DESIGNING INSTRUCTIONAL SEQUENCES FOR ETHICAL, CRITICAL AND MATHEMATICAL REASONING

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Designers of critical mathematics instruction have documented difficulties in simultaneously fostering the development of critical consciousness while supporting students in developing understandings of new mathematics. However, confining justice-oriented tasks to applications of previously learned mathematics limits the degree to which these tasks will be taken up by teachers. We describe our attempt to employ heuristics from the instructional design theory of realistic mathematics education [RME] to create a sequence aimed at developing students' critical and ethical reasoning while also developing new mathematical understandings of ratio, proportion and percents. We propose emergent adaptations to two of the realistic mathematics education design principles then propose an additional ethical principle to guide the development of future RME sequences.

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Ernest's work in the philosophy of mathematics education has set the stage for the argument of ethics as its first philosophy (Ernest, 2013). For Ernest (1998) "ethics arises from the ways in which persons live together and treat each other" (p. 9) including what is deemed right or wrong when making decisions and how we generate knowledge. He proposes that ethics should serve as the foundation for mathematizing and philosophizing and calls for "an ethics of mathematics" that acknowledges its social responsibility as well as its implications for freedom, justice, and cooperation (Ernest, 1998, 2013). "Ethics in mathematics education supports, and lays the foundation for, concerns about social justice" in that issues of social justice are concerned with the social activity of groups and the fair enjoyment of social benefits, while issues of ethics are concerned with interactions between people more generally (Atweh & Brady, 2009, p. 268). From this perspective, ethical considerations are based upon people's moral responsibility to one another, establishing "social justice concerns as a moral obligation, rather than charity, good will or convenient politics" (Atweh & Brady, 2009, p. 268). Accordingly, we view ethical reasoning as notions of what is right or wrong in social contexts, with considerations of social justice as one of its key components.

A primary goal of an ethical mathematics education is fostering students' epistemological empowerment through mathematics (Ernest, 2002). In other words, developing both mathematical and social empowerment in which the learner establishes a sense of self-efficacy in "the language, skills and practices of using and applying mathematics" in school settings, and their ability to use mathematics to "participate more fully in society through critical mathematical citizenship" (Ernest, 2002, p. 1). Such an education concerns the individuals' growth of confidence in using mathematics, creating knowledge, validating it, and transforming the world through mathematics (Ernest, 2002). Educators have attempted to develop students' awareness of the power that mathematics holds to both help and harm society through the teaching of critical mathematics, which aims to develop students' critical consciousness, or

awareness of social, political, and economic oppression (Frankenstein, 1983; Freire, 1970; Gutstein, 2006). If ethical reasoning is primarily concerned with notions of what is right or wrong, we see critical consciousness as the component of ethical reasoning concerned with identifying oppressive systems. While critical mathematics focuses on responding to these systems, ethical mathematics also includes the responsible creation of mathematical products. Many efforts at implementing critical mathematics have done so with students who experience intersecting oppressions; this is understandable, given that developing critical consciousness is a pillar of culturally relevant teaching (Ladson-Billings, 1995). Some scholars, though, have argued for the importance of developing critical consciousness of students from communities of privilege, proposing that without such consciousness, students from these communities may, wittingly or unwittingly, abuse the disproportionate power they wield, which continues the dehumanizing effects of oppression on both the powerful and those with less power (Kokka, 2020; Stephan et al., 2021). These scholars propose that critical mathematics, like any critical pedagogy, works toward liberating the oppressed and oppressors (Freire, 1970).

