"You Can't Unring the Bell:" Examining Relationships Between Objects, Tools, and Outcomes From a NIC Working Toward Critical Transformation in Undergraduate Mathematics

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Developing reflective practitioners can lead to and sustain new practices in undergraduate mathematics. In this study, we used Cultural Historical Activity Theory (CHAT) to examine relationships between objects, tools, and outcomes from a Networked Improvement Community (NIC) seeking to critically transform introductory mathematics. By examining interviews and observer field notes, we found three pathways that connected NIC members' individual and collective goals (objects), NIC activities and resources (tools), and NIC members' perspectives on teaching and students (outcomes). We found that sometimes objects, mediated by tools, led to outcomes, but not always. Although the transformation that NIC members envisioned was not realized, the experience shaped their thinking about teaching and students in impactful ways such that "You can't unring the bell."

Keywords: Institutional change, reflective practitioners, Cultural Historical Activity Theory, introductory mathematics

Despite evidence that traditional teaching practices do not serve a diversity of students, practices in undergraduate mathematics remain largely unchanged (Seymour, et al., 2019, Stains et al., 2018) and disproportionately impact the academic success and persistence of students belonging to historically underrepresented groups (e.g., racial/ethnic minorities, women, first generation students) (e.g., Olson & Riordan, 2012; Theobald et al., 2020, Totonchi, et al., 2023). Research shows that one way to effectively cultivate change is through engaging mathematics faculty in experiences that develop them as reflective practitioners. This grass-roots change strategy encourages and supports faculty in trying new instructional practices and sustains their commitment to change (Borrego & Henderson, 2014). Communities of faculty, administrators, and students can be particularly effective in prompting such changes. One structure for forming such teams is a Networked Improvement Community (NICs; Penuel et al., 2020). NICs engage in multiple cycles of inquiry and improvement (e.g., observe-plan-act-reflect cycles) to collect and analyze data and make data-informed decisions (Martin et al., 2020).

The project described herein involved members of a NIC at one institution working together toward critically transforming introductory mathematics. The purpose of this qualitative study was to understand how the original objectives (objects) of the NIC compared to its outcomes as mediated by activities and resources (tools). This NIC was part of the ACT UP Math grant, a research practice partnership that engaged institution-based NICs comprised of mathematics personnel (e.g., faculty, instructors, administrators, and students) to explore data on student performance and experiences in introductory-level mathematics courses in order to make critical transformations within their mathematics departments. The goal of ACT UP Math was to help mathematics departments achieve critical transformations in their undergraduate programs, specifically by increasing members' awareness of how historically marginalized students experience the dominant culture of mathematics.

Theoretical Framework

Drawing primarily from participant reflections and researcher field notes, we use Cultural Historical Activity Theory (CHAT; Engeström, 1987; Vygotsky, 1978) to examine relationships between the objects, tools, and outcomes of the NIC. CHAT is an anthropological framework used to explain the object-oriented activity of an individual or group of individuals (Engeström, 1987; Vygotsky, 1978). The CHAT framework has multiple iterations, for the purpose of this study we focus on the second generation CHAT framework (Engeström, 1987) as it highlights the importance of collective activity, including the social, cultural, and historical components that shape said activity. In this iteration of the CHAT framework, an activity system is conceptualized as involving seven components: subject, tools, object, outcomes, rules, community, and division of labor. A subject (i.e., an individual) uses tools to make progress toward an object (i.e., a goal). Through the successful use of mediating tools, objects are turned into outcomes of the activity system (Engeström & Sannino, 2017), but an individual's actions are shaped by the broader community in which they're situated, and the rules (or norms), and division of labor within that community which collectively govern how that community operates.

The CHAT framework has been applied to study how activity systems operate as they work toward transformative action. Reinholz et al., (2017) examined the efforts of departmental action teams (DAT) within university STEM departments and compared their objects, tools, and outcomes to a faculty learning community via an activity theory lens. Hancock and Miller (2018) focused on an activity system of K-12 teacher candidates within the Department of Special Education. The object of their activity system was learning to teach with inclusive practices, and alongside the governing rules, surrounding community, and division of labor, the tools collectively mediated the outcome of preparing teacher candidates for inclusive education.

