ways of knowing, and mathematical modelling offer resources for research and practice in the interdependencies of mathematics education and the socio-ecological.

These published ICMI Study 27 Conference Proceedings represent a significant step in the ICMI Study 27 process of community building and knowledge production. Prior to the announcement of the Study, a one-day, online, ICMI symposium – the first such ICMI event – brought together 170 participants from diverse contexts to discuss work in this area of interest, in sites such as classrooms, universities and community spaces, in interdisciplinary relations with other subjects, and including issues such as teacher education, research practice and policy (see the **proceedings** here).

The ICMI Study 27 Mathematics Education and the Socio-Ecological Discussion Document (Coles at al., 2024), was published in January 2024, an edited version is the Appendix (p.519). The discussion document was conceptualised and authored by the 13-member International Programme Committee (IPC) listed below. The Document invited empirical and theoretical submissions (of eight pages) from across the globe, of those working on issues in mathematics education that span social (including political) and ecological (environmental) problems, and related ethical concerns. Collaborations involving researchers, teachers, teacher educators, policy makers, and other stakeholders from diverse contexts and sites of education were encouraged. Authors were tasked with responding to one of the four study themes: (A) Aims of mathematics education; (B) Scales of mathematics education; (C) Resources of and for mathematics education; and (D) Mathematics education futures. These themes were conceptualized and are led by: Paola Valero and Nathalie Sinclair (A); Mariam Makramalla, Rochelle Gutiérrez and Armando Solares-Rojas (B); Marcelo Borba and Vince Geiger (C); Arindam Bose and Catherine Vistro-Yu (D).

The paper review process was aligned with the orientation of ICMI Study 27 towards fostering a knowledge community that offers thought leadership on and opens space for new directions in mathematics as it relates to the socio-ecological across local and international levels. In an open review process, each submission was reviewed by two or more members of the ICMI Study 27 IPC, all of whom are recognised internationally as experts in this area of mathematical education. Authors received detailed, constructive feedback on their papers, with a particular focus on the (potential) contribution of the paper to thinking about mathematics education *and* the socio-ecological.

Following the review process (which included, for some authors, the option of submitting a revision for further review by IPC members), all the papers that follow were accepted. These are presented alphabetically by Theme in this volume. Copy editing was overseen by Alf Coles and Kate le Roux and supported by Arindam Bose and Armando Solares-Rojas. We recognize these different kinds of contributions in reverse alphabetical order, in the listing of editors of this document.

As co-chairs of ICMI Study 27 we express sincere gratitude to many in the mathematics education community, both local and translocal. We thank the ICMI Executive Committee for affording the space for this important and timely work, as well as the administrative support offered by ICMI. We thank the ICMI Study 27 IPC for their generosity – offering their time and expertise to provoke and push our thinking about mathematics education in interdependence with the socio-ecological. We thank the Study Conference Local Organising Committee (listed below) for creating the space at Ateneo de Manila University, Quezon City, Philippines, for conversations across diverse contexts towards new directions for research and practice.

Alf Coles and Kate le Roux

ICMI Study 27 Co-chairs.

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    a) Mathematics Department, School of Science and Engineering
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    e) Office of the Assistant Vice President for University Partnerships and Internationalization
    f) Office of the President
    g) Ateneo Institute of Sustainability
    h) Ateneo Art Gallery
    i) Manila Observatory

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3. Ecology and Jesuits in Communication

We also express our appreciation to Lena Koch (IMU Secretariat) who assisted us which such efficiency at every step along the way.

CROSS-CULTURAL EXPERIENCES IN CURRICULUM INNOVATIONS: VOICES FROM ASIA

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In this paper, scholars from three Asian countries share their collective experiences in curriculum innovation. The common point being highlighted is the need for countries to focus on the very heart of mathematics education – its people. Mathematics in schools and other institutions of learning should draw from Indigenous knowledges and unique contexts of its people, paying special attention to the rich cultural heritage of the communities. We argue that mathematics curriculum is part of a socio-ecological system and, thus, cannot be innovated piecemeal. Instead, by considering all factors that make up the ecosystem, curriculum innovations can truly be more responsive to the learners' needs in each culture. We identify and analyze the tensions that all three countries have experienced.

INTRODUCTION

Every country hopes to provide the best education they could offer to their pupils. But clearly not all countries are the same; many struggle to reach the desired achievement levels for a variety of reasons – low budget, marginalizing policies, ineffective teaching methods, among others. Poor achievement levels are often attributed primarily to curriculum; especially in mathematics, often the first thing that a country scrutinizes is its curriculum. Education leaders scramble to "fix" the curriculum but fail to get to the heart of the problem or fall short in culling all interventions.

