

Replication-based learning in mathematics education

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Abstract

In the last ten years, more attention has been given to building a culture of replication in Mathematics Education. Many now agree that replication studies are essential to scientific research and should be carried out and published. This paper initiates a conversation about the need to explore and develop theories of replication-based learning to support the growth of future Mathematics Education researchers. We share our first experience running a replication project with eight graduate students in a Mathematics Education MSc program. After the project, we asked the students about what they learned. Their answers suggest several potential benefits of participating in replication projects. They saw the value in checking whether well-known findings hold true in their own context and considered what their results mean in practice. We suggest that introducing replication early in the training of future mathematics education researchers can help make its ideas and purpose a core part of their professional identity.

Keywords: communities of practice, graduate students, mathematics education, replication culture.

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Introduction

Over the past decade, cultivating a culture of replication in Mathematics Education has received growing attention. Although debates about the role of replication in education are longstanding, central arguments highlight that replication studies are vital for detecting errors in individual research (Bauernfeind, 1968) and for improving the generalisability of findings. In Mathematics Education, where both individual and contextual factors shape teaching and learning, replication studies help delineate the limits of generalisability. Furthermore, replication contributes to the development of knowledge that can meaningfully inform learners, teachers, and policymakers. Another way in which replication can benefit the discipline is by using replication-based learning to foster the professional development of future researchers in Mathematics Education. The current work aims to initiate a discussion on the need to study and theorise this issue.

The editors of the 2018 special issue of the *Journal for Research in Mathematics Education* initiated a discussion on the value of replication practices for advancing the discipline (Cai et al., 2018). Subsequent discussions have examined how various forms of replication may benefit the field. For instance, Sánchez Aguilar (2020) argued that replication studies can deepen understanding of phenomena in Mathematics Education. Replication also enables the assessment of the value of findings or theoretical proposals by providing objective, credible, and generalisable research results. Star (2021) identified key changes required to foster a culture of replication in Mathematics Education, noting that the prevailing approach has been to conduct “idea-initiated studies,” where researchers prioritise their own concepts over replicating the methods and results of prior studies. Star recommends supplementing this with more “results-initiated studies,” which build on previous findings to confirm, refute, or extend them. In such studies, researchers should closely replicate original methods, introducing and justifying modifications as necessary.

These ongoing discussions have led to notable progress in **the adoption of** replication practices within the Mathematics Education community. There is now widespread recognition that replication studies are a fundamental aspect of scientific research and should be both conducted and published. Despite this advancement, further efforts are required. We argue that it is essential to provide future mathematics education researchers with opportunities to understand the rationale and methods of replication during their formative training. In the following sections, we present arguments for involving graduate students in replication projects and share our exploratory experience. We also propose using the Situated Learning framework by Lave and Wenger (1991) to theorise how replication-based

learning may shape students' identities as researchers and promote a culture of replication.

Why learn about replication in graduate studies?

The formative role of replication culture has been emphasised in Psychology, a related discipline. For example, a student-led replication project replicated about half of the original studies, and further analysis identified research designs with higher replicability (Boyce et al., 2023). In Sociology, Stojmenovska et al. (2019) demonstrated that teaching replication studies promotes active learning. Reported benefits include learning from established scholars by following their research processes step-by-step, gaining a realistic understanding of the research process, including practical challenges, and contributing to knowledge accumulation by testing the robustness of key empirical findings. Additional experiences in the social sciences (e.g., Schwab et al., 2023) suggest that conducting replication studies enables graduate students to deepen their understanding of research design, data collection, and analysis by closely modelling previous studies, as well as to develop practical skills such as participant recruitment, obtaining IRB approval, and data coding.

Beyond the potential benefits for students, these experiences offer insights into the practicalities of replication-based learning. Faculty members play a crucial role in facilitating learning through replication studies. For instance, Schwab et al. (2023) argue that mentors can guide students to target a range of journals for conducting and publishing replications, thereby helping students develop essential publication skills. Mentors must balance fostering independent learning with providing guidance to ensure high-quality replication studies. Their expertise and familiarity with the research literature are also vital for helping students identify studies that are feasible to replicate. Stojmenovska et al. (2019) identified several challenges in teaching replications, including the need to recruit students for non-mandatory courses and to persuade them to participate. Additional challenges include assessing the feasibility of replication projects and advising against projects likely to encounter significant delays or obstacles within the time constraints. It is also important to guide students through data preparation and help them avoid and detect errors.