In this study, the community of the activity system consists of the Tau NIC, the subjects are the NIC members, the objects are the members' collective and individual goals for their work, the tools are the resources, activities, and opportunities throughout the experience, the rules are the explicit and implicit norms determining how NIC members interact with one another, and the outcomes are the results of the NIC's efforts. We address the research question: *What is the relationship between the objects, tools, and outcomes of a two-year networked improvement community that sought to critically transform undergraduate mathematics?*

Methodology

Tau University is a public, research-oriented university in the Southeast United States. The NIC included 11 mathematics department members, nine instructors and three (not mutually exclusive) administrators. In the following paragraphs, we provide more context about the Tau NIC and describe how Subjects (Tau NIC members) made progress toward an Object (their collective and individual goals for the NIC) through the use of tools (resources, activities, and opportunities within the NIC).

Our study methodology is critical ethnography (Palmer & Caldas, 2015). Within this research-practice partnership (Coburn et al., 2021), we were embedded within the NIC community as ethnographic researchers and as members who regularly attended NIC meetings (e.g., Hagman et al., 2024). The primary source of data for this study is individual interviews conducted with NIC members during Jan-Feb 2025, which occurred at the conclusion of their (formal) work as a NIC within the ACT UP Math project. We triangulated quotes from NIC members with a secondary data source, observation field notes that two researchers completed during each monthly NIC meeting. Since the NIC operated as an activity system, the observation

notes allowed us to look up specific tools and events that NIC members mentioned in interviews and create a cohesive story of the NIC's journey. All names are pseudonyms; most NIC members opted for the research team to select a pseudonym for them.

We operationalized the second generation of CHAT as an analytical framework (Engeström & Sannino, 2017) to describe the work of the Tau NIC as an activity system. Our data analysis consisted of several iterations of analyses for each data source (e.g., interviews, observation field notes), similar to narrative coding (Saldaña, 2016). In previous work, we described the community of the Tau NIC and focused on their early efforts during the first year, as described by the NIC's three co-leaders (Bennett et al., 2025). Our prior analysis focused on the implicit rules that existed in the NIC (e.g., collegial, honest discussions during meetings), which led to the leaders establishing an explicit rule that deficit-oriented discourse about students, such as student lack of preparedness, was "off the table" for NIC meetings. The co-leaders shared that dwelling on topics about which they did not have agency hindered their progress as a NIC, thus, creating a rule that limited unproductive conversations helped the NIC focus on achieving their goals. The analysis of this study continues through the end of the project and captures NIC members' reflections on their overall experience.

Engeström & Sannino (2010) elaborated on how to describe the object of an activity system, emphasizing that "one needs to distinguish between the generalized object of the historically evolving activity system and the specific object as it appears to a particular subject, at a given moment, in a given action" (p. 6). Similarly, in our analysis of individual member interviews within the collective NIC experience: we found that individual-level objects did not always match the collective NIC goals, similar to the idea that "the generalized object is connected to societal meaning, [while] the specific object is connected to personal sense" (p. 6). Thus, we analyzed parallel planes within the NIC activity system (Grimalt-Álvaro, & Ametller, 2021).

Grimalt-Álvaro and Ametller (2021) describe how each element of the second generation of CHAT can be viewed through different planes, or grains of focus. For instance, the Tau NIC is an activity system situated within a mathematics department; thus, the subject could be defined as an individual member or the entire NIC (or perhaps, the entire department, if the department was working toward similar goals). Selecting a particular plane of focus determines other components of the system, that is, selecting the individual plane dictated that objects correspond to individual NIC members' goals. However, as Grimalt-Álvaro and Ametller (2021) note, the planes cannot be held fully separate, as they are still part of the entire activity system. Thus, we analyzed the NIC activity system along the individual-level plane, but recognized that NIC members were situated within the NIC community and had some shared objects, tools, and outcomes. The relationship between these components are described in our findings.

Findings

In this section, we share characteristics of the Tau NIC as an activity system. We focused on the individual plane of analysis to identify Objects (goals), Tools, and Outcomes of NIC members and then organized them into salient themes they expressed in common. Then, we explore the relationship between these components by providing rich examples of the connections between them.