Tensions in Designing for Ethical and Mathematical Reasoning

Reports on efforts to design and implement critical mathematics lessons aimed at developing students' mathematical power and critical consciousness highlight the difficulty of the work. One primary tension, raised by numerous scholars, involves balancing the goals of developing students' mathematical power so that they can succeed in dominant mathematics while also developing their critical consciousness (Gutiérrez, 2002). Gutstein (2006) proposes that productively navigating this tension is possible but admits that he relied primarily on a reform-based but non-critical textbook series, *Mathematics in Context*, to develop students' mathematical power. Brantlinger (2013) also grappled with the tension between the two goals. After finding himself unable to navigate the tension by simultaneously addressing social justice and mathematical concepts, he then tried separating them hoping for later syntheses. Brantlinger ultimately concluded that he was unable to resolve the tension between the two goals, at least in the secondary mathematical setting of geometry which the project addressed. Other scholars document teachers' (rather than their own) efforts to implement social justice themed mathematical lessons and their attempts to navigate the tension by separating social justice contexts and the development of mathematical ideas (Turner et al., 2009; Bartell, 2013) or simply focusing primarily on either the mathematical goals or social justice goals, leaving the other goal as more of a background possibility if the opportunity arises (Bartell, 2013).

In our reading of the literature on critical mathematics and teaching math for social justice, we noticed that studies of implementation were well grounded in the literature on critical mathematics and tenets of teaching math for social justice, but these studies tend not to cite instructional design theories for developing mathematical ideas. In other words, while the social justice aspect of these lessons was grounded in theory, the mathematical aspect relied on the intuition of the teachers or instructional designers rather than an established instructional design theory. We hypothesized that this theoretical imbalance may contribute to the difficulty in designing for new mathematical concept development simultaneous with critical consciousness. In our attempt to address the goals of developing new mathematical ideas through ethical and critical contexts, we relied heavily on an instructional design theory that uses realistic contexts to ground the development of mathematical ideas.

Instructional Design Principles

To reconcile the aforementioned tensions, we anchored our study to critical mathematics frameworks (Frankenstein, 1983; Gutstein, 2006; Skovsmose, 1994) as well as the Dutch instructional theory of realistic mathematics education [RME] (Gravemeijer, 1994), which provides a robust set of design principles for developing sequences that develop students' mathematical understanding. Van den Heuvel-Panhuizen and Drijvers (2014) present six core teaching principles which correspond to instructional design heuristics: activity, reality, level, intertwinement, interactivity, and guidance. Rather than elaborate all six, we focus on the reality and level principles to illustrate how we foregrounded these particular heuristics in our design activity when confronted with critical and ethical challenges.

The *reality* principle advises that instructional sequences begin in *experientially real scenarios*. The term experientially real does not mean that problem contexts need to be authentic, or real-world, but rather the problem context needs to be imaginable, so that students can act on the problem elements in sensible ways. An earlier interview study of similarly aged students (Stephan et al., 2021) inspired an initial conjecture of how this principle might be adapted for critical mathematics instruction: we hypothesized that problem contexts in which students felt like they themselves were targets of oppressions could be a more experientially real starting point for students than situations where others were targeted.

The *leveling* principle describes the notion that students' understanding passes through various stages. Their early conceptions often involve concrete, context-bound solutions to initial problems. As their understanding develops, their *models of* these situations become more abstract and less attached to these problem situations, and become *models for* use in other, mathematically isomorphic situations (Gravemeijer, 1999). Our earlier work provided a hypothesis of how this principle might be adapted for the development of critical mathematics instructional sequences as well; we conjectured that students' initial understandings *of* how they themselves were targeted might lead to an empathy *for* other vulnerable populations.

Given our experience in designing RME sequences, we were hopeful that we could develop an instructional sequence that simultaneously developed students' understanding of new mathematical concepts (namely proportional reasoning and percent change) while also developing their critical and ethical reasoning. The following questions guided our study:

Research Question

When designing a mathematics instructional sequence for developing ethical and critical reasoning,

1. What adaptations to the existing RME design heuristics emerged and why?
2. What additions to the existing RME design heuristics emerged and why?