Although experiences from other disciplines are informative, the implementation of replication-based learning in Mathematics Education remains uncertain. The field is primarily applied and values both theoretical and methodological diversity. As a dynamic community, we continually seek innovative approaches to advance research. Adopting a replication culture requires a shift in research paradigms, moving from idea-driven studies to

results-based research that extends or challenges previous findings (Star, 2021). Replication-based learning may play a key role in supporting this transition.

Replication research can also enhance the impact on mathematics teachers and learners. While engagement with replication has historically involved a process of adoption, it should become an integral and routine aspect of research culture. The following section presents an initial exploration of this approach.

An initial experience with replication-based learning

We describe an initial experience implementing a replication project for graduate students. This exploratory study sought to identify the potential benefits and requirements of replication-based learning. In this qualitative research, we worked with eight students (five female) enrolled in the Mathematics Education MSc program at Cinvestav in Mexico City, all of whom were primary or secondary teachers with varying teaching experience. During their second semester, students were required to conduct a replication project as part of an Introduction to Mathematical Cognition course.

We selected the quantitative study, “Substitution and sameness: Two components of a relational conception of the equals sign” by Jones et al. (2012), which compares Chinese and English samples in their understanding of the operational, relational, and substitutive meanings of the equals sign. This study was chosen because it was included in the previous semester’s reading materials and its replication was feasible within the course timeline. Our intended learning outcomes included providing hands-on experience with quantitative research and enabling students to observe how established findings, such as the meanings of the equals sign (Knuth et al., 2006), may vary depending on contextual factors like teaching approaches and materials.

At semester’s end, after the project, we asked students four questions that Smith et al. (2021) used to gather feedback on a graduate student replication project.

1. What have you learned about the replication process?
2. What would you recommend to future students who are starting a replication project?
3. How useful has the replication process been in your graduate studies?
4. How can the replication process improve?

Here we present an interpretative account of students’ responses to these questions.

Results

What have you learned about the replication process?

When discussing the learning from the replication project, students emphasised the importance of replication for generalising across contexts and for making an impact on understanding local issues. For example, in the following extract, the student acknowledges that approaches such as the meanings of the equals sign are a topic that requires further study in the Mexican context.

Student 1: *Replication processes allow the use of tools developed by experts and their modification to conduct research on understudied issues in Mexico.*

Another learning outcome mentioned by the students was the acquisition of research methods and data analysis skills. Some students discussed using prior research as practical guidance for study design and results analysis, for example, in preparing a research project for their thesis.

Student 4: [The replication process] *allowed me to know how to make a questionnaire for investigating a mathematical idea.*

Finally, other learning outcomes mentioned by the students referred to gaining a sensitivity and practical understanding of how to engage with authentic contexts, i.e., schools, for conducting research, and an increased awareness about the importance of considering ethical issues in the design and implementation of a study. For example, students had to produce an informed consent form and engage with school authorities for ensuring ethical approval of the study. The following extract illustrates this kind of learning.

Student 3: *The research process, time management, and the importance of ethical documents.*

What would you recommend to future students undertaking a replication project?

This question helped us touch on different aspects of conducting research that students might have encountered in the replication project. They mentioned the importance of a broader, deeper reading of the topic to understand the theoretical framework and methods of the replicated study.

Student 2: *It is very important to have a deeper understanding of the theoretical framework, the methods (with an emphasis on the tasks employed in the study), and the findings of the previous replication studies before designing an action plan for successfully implementing the task replication.*

Apart from theoretical and methodological aspects, students also mentioned that, in the future, students conducting replication projects should consider practical issues, including project planning and negotiating access to schools for research.

Student 6: ... *And negotiating with the school where you are planning to apply the replication instruments, as well as considering the times and moments determined for that.*

How useful has the replication process been in your graduate studies?