In this paper, we, scholars, from three countries in Asia, come together to share our ideas and experiences in addressing curricular issues in mathematics. Because we are scholars who are not in national leadership positions, our contributions to "fixing" the mathematics curriculum may be seen as small-scale innovations in mathematics. Yet, as we shall point out at the end of the paper, these small-scale curricular innovations must be given more attention as they address more the most essential parts that coherently make a mathematics curriculum truly responsive to the needs of their pupils. This is where the socio-ecological perspective becomes valuable. Curriculum, specifically, the mathematics curriculum is at the heart of an ecological system in mathematics education and as such can only be fixed by attending, synchronously and coherently, to the variables of the system.

CURRICULUM INNOVATIONS IN INDONESIA

Pendidikan Matematika Realistik Indonesia (PMRI) is an Indonesian adaptation of Realistic Mathematics Education (RME), a domain-specific instruction theory for mathematics founded by Freudenthal in the Netherlands (Sembiring et al., 2008; Zulkardi et al., 2020). The adaptation of RME into the Indonesian context was initiated as there was a growing awareness among Indonesian scholars of the need to improve mathematics teaching in Indonesian classrooms (Sembiring et al., 2008). The development of PMRI from 1994–2015, conducted using a bottom-up approach, included numerous programs aimed at introducing a new way of teaching and learning that emphasized students' activity in their reconstruction of mathematical knowledge under the guidance of the

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teachers (Zulkardi et al., 2020). Some of these programs included initiating the International Master's Program on Mathematics Education (IMPoME), conducting international conferences on design research, and organizing mathematical literacy contests (Zulkardi et al., 2020). These efforts resulted in research studies focusing on designing and testing innovative ways for students to learn mathematics through guided reinvention, which were published either in national or international journals. Additionally, the fifth author has also conducted studies on the implementation of PMRI in Indonesian schools (see Larasati & Rianasari, 2017; Rianasari et al., 2012; Rianasari & Julie, 2018). The research results from Indonesian scholars on the implementation of PMRI at Indonesian schools indicated that mathematics instructions designed based on the principles of PMRI make positive contributions to the quality of mathematics teaching and learning.

Reflection on the impact of the reformation movement

Despite the positive contributions of PMRI to mathematics teaching and learning in Indonesian classrooms, the mathematics performance of Indonesian students in solving mathematics problems situated in real-life contexts was poor, as evidenced by the PISA results released by the OECD. From 2009 to 2022, Indonesia ranked among the lowest-performing countries in PISA assessments. In the PISA 2022 results, 82% of Indonesian students did not attain level 2 proficiency, indicating that they could only solve simple problems requiring routine mathematical procedures (OECD, 2023). The stagnancy in students' mathematics performances in PISA assessments seems contradictory to the positive contributions of PMRI in schools.

Analyzing the main factors that caused this stagnancy is not an easy task since education, especially mathematics education, is a complex field. In addition to this, there have been very few studies criticizing the adaptation of RME in Indonesia. A study by Revina and Leung (2019) revealed that the RME adaptation in Indonesia has deviated from its original form. First, there were inconsistencies between the Indonesian curriculum and RME. While the Indonesian curriculum emphasizes the mastery of mathematical content, the Dutch curriculum emphasizes learners' cognitive and personal development, which aligns with RME (Revina & Leung, 2019). Second, the Indonesian curriculum implements a centralized decision-making process for the contents to be taught, which might hinder the realization of some characteristics of RME (Revina & Leung, 2019). These findings indicate that much of the research on the development and implementation of PMRI has not provided suggestions to orient Indonesian education policymakers toward finding a proper balance between RME and the Indonesian educational context. Third, the implementation of RME in Indonesia was somewhat inconsistent with the theory of RME, possibly due to cultural differences between Indonesia and the Netherlands. Indonesian culture, rooted in the Javanese culture, emphasizes compliance, obedience, and harmony, which differ significantly from Dutch culture (Revina & Leung, 2019). In conclusion, the findings of Revina and Leung's (2019) study indicate that much of the research on the development and implementation of PMRI has not provided a critical explanation to Indonesian mathematics educators on how to interpret the borrowed approach (RME) through their own culture and to identify what is best for their local conditions.

In conclusion, the analysis of factors influencing the mathematics curriculum innovation in Indonesia reveals a complex interplay of cultural, educational, and policy-related challenges. This discrepancy highlights the need for a deeper analysis of the factors influencing Indonesian mathematics education.