Method

Setting

In identifying a suitable context for our study, we drew on Kokka's (2020) conceptualization of privilege as the "set of advantages one group has over others, granted because of membership or perceived membership in social categories" (Kokka, 2020, p.3). This conceptualization considers race, socioeconomic status, and educational privilege, as well as other intersectional identity traits including, but not limited to, sexual orientation, gender, and ability status, that are both interrelated and influence students' experiences of privilege and marginalization (Kokka, 2020, p.3). As such, the instructional sequence was designed with partners who work at a school

we refer to as Lakeview Charter Middle School (LCMS). The student population at LCMS is approximately 68% White, 13% Black, 8% Asian or Pacific Islander, 6% multiracial, 6% Hispanic and less than 1% Native American. Families are responsible for providing transportation for their students to and from school. There is no possibility for students to have free or reduced lunch due to the requirement that students bring their lunch from home. Due to these requirements, the student population generally draws students from economically advantaged families. The Design Team consisted of the three co-authors (two white females and a white male in comfortable socioeconomic positions) as well as two LCMS teachers (one male and one female) and their principal (female), all three being people of color. The team met four times over the summer to brainstorm contexts and develop an outline of the unit, then the three co-authors worked and met intermittently over two months to develop the unit.

Data Analysis

Data for this paper consisted of field notes that captured design decisions as well as 13 different iterations of the instructional sequence, which aimed to develop students' understanding of ratio, proportion, and percent change within a context of nicotine vaping. To analyze our design decisions related to ethical and critical challenges, two co-authors independently coded the documents by marking each instance in which an ethical or critical challenge was raised. We then compiled the results and resolved any inconsistencies. For instance, both coders identified tensions related to a task asking students to analyze a graph showing the correlation between the amount of nicotine users ingest per day and the proportion of those users who meet the established criteria for addiction; students were asked "how many mg of Nicotine would you say leads to addiction in most people?" One author coded this as an *ethical* challenge, recalling the team's discussion of whether the idea of a threshold might encourage students who are interested in vaping to try to vape 'just under the amount' they think would get them addicted. The other author noted a *critical* tension with this same task recalling that the 5 mg threshold proposed by epidemiologists seemed somewhat arbitrary to the design team, who did not want the students to accept this threshold uncritically. Upon discussion, both codes were deemed appropriate.

Findings

Our analysis suggests some extensions to the RME reality and leveling design principles as well as the inclusion of an additional principle. We first discuss some new perspectives on the reality and leveling principles and then introduce the ethics principle.

Navigating the Reality Principle in Choosing Critical Contexts

When searching for an experientially real context to serve as the semantic grounding for the instructional sequence, we found ourselves rejecting many of the contexts that would have been rich for critical investigation because they were not *didactically rich,* in the mathematical sense. For example, the mathematics involved in water contamination, lead poisoning, and air pollution were too complex to support our ratio and percent learning goals. At other times, the context may have been didactically rich, and from the designers' point of view, *critically rich*, but when considering it from the students' points of view, they would not be engaging or may produce anxiety in students. Exploring critical issues around SAT [a college entrance exam] scores was one such context that the teachers rejected for two reasons. First, at this middle school, the SAT is introduced very early to students and is a topic that students are confronted with frequently. The teachers felt that students hear about it so often that they may not be interested in it. Furthermore, they felt their students are overly pressured to perform well on the SAT and this might produce anxiety.

After two brainstorming sessions, we decided on developing a unit related to the context of vaping, because we deemed the context to be both didactically rich and critically rich from the students' perspective. Because researchers had documented efforts to target teenagers with candy and fruit vaping flavors as well as sensational advertising (e.g., Center for Disease Control, 2016), the context also fit our initial hypotheses about how an experientially real situation, where students themselves were targeted, could provide initial access to critical perspectives. Tobacco companies' targeting of African American communities with advertisements and promotions for highly addictive menthol cigarettes (Henriksen et al., 2012) and their efforts to attract Native American customers with ethically questionable promotions (Lempert & Glantz, 2019) provided potential opportunities for students to practice empathy and critical intuition about situations where other populations are targeted.