Participants' responses indicate that replication projects provide valuable, hands-on experiences that introduce students to research practices in Mathematics Education. Students reported gaining direct experience with the research process. Several noted that the replication project enabled them to acquire transferable knowledge applicable to their thesis work, as illustrated in the following extract:

Student 5: *It was very useful, because we had to conduct a similar process again for our master's thesis, and having a previous experience eased our work.*

Some participants also observed that the replication project's results had positive implications beyond their academic experience and could benefit their teaching practices. In particular, the project fostered a deeper understanding of how students interpret the equals sign, as illustrated by the following extract:

Student 7: *I recognise that, as a teacher, I did not know what the equals sign meant, of course I understood it, but I saw it as something you develop with the learning of equations. Now I see that it is easier to approach the topic of equations if you learn well about the equals sign beforehand. You can learn from first grade in primary school as Japanese students do. Without doubt, I will focus more on the understanding of the equals sign when I am back to teaching with my students.*

How can the replication process improve?

To improve the replication project experience, participants suggested that closer interaction with experienced researchers would help them better understand the theoretical background and methods of the replicated study, as reflected in the following extract:

Student 4: *Personally, I would have liked to have more precise knowledge of the theory (more explicit guidance about the construction of the instrument, instead of just having the translation), and closer feedback to learn how to visualise if the obtained results are similar or different to those of the [original] authors.*

Some participants also emphasised the importance of extending the replication process to engage learners and practitioners, as illustrated by the following extract:

Student 8: ... *Maybe with a pool of schools that are willing to collaborate in the application of those studies.*

Discussion

Students' responses reveal several potential benefits of engaging in replication projects. They recognised the importance of critically examining the generalisability of established findings across contexts. As anticipated,

students reported that the replication project facilitated the acquisition of specific research methods and data analysis skills, consistent with previous studies (Boyce et al., 2023; Schwab et al., 2023; Stojmenovska et al., 2019). Another key learning outcome was recognising the need to thoroughly understand the theoretical framework of the original study. We argue that replication experiences can help students translate theoretical concepts into practice and interpret results within an appropriate theoretical context. Additionally, developing ethical awareness when conducting research in schools is equally significant and should be considered when designing replication-based courses or projects.

We highlight two key aspects from participants' responses. First, students recognised the importance of testing whether established findings are replicable in their local context, which is particularly relevant in Mathematics Education, where diversity and contextual factors are valued. Their interest in replicating the results from Jones et al. (2012) in Mexico suggests that such curiosity may foster theoretically driven engagement. Second, students reflected on the practical implications of their replication project's results, aligning with the discipline's emphasis on research impact. These findings provide insights for future research and practice in replication-based learning, such as evaluating the impact of replication projects on graduate students' experiences and determining which types of replication are most suitable for student involvement. We also emphasise the importance of situating the study of replication-based learning within a specific theoretical framework.

How to theorise about replication-based learning?

The results of this exploratory study suggest that replication projects offer a range of benefits for graduate students. Future replication projects should address curricular issues, such as the steps and resources required to integrate replication into existing graduate curricula and the assessment of the quality and impact of student-led replication. However, in this work, we focus on replication-based learning as a means of constructing identity and cultural practices.

Although graduate studies are institutional endeavours, becoming a researcher involves more than acquiring knowledge and skills; it entails becoming a member of a community. To understand how replication can become a formative practice that shifts research philosophy and practice, an appropriate learning theory that views learning as a social phenomenon is required. The situated learning in communities of practice perspective by Lave and Wenger (1991) provides such a framework. This cultural-historical approach defines Communities of Practice (CoPs) as groups where individuals share a common interest and learn from one another

through regular interaction. CoPs are characterised by domain, community, and practice. Membership involves a shared understanding of issues relevant to the community, and individuals collaboratively construct practices to address these issues. While institutional structures are necessary, the defining feature of a CoP is the identity members develop as they construct a shared understanding of what is important to the community.

We propose that the principles of the CoP approach can effectively frame future research on integrating replication-based learning into the development of a culture of replication. According to Lave (1991), learning is not solely an individual cognitive process but also a process of becoming a member of a sustained community of practice. In this context, developing an identity as a member of the Mathematics Education community and becoming a knowledgeable researcher are interconnected, with the former shaping and motivating the latter. We advance two initial questions: First, regarding the construction of students' identities, what kinds of identities can be formed through engagement with replication practices in graduate education? Second, what is the expected long-term impact of replication-based learning on constructing a research culture that values both ideas and results?

In conclusion, replication-based learning has significant potential to foster a culture of replication in Mathematics Education. For our community, replication is a relatively new practice that has prompted reflection on the discipline's purposes and methodologies. Introducing replication during the formative years of future mathematics education researchers can help embed its philosophy and rationale into their professional identity. As a result, replication may become a shared practice within the community.

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