Objects

When the Tau NIC formed, their stated, collective goal (object) was to achieve critical transformations in their undergraduate mathematics program. In reality, "critical transformations" were interpreted and operationalized in various ways; namely, each NIC

member held a different idea about the goal of the NIC. NIC members operationalized "critical transformations" as a "massive, structural change" that was "truly innovative" and gained "buy-in from the whole department." Beyond this notion of grandiosity and overall improvement, there was not a tangible object. In this way, the specific object varied as it related to a specific subject (each NIC member) at a given time. Here, we share individual-level objects that at least three NIC members held in common.

1. Change course content and policies and develop shared resources for teaching,
2. Help students learn and develop metacognitive skills,
3. Challenge perspectives about students and "change hearts and minds"
4. Learn how to collect and analyze student data, and
5. Develop relationships and collaborations with colleagues.

In a later section, we describe in more detail the challenges, barriers, and frustrations that NIC members faced as they worked toward critical transformations.

Tools

Faculty described several tools that influenced them or their experiences in the NIC. We organized these tools into four primary themes:

1. opportunities to reconsider traditional approaches to undergraduate mathematics teaching and learning and the impact on students overall and on historically marginalized populations in particular,
2. reflection exercises to surface attention to cultural biases and their own teaching practices,
3. qualitative and quantitative data collected from their students, and
4. resources to support student learning.

The NIC read and discussed articles on traditional approaches to mathematics and the impact on students' sense of belonging, motivation, and academic outcomes. They took cultural bias assessments and viewed recordings of themselves teaching class with attention to their interactions with students and how different students were engaging in the learning experience. Qualitative data about students' experiences in NIC faculty's courses and suggested improvements were collected from students through interviews, focus groups, small-group discussions, and end-of-course surveys. NIC faculty also collected qualitative and quantitative data by surveying their students at midterm and toward the end of the semester about their experiences during class (e.g., opportunities to ask questions) and outside of class (e.g., working, care-giving), and their academic engagement, self-efficacy, and sense of belonging. These data were compared to students' grade predictions and performance on assessments at mid-term and at the end of the course. The NIC discussed patterns and trends in the data and reflected on what they expected and what the data revealed. Then, NIC faculty discussed ways to address challenges that students were having in mathematics courses and shared ideas related to cultivating a growth mindset and teaching students how to learn. Through the use and discussion of these tools, faculty were regularly reflecting on their own beliefs and practices and students' learning experiences, identifying instructional changes they could make to better support their students, and then supporting each other as they planned, implemented, and revised their practices.

Outcomes

Individual NIC members reflected upon their journey within the NIC, and in so doing shared multiple outcomes from their experience. The majority of outcomes related to an individual or

personal outcome rather than a collective outcome; for instance some members felt that their own awareness of student perspectives increased. However, many of these individual outcomes were shared in common by (at least three) members of the NIC. Here, we share the outcomes which were most salient:

1. an increased knowledge and appreciation of student perspectives based on data,
2. a shifting perspective on one's relationship with students,
3. increased critical consciousness,
4. closer relationships with colleagues, and
5. an increased willingness to experiment and adapt instructional practices in their own classroom.

For example, some NIC members described having a greater understanding of the factors impacting their personal relationships with their students. One NIC member, Ethan shared how being involved in the NIC increased his awareness that "different people have different needs," and also emphasized that this knowledge made interactions with students more complicated, or a "mixed bag".

Relationship between Objects, Tools, and Outcomes

Recall in the CHAT framework, tools are intended to mediate from the activity system's object to the outcome. In our analysis of NIC members' objects, tools, and outcomes along the individual plane, we found the common themes listed above for each CHAT component. To explore the connections and relationship between the Tau NIC's objects, tools, and outcomes as an activity system, we now look across components and focus on specific examples from NIC members. We observed that the three CHAT components were evident in different combinations. Sometimes, tools clearly mediated the path from an object to an outcome. However, there were also times when specific tools led to an outcome, but an initial object was not explicitly stated, or other times, objects were realized as different outcomes due to a lack of mediating tools. We organized the examples of the relationship below to illustrate these relationships as reflected in the data. Figure 1 illustrates three different pathways we observed that connect CHAT components within the Tau NIC activity system. Each pathway is indicated by a different color.