Integrating Ethnomathematics into Socio-Ecologically Responsive Education

The challenges faced by mathematics education in Indonesia extend beyond the classroom, calling for further research and critical reflection to ensure that curriculum innovations align with the socio-ecological realities of the country. Indonesia's rich cultural diversity, particularly among Indigenous communities, offers a unique opportunity to develop curriculum materials that are not only contextually relevant but also deeply rooted in these communities' cultural practices, knowledge systems, and lived experiences. The integration of ethnomathematics into the curriculum, particularly for Indigenous people in Indonesia, is illustrated by various culturally rooted practices. For instance, the Kampung Naga Indigenous community in West Java demonstrates the practical use of geometric concepts in their daily lives without formal mathematical education. The community's craftsmanship, architectural design, and traditional measurement systems embody mathematical principles that can be used to create culturally relevant mathematics education. This approach preserves cultural heritage and provides students with relatable and meaningful mathematical learning experiences (Hermanto and Nurlaelah, 2019). In another example, the Korowai people of Papua live in a unique socio-cultural environment where their traditional treehouse architecture and forest-related activities form the basis of their learning needs. Integrating these cultural elements into the school curriculum can help bridge the gap between formal education and the student's Ies. The school environment can be adapted to reflect these cultural aspects by incorporating traditional building designs and maintaining a connection to the surrounding forest. This culturally responsive approach helps ensure that education is inclusive, engaging, and relevant to the Indigenous students' cultural context (Fiharsono et al., 2024). These examples show how ethnomathematics can be a powerful tool to connect students' cultural backgrounds with their mathematics learning, making education accessible and meaningful.

CURRICULUM INNOVATIONS IN NEPAL

Nepal's current mathematics curriculum suffers from a one-size-fits-all approach, prioritizing rote memorization and theoretical content at the expense of real-world application and cultural relevance. This fails to cater to the diverse needs of students in a multicultural country like Nepal. Nepal boasts a rich cultural landscape. As per the 2011 population census, there are 125 ethnic groups and 123 linguistic groups in the country. Indigenous peoples (Adivasi Janajati) comprise 36% of the total population of 26.5 million (Upadhaya, 2023). However, the current curriculum ignores this diversity, focusing on standardized content delivery (top-down approach) instead of engaging their students through their lived experiences (bottom-up approach). This approach leads to disengaged learners and fails to cultivate a deep understanding of mathematical concepts.

The wealth of Indigenous knowledge systems within Nepali communities offers a valuable resource for curriculum reform. By interweaving math concepts with Indigenous knowledge and their lived experiences, the students develop a sense of ownership and a deeper understanding of math concepts (Panthi, 2021). However, incorporating cultural elements risks perpetuating a colonial narrative if does not address underlying power dynamics (Battiste, 2013). True integration requires a decolonized approach that acknowledges colonialism's legacy and social justice's importance. This involves critically reflecting on the current curriculum while seeking ways to integrate relevant Indigenous knowledge. For instance, the teachers can use "nanglo" (a traditional round woven bamboo tray) or "sikka (coins)" in the discussion of circles and "dhungro" (a bamboo barrel used for cooking) in the discussion of cylinders, drawing connections between these artifacts and formal mathematics. There is a need to construct a curriculum from a multicultural perspective.

Building a curriculum from a multicultural perspective also requires the use of critical theory as a lens, recognizing how social and cultural forces influence education (Yang & Li, 2019). This approach allows for studying curriculum practices within a sociocultural context, highlighting the challenges faced by educators during innovation. The country's current top-down curriculum development approach, which relies solely on subject experts, should be expanded to include a wider range of stakeholders, including students themselves (Sullivan, 2011). Cross-cultural learning research emphasizes understanding how students from diverse backgrounds approach learning. Connecting mathematics with students' communities' experiences and aspirations makes learning meaningful and can address issues like poverty, climate change, and social justice.

Connection between Mathematics Education and Socio-Ecological Environment

As discussed, Nepal's current mathematics curriculum suffers from a disconnect between rote memorization and real-world application. This gap extends to critical socio-ecological challenges like climate change, pollution, and resource management. We need a curriculum that bridges this gap and equips students to grapple with these pressing issues, especially since these are what their communities are deeply concerned about.

In other words, mathematics education must become more socio-ecological. This doesn't mean abandoning core mathematical concepts but finding ways to connect them to the environment and the social issues impacting it. Is mathematics useful to reduce pollution? Is mathematics helpful to address climate change issues? Is mathematics useful to reduce socio-ecological issues? The urgency is clear – the very systems sustaining life on earth are threatened. As Coles et al. (2024) argue, mathematics education needs to re-evaluate its role in addressing the broad socio-ecological crisis.

