Digital Tools in Mathematics Education: A Decade of Insights from the MEDEra Series

Viktor Freiman and Dragana Martinovic

Abstract. This presentation reflects on the 10-year retrospective of the Mathematics Education in the Digital Era (MEDEra) Book Series. The first volume utilized Activity Theory to highlight the transformative potential of digital tools in mediating contemporary mathematics activity. Spanning a decade (2013-2023), the 23 volumes of this Series provide a comprehensive examination of how tools, viewed through their inherent connections to broader activity systems, have driven advancements in both research and practice. The insights gained illuminate their critical role in fostering areas such as collaborative learning, self-directed learning, democratization, the emergence of discourse, and embodied cognition.

Introduction

The integration of digital tools in mathematics education has undergone significant transformation over the past decade. The Mathematics Education in the Digital Era (MEDEra) Book Series, spanning from 2013 to 2023 with 23 volumes, provides a comprehensive examination of this evolution. The foundational work in this series, *Visual Mathematics and Cyberlearning* (Martinovic, Freiman, & Karadag, 2013), established Activity Theory (Vygotsky, 1934/1962; Engeström, 1999) as a theoretical framework for understanding how digital tools mediate mathematical activity and influence learners' mental development when internalized (Jonassen & Rohrer-Murphy, 1999).

1. Theoretical Frameworks

Activity Theory provides a robust framework for analyzing how digital tools transform mathematical learning activities. These tools serve as mediators that reshape the relationship between students and mathematical content, creating new possibilities for conceptual understanding and problem-solving approaches.

The psychological and socio-cultural theory of instrumental genesis, rooted in Vygotsky's work, illuminates how artefacts become instruments through individual processes. This framework clarifies the reciprocal relationship between users and their tools, where the subject acts on the instrument while the instrument simultaneously acts on the subject's thinking. Haspekian's (2014) study on spreadsheet use exemplifies this dynamic relationship.

Further demonstrating its explanatory power, de Champlain et al. (2018) utilized instrumental genesis to analyze creativity in students' mathematical problem-solving within the CAMI virtual learning community (Freiman & Lirette-Pitre, 2009). Their findings showed that diverse student approaches, fostered by tool use, actively transformed the nature of mathematical knowledge.

2. Challenges in Digital Mathematics Education

Drawing on the theory of mathematical working spaces, we examine how the shift from paper-and-pencil to digital environments complicates instrumental genesis in mathematics education. While foundational theory highlights the appropriation of artefacts into instruments (Lagrange & Richard, 2022, building on Verillon & Rabardel, 1995), digital tools introduce significant challenges to achieving mathematical learning outcomes.

Research demonstrates that digital tool integration is not automatically beneficial. For example, Abboud and Vandebrouck (2023) show that GeoGebra use on tablets does not automatically lead to conceptual understanding for all students, emphasizing the need for teachers to be aware of digital tool "tensions." Furthermore, Freiman and Lingley (2024) illustrate how 3D printing software can demand mathematical knowledge (e.g., 3D geometry) far beyond curriculum expectations for young learners.

3. The Changing Role of Teachers

We particularly delve into the changing role of the teacher, emphasizing their function as a facilitator of student learning. The presentation explores the critical elements in establishing an environment where students can actively engage in educational activities, aligned with pedagogical principles, educational goals, and collaborative classroom norms. Special focus is given to the subject-object relationship (student-actor versus content knowledge) and its significance in attaining desired learning outcomes (Martinovic et al., 2013).

Integrating technology effectively in mathematics classrooms is complex, demanding heightened teacher awareness of the interplay between digital artifacts, curriculum, and mathematical understanding. This presentation utilizes the continually developing framework of instrumental genesis and orchestration to unpack these complexities, referencing studies such as Bureau et al. (2023), which reveal the subtle dialectical relationships in programming for mathematical inquiry.

4. Future Directions

We conclude by charting new frontiers in mathematics education, exploring the implications of rapidly advancing Artificial Intelligence (AI) tools and environments (including augmented reality, machine learning, and data science) for future teaching and learning paradigms. The ongoing evolution of digital tools continues to reshape mathematical learning, requiring adaptive pedagogical approaches and continued research into effective integration strategies.

References

[1] Abboud, M., & Vandebrouck, F. (2023). Tensions and Proximities in Teaching and Learning Activities: A Case Study of a Teacher's Implementation of Tablet-Based Lessons. In *The Mathematics Teacher in the Digital Era: International Research on Professional Learning and Practice* (pp. 181-209). Cham: Springer International Publishing.

[2] Buteau, C., Muller, E., Mgombelo, J., Sacristán, A. I., & Dreise, K. (2020). Instrumental genesis stages of programming for mathematical work. *Digital Experiences in Mathematics Education*, 6, 367-390.

[3] de Champlain, Y., DeBlois, L., Robichaud, X., & Freiman, V. (2018). The nature of knowledge and creativity in a technological context in music and mathematics: implications in combining Vygotsky and Piaget's models. *Creativity and technology in mathematics education*, 479-505.

[4] Engeström, Y. (1999). Activity theory and individual and social transformation. *Perspectives on activity theory*, 19(38), 19-30.

[5] Freiman, V., & Lirette-Pitre, N. (2009). Building a virtual learning community of problem solvers: example of CASMI community. *ZDM*, 41, 245-256.

[6] Freiman, V., & Lingley, J. (2024). Micro-tensions from students' prototyping in a school makerspace: Lessons from an unfinished work. In *Sociocultural Approaches to STEM Education: An ISCAR International Collective Issue* (pp. 259-293). Cham: Springer International Publishing.

[7] Haspekian, M. (2014). Teachers' instrumental geneses when integrating spreadsheet software. *The mathematics teacher in the digital era: An international perspective on technology focused professional development*, 241-275.

[8] Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational technology research and development*, 47(1), 61-79.

[9] Lagrange, J. B., & Richard, P. R. (2022). Instrumental genesis in the theory of MWS: Insight from didactic research on digital artifacts. In *Mathematical work in educational context: The perspective of the theory of mathematical working spaces* (pp. 211-228). Cham: Springer International Publishing.

[10] Martinovic, D., Freiman, V., & Karadag, Z. (Eds.). (2013). *Visual mathematics and cyberlearning*. Springer Science & Business Media.

[11] Verillon, P., & Rabardel, P. (1995). Cognition and artifacts: A contribution to the study of though in relation to instrumented activity. *European journal of psychology of education*, 77-101.

[12] Vygotsky, L. (1934/1962) *Thought and Language. The Development of Scientific Concepts in Childhood*. Cambridge, MS: MIT, p. 87-96.

Viktor Freiman
Université de Moncton
Canada

Dragana Martinovic
University of Windsor
Canada