Navigating the Leveling Principle in Choosing an Entry Point

Once we settled on the vaping contexts, we grappled with the joint goals of staying authentic to the context, while also following the RME modeling principle of beginning with more informal models and progressively introducing more formal models. In our attempt to find an accessible starting point for the unit, we initially looked for authentic ratios related to vaping that students could visualize using contextual imagery. We learned that nicotine channels require two molecules of nicotine to open the receptor, but quickly realized that that particular 2:1 ratio was likely too simple to prompt students to develop creative informal solutions; furthermore, the ratio does not change, so that particular relationship did not support an instructional sequence. Aware of the frequent use of varying concentrations of lemonade or other beverages at the beginning of ratio instructional sequences, we also attempted to begin the sequence by investigating the concentration of nicotine in e-cigarette cartridges, but we could not find a way to avoid the use of fractions or decimals because of the small concentration of nicotine relative to the other ingredients, so the authentic situation proved too complex.

Ultimately, we decided that the ratio of puffs per hour presented an accessible and rich possibility. Students could draw pictures of puffs of smoke and either hourglasses or small clock faces to represent hours, so that they could visualize and iterate the ratio. Once we had identified an accessible entry point, we attempted to identify realistic problems that involve this relationship.

- Given the data for an individual, can we determine if they are puffing more than they were? In other words, is the individual possibly becoming addicted?
- Who puffs more, one individual or another?
- How long would one cartridge last, given a set puff rate?

Navigating both Reality and Leveling Principles in Developing the Sequence

Given our desire to use the puff per hour ratio and a dearth of authentic data for individual vapers, we decided that for the outset of the instructional unit, we would not use actual data. Rather we would create fictional data within the vaping context, to provide maximum flexibility to meet our needs in developing the mathematical concept. Leaning on the RME principle of experientially real or imaginable scenarios, we created a fictional story of a teen named Sara, who tracked her puffing using a smartphone app. This fictional story allowed us the flexibility to start with appropriately accessible ratio (3 puffs:1 hour), ask a variety of questions (How many puffs would she take in 8, 24 hours?) and adjust that ratio as needed to increase complexity (5 puffs:2 hours) Although we incorporated real-world data (one cartridge contains enough vape

liquid for approximately 200 puffs), much of the data was hypothetical, yet positioned students as friends, wondering if Sara should worry about increases in her puffing.

Once we had progressed from informal (pictorial) to preformal (long ratio tables) to formal (short ratio tables analogous to formal proportional notation using equations) representations of ratios, we then made a design decision to transition to an authentic and not hypothetical scenario: determining a reasonable puff rate threshold for different concentrations of vaping liquid that would correlate to a scientifically-backed definition of addiction.

An emergent design heuristic. The tensions between authenticity and the desire to attend to the leveling principle and our decisions in navigating the tension illustrate an emergent design heuristic that represents our efforts to adapt the reality and leveling principles to a critical mathematical instructional sequence. When the authentic data and mathematical relationships proved more complex to provide an accessible and didactically rich starting point, we employed the use of relevant, believable, fictional stories in early stages of the progression to provide access to informal strategies and more accessible number choices. Then, once students were able to use more formal representations that could be used for other situations, we transitioned to more authentic, non-fictional inquiry.

Our efforts to design with and for ethical reasoning resulted in a number of situations for which existing RME principles provided little guidance. In response, we propose an additional principle.

The ethics principle: A seventh principle

In designing mathematics instruction for ethical and critical reasoning, we found ourselves facing design challenges that were not addressed in the six principles. The analysis of our design field notes indicated that we were attending not only to the nature of the problems we chose to provoke students' ethical awareness, but also calling into question the ethics of our choices as designers. Thus, we humbly introduce the ethics principle that has emerged from our work. The *ethics principle* refers to the fact that mathematics is done by human beings and thus has the potential for bias, at best, and oppression, at worst. Conversely, doing mathematics can be liberatory and students must learn to recognize the impact that their mathematical solutions may have on the world. This principle can be viewed in two ways. First, designers must intentionally build ethical problem solving into instruction to provide opportunities for ethical decision making to arise. Second, designers themselves must problematize the ethical dimensions of their design activity and products. The ethics principle manifested itself in two ways during our design work: attending to ethics in the grounding context and attending to ethics when writing problems.