This requires a shift in perspective. Traditionally, we view ecological and social relations as separate entities. A more progressive approach recognizes them as entangled and interdependent. This "entanglement" offers a framework for reforming mathematics education. Coles et al. (2024) propose three key practices: listening for socio-ecological entanglement; attending to the scales of socio-ecological entanglements; and living entanglement as mathematics educators. There are several barriers to curriculum innovation through socio-ecological perspective including curriculum policy, bureaucracy, teachers' and students' interest, politics, geographical diversity, multicultural and multiethnic society. We can address the issues by engaging relevant stakeholders.

By embracing a socio-ecological approach through these practices, we can equip students not only with mathematical skills but also with the critical thinking necessary to address the environmental and social challenges of our time. This aligns perfectly with the call for a curriculum that incorporates cultural relevance and empowers students from diverse backgrounds.

CURRICULUM INNOVATIONS IN THE PHILIPPINES

The Philippines is home to over 9.84 million indigenous people, comprising 9.1% of the total household population (Philippine Statistics Authority, 2020). These communities live across the islands, have deep connections to their ancestral lands, and face significant challenges. The education system historically marginalized indigenous communities, but in 2011, the Department of Education

(DepEd) released a policy framework (DepEd Order No. 62 s. 2011) aiming to empower them in shaping their educational experience (Philippine Department of Education, 2011). The shift in the education curriculum was influenced by international agreements such as Education for All (1990) and the Millennium Development Goals (2000), which pressured national governments to provide inclusive education for marginalized groups (Victor & Yano, 2015). Following the release of the policy framework, DepEd implemented the K to 12 curriculum in 2013, focusing on addressing the diverse needs of learners, including indigenous communities. The Indigenous Peoples Education (IPEd) Curriculum Framework (DepEd Order No. 32, s. 2015) was released in 2015, providing strategies for tailoring the curriculum to the specific cultural contexts of indigenous learners.

Indigenization through Collaboration

learners by incorporating their rich cultural heritage and ecological context into the curriculum. This curriculum innovation has resulted in significant changes in classroom practices, as lesson preparations become collaborative endeavors, with teachers no longer being the sole source of knowledge. Learning extends beyond the classroom walls, taking place within the community's ancestral domain.

A cornerstone of this approach is "learning with" indigenous communities. This recognizes the invaluable knowledge and practices that Indigenous Peoples (IPs) possess. Indigenous elders and culture bearers are given significant roles in deciding curriculum content and delivery.

The collaborative project of the DepEd Indigenous Peoples Education Office and the Department of Science and Technology Science Education Institute (DOST-SEI) on indigenization in STEM education, where one of the Filipino authors serves as a technical expert, exemplifies this approach. In this project, a team of technical experts, teachers, local leaders, elders, and cultural knowledge bearers collaborate to indigenize science and mathematics lessons. In the Ilocos Region (situated in northern Philippines) leg of the project, the team focused on indigenizing mathematics lessons, which are arguably the most difficult to indigenize, for the Bago and Kankana-ey indigenous groups. One lesson plan developed under the study integrated the Bago's "panagrama" fishing method into probability lessons, later expanding to include geometry concepts.

The lesson plan underwent a rigorous development process, ensuring accurate representation of indigenous practices and values alongside sound mathematical content. Importantly, cultural practices were discussed in the context of change and sustainability. Using panagrama, the dangers of dynamite fishing were compared to the eco-friendly process, which involves natural resources.

The teacher who was developing the lesson plan was in constant consultation with elders and culture bearers to ensure that the indigenous practices and values were accurately covered in the lesson, and with the technical experts to make sure the math content remained accurate and challenging, maximizing learning opportunities. The project's ultimate goal is to empower teachers and create adaptable lesson plans for various indigenous communities. To ensure best practices are shared, the team communicates their approach through various speaking platforms, benefiting future efforts.

There are also independent efforts of helping in the contextualization of mathematics lessons for IPs. The second author, for instance, collaborated with teachers and elders of the Dumagat Indigenous group in developing lessons on addition and subtraction of fractions for Dumagat primary school students. The lessons leveraged on natural resources available in the ancestral domain of the Dumagat group, using these as springboards and learning aids. The lesson included a discussion of the Dumagat's practices of farming, betel nut chewing, and their core value of camaraderie. Doing so made the abstract concepts of fractions relatable and engaging, demonstrating the far-reaching positive impact that indigenization can have in these communities.