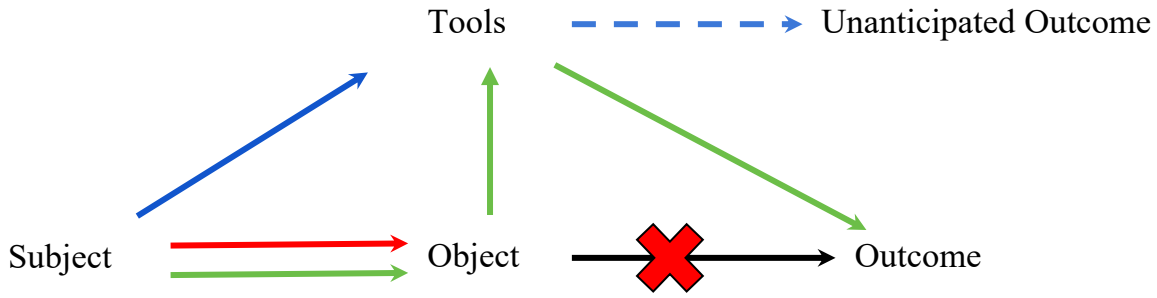

Figure 1. Pathways of connections between CHAT components within the Tau NIC activity system

Objects, mediated by tools, led to outcomes. For some members, all CHAT components aligned in the ideal relationship that the framework emphasizes. Kayla's experience illustrates this connection: her goal of supporting students' metacognitive development (Object #2) shaped how she approached student data (Tool #3). She explained that she would need to have a goal in mind before looking at the data, so that she could better focus her analysis. By organizing and interpreting student data through the lens of fostering students' metacognitive skills, she identified concrete strategies for course development (Outcomes #1 & #5), later noting, "I have

opportunities to do instructor meetings with my college algebra instructors [and metacognitive skills] will be the focus of the meetings, because the data said, this is what our students need. So to me, that's the biggest takeaway." Kayla identified a goal and reached her desired outcome through the mediation of proper tools provided by the NIC. This relationship between subject, object, tools, and outcome is indicated by the green pathway in Figure 1.

Specific tools led to a [new] outcome. In other cases, tools were the most salient link between the NIC experience and outcomes, but there was no explicitly stated object at the outset. Jordan, for instance, described how metacognitive discussion prompts (Tool #4) and student surveys (Tool #3) provided through the NIC informed his classroom practices (Outcome #5): "This allowed me to think about ways in which I can foster better cognition in my classroom." Similarly, Adele emphasized how the collection of student data (Tool #3) prompted a shift in her instructional priorities (Outcomes #1 & 5) to focus on teaching students how to learn: "After seeing the numbers… it made me shift my attention in other directions instead to work more on how to help students with their study skills and their learning skills and all that." This relationship seemingly excluded the object component of CHAT, which led to an unanticipated or secondary outcome. We indicated this relationship between subject, tools, and outcome (2) by the blue pathway in Figure 1.

Lack of [the right] tools led to a disconnect between object and outcome. Ethan joined the Tau NIC with a goal of collecting and analyzing student data (Object #4) to better understand the relationship between student identity and learning, specifically, how a student's identity might impact their learning of mathematics. However, the NIC struggled to find the relevant tools to address this goal; they collected survey data about student identity (e.g., demographics, learning disabilities; related to Tool #3) but were unable to come to any conclusions about their analysis that were clearly connected to Object #4. Ultimately, Ethan reflected that the outcome of his experience in the NIC was a personal change in himself (Outcome #3):

> You ring a bell, and you can't unring the bell. And so I think [the NIC] has changed the way that I think about things. […] I think that the way that an individual's identity impacts them and everything, including their learning in a math class is– it's very complicated, and it's delicate. [...] Different people have different needs.

Ethan noticed that he became "overly aware" of his students in a more holistic way and that his increased critical consciousness would continue to influence how he interacted with students in his classes; he "can't unring the bell."