Indigenizing education in the Philippines faces challenges on multiple fronts. Standardized curricula clash with the unique needs of Indigenous learners, with rigid testing leaving little room for incorporating valuable local knowledge and cultural learning approaches. Gaining community support is also complex, as students often prioritize family and traditional activities over regular school attendance. This necessitates a more flexible academic calendar. Bureaucracy further hinders progress, with lengthy approval processes from various government departments stifling research and innovation in indigenization initiatives. Finally, logistical challenges inherent to remote locations can make research efforts difficult. Increased funding, improved infrastructure, and making Indigenous communities and schools more accessible are all essential. Despite these challenges, the potential benefits of indigenization are undeniable. Continued efforts are needed to address the challenges faced by indigenization initiatives and invest in culturally responsive education.

Socio-Ecological Issues and Practices that Influence Curriculum Innovations

Traditionally viewed as a theoretical subject, indigenization transforms mathematics into a tool for understanding the interconnectedness of social and ecological systems. By incorporating elements of indigenous knowledge, such as the Bago's "panagrama" fishing method or Dumagat practices, students grasp mathematical concepts while gaining a deeper appreciation for sustainable resource management and the relevance of mathematics in their cultural context. Thus, indigenization builds a holistic understanding of mathematics and its role in environmental stewardship. Furthermore, indigenization promotes inclusivity and equity. Collaborative curriculum development with indigenous communities ensures lessons resonate with their values and needs. It empowers learners by fostering a sense of cultural identity and environmental responsibility. Learning about traditional practices alongside mathematics creates a connection between cultural heritage and environmental sustainability. Indigenization addresses socio-ecological issues by enriching mathematical understanding and cultivating responsible and culturally aware future citizens.

SYNTHESIS

Looking across the curriculum innovations in three Asian countries, our focus centers on culturally responsive approaches considering socio-ecological factors, including learners' unique needs and context. A recurring theme is the significance of integrating cultural heritage and ecological context into the mathematics curriculum and addressing students' needs, as exemplified by Ethno-Realistic Mathematics Education in Indonesia and the process of indigenization in Nepal and the Philippines. The scholars' endeavors to create an inclusive, culturally relevant, learner-centered curriculum may be perceived as small-scale innovations. Still, they are pivotal in addressing the fundamental aspects of a mathematics curriculum. Listening to the different voices, we witness the dynamic interactions among curriculum innovations, socio-ecological factors, educational and cultural practices, and the evolving demands of society. Indeed, the mathematics curriculum lies at the heart of a socio-ecological system in mathematics education. The shared experiences shed light on various educational decision-making approaches, from the top-down model in Nepal and the Philippines to the bottom-up approach in Indonesia. While the top-down method limits diverse ideas and the bottom-up strategy struggles to catalyze large-scale improvements, the potential of collaborative efforts to drive innovation within a centralized curriculum is a beacon of hope. It is important to note that challenges in curriculum innovation are intertwined with complex socio-ecological issues.

Using the lens of critical theory, the researchers identified tensions in developing and implementing an inclusive and culturally responsive curriculum in mathematics classrooms. These tensions are not just challenges, but they are urgent issues that need to be addressed. First, there are tensions among teachers as they try to align their teaching tasks with indigenous perspectives or use resources provided by the country's leading government agency in charge of education. Changing the typical class structure is different from the usual mathematics teaching methods. The conformity demanded by the departments or bureaus sometimes limits or hinders the teachers' desire to innovate. It is hoped that the government or school leaders will allow for *reinvention* rather than merely *following* prescribed formats and structures for curriculum innovations. To Freire, reinvention "demands the historical, cultural, political, social, and economic comprehension of the practice and proposals to be reinvented" (Freire & Macedo, 1987, p. 133, as cited in Gutstein, 2012, p. 23). Another tension exists between the curriculum offered and the needed curriculum in mathematics classrooms. With the model of top-down education power, the national curriculum is prescribed, and the top government agency centralizes the management with some appointed government officials. Gutstein (2012) states that these authorities influence curricula and textbooks with little or no responsiveness to local needs or desires. Because of this, it is not easy to apply any innovation in curriculum or textbooks targeted at a specific area or group in all government-supervised schools. Lastly, drawing from Bishop's (1994) assumption that "all formal mathematics education is a process of cultural interaction, and every child experiences some degree of cultural conflict in the process" (Bishop, 1994, p. 16), the schools are different from social institutions (home or community). Tension exists between the school (formal mathematics curriculum) and the community (non-formal curriculum). With the unclear educational tasks, the learners encounter dissonance between out-of-school and in-school cultural norms.

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