Other NIC members experienced a disconnect between their goals and outcomes. Abel shared, "when I joined the project, I thought we were going to, you know, create something that we could use in the course. And I saw that that wasn't happening right away, and there wasn't any sign of a concrete deliverable that we could get." Abel first states his goal of creating materials to use in his course (Object #1), then expresses his realization that the object would not come to fruition as an outcome. Similarly, Garrett hoped for the NIC to accomplish a "massive structural change," like new departmental policies on "using calculators and notecards" or "content changes to courses to make them more accessible to students (Object #1). He drew on initial tools, such as reading articles about other institutions enacting similar departmental changes (Tool #1) and then attempted (unsuccessfully) to get buy-in from Tau administrators. Ultimately, his object was not realized as an outcome but did lead to unexpected outcomes: "I didn't really necessarily pull off a big, huge structural change. But I think I made a significant impact to some students in my classes" (Outcome #2). The relationship between CHAT components described by Ethan's, Abel's, and Garrett's experiences is indicated by the red

pathway in Figure 1. We note that there was an attempt to use tools in these cases, but they were not used successfully to mediate a desired outcome.

Discussion

We addressed the research question: *What is the relationship between the objects, tools, and outcomes of a two-year networked improvement community that sought to critically transform undergraduate mathematics?* We investigated this relationship by first conducting analysis on the individual plane (Grimalt-Álvaro, & Ametller, 2021) to identify objects, tools, and outcomes that were meaningful to each NIC member, as well as relationships between these three components. This analysis aided us in describing how each of these three components were connected (or not) within the work of the NIC. Our analysis of pathways between components (see Figure 1) revealed three distinct relationship types: (a) a clear connection between object, tools, and outcome, (b) tools leading to an outcome (without an explicit object), and (c) a disconnect between objects and outcomes (due to a lack of the right tool mediating this relationship). To describe the third relationship, we shared examples of how objects fail to be realized as outcomes when the appropriate tools are not present. For a community aimed at achieving critical, institutional transformation, it may be imperative that the activities, resources, and opportunities available to individual members are aligned with explicitly stated objects.

We note that several of the tools used were chosen by the Tau NIC leaders or implemented due to recommendations from the larger ACT UP Math team. Additionally, Objects #3 and #4 were emphasized by the ACT UP Math project. These objects were realized as outcomes for a subset of individual NIC members, but as externally driven goals, they were not taken up by the NIC as a whole. Research on departmental action teams (DAT) to transform undergraduate STEM programs emphasize that departments are key locations for initiating sustainable change within the complex university system, but it is crucial that the "DAT's focal issue is not externally defined" (Reinholz et al., 2019, p. 66). Reinholz and colleagues argued that DATs should focus on the collaborative process of their work, suggesting that "the DAT begins with a series of activities to develop a shared vision, consensus on the focal issue, and a set of goals" (p. 66). In our past work (Hagman et al., 2024; Tremaine, 2024), we acknowledged the challenge of aligning individual goals to the collective efforts of the NIC and highlighted tensions that arose when there was a disconnect between the vision of the NIC and that of the project leadership team. In this study, we again observed this tension between competing goals. As others have recognized (e.g., Reinholz et al., 2017), there are advantageous and disadvantageous ways of including external influence on a community working toward change (e.g., via facilitators), which could be explored further in future studies.

In spite of challenges, the experience of participating in the Tau NIC helped to develop reflective practitioners. We found that through the NIC, faculty reflected on their own beliefs and practices and on students' learning experiences and outcomes, which in combination with their objects and tools, influenced outcomes impacting their perspectives on teaching and approaches to supporting students (e.g., Borrego & Henderson, 2014). For instance, Ethan's critical consciousness development, while not his initial intention, significantly impacts how he interacts with students and views them as whole, complex individuals. By first understanding the personal and intrinsically motivated goals of faculty, we can purposefully select the tools and objects of collective transformation efforts. This intentionality and alignment may result in sustainable changes and have long-lasting impacts on faculty members' teaching and views of students. We encourage those who work with mathematics department faculty toward institutional change to consider the alignment of goals, tools, and objects as they develop reflective practitioners.

Acknowledgements

This work was initially supported by a grant from the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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