Attending to ethics in the grounding context. Using the context of vaping presented our first ethical challenge. We wondered if it was ethical to have discussions about vaping with teenagers, and worried in particular about introducing a potentially harmful practice to students who may not have been aware of the practice before our instruction. We considered whether we should use the names of actual companies, such as JUUL, in our materials, as that might promote the company's product to students. Another ethical consideration that emerged was that some students might be vaping and become anxious when they learn of the potential negative health consequences.

Potential design solution. We resolved these ethical dilemmas by consulting outside stakeholders such as the school's principal, teachers, and teenagers. As a member of the design team herself, the principal agreed that vaping might be a controversial topic for some parents, but revealed that the health teacher teaches about nicotine, and many students will already know

about it. The teachers on the design team talked with other teachers, one of whom had a child in the class. The teacher-parents indicated that they did not think the vaping context would be harmful to their children. Finally, we talked with some teenagers who indicated that most teens know about vaping, adding that many middle schoolers they know are actually engaging in the practice. This feedback from stakeholders at the school led us to settle on the vaping context.

Attending to ethics in the problems. Once we committed to vaping as the context, there were ethical issues that arose as we wrote specific problems. We considered launching the instructional sequence with a video from the Truth Initiative (Shank, n.d.) that shows teens glorifying vaping, participating in vape challenges, and getting a buzz from the nicotine. Our intention was to acknowledge upfront that teens are vaping and to invite them into a serious conversation. From an ethics perspective however, we worried that the content of the video might inadvertently encourage teens to vape because it *looks cool and fun.*

A second time we were confronted with an ethical dilemma as designers occurred when we were considering introducing the idea of a "nicotine threshold" amount. A nicotine threshold refers to the minimum amount of nicotine an individual could ingest without becoming addicted. We worried that students who want to vape might think that, as long as they stay under this threshold, they can vape without getting addicted.

A third ethical issue arose as we were writing problems that might help students see themselves as the target of vaping companies. We created an instructional task that showed actual advertising photos by vaping companies. These advertisements contained pictures of candy flavored vape juice products, the Sesame Street Muppet Elmo encouraging vaping, young people partying with vape products, and famous entertainers holding vape pods. Our intent was to have students analyze the advertisements to see that vape companies were intentionally promoting their product to youth, but we worried the ads would attract students to the product. They might be inclined to think that *vaping looks cool;* or *if my favorite stars do it, it must be ok*.

Potential design solution. One way we attended to these ethical dilemmas involved creating what we refer to as a *contextual storyline*. We intentionally introduced a fictional character named Sara who became increasingly aware that she might be vaping enough to become addicted to nicotine. The mathematical problems we introduced not only supported our conjectured *mathematical* learning trajectory*,* but were couched in an ongoing narrative of Sara thinking about her vaping habit. We weaved the mathematical and contextual trajectories together so that students would develop proportional reasoning as they helped Sara and other fictional teen characters think about addiction. As the mathematical learning goals shifted to percent, the storyline changed to using a fictional app called the iVapeless meter so students could analyze how close Sara was to her self-imposed vaping limit. In this way, we used Sara's storyline to both develop students' mathematical understanding of ratio and percent while also learning about how vaping, even in small amounts, might lead to nicotine addiction. We also elicited students' knowledge from health class about the potential health consequences of nicotine throughout the storyline. In this way, we hoped the storyline we created would, at minimum, de-glorify vaping and maximally, deter students from using nicotine.

Discussion and Implications

In this study, we attempted to address an identified tension from previous studies of critical mathematical lessons: the difficulty in simultaneously teaching new mathematical concepts as well as ethical/critical reasoning. Unable to find critical mathematics studies that utilize established mathematics instructional design theories, we attempted to use tenets of realistic mathematics education to support our design toward the mathematical goals, while also attending

to critical mathematics frameworks. One notable difference that emerged between the lessons we developed and lessons present in the existing literature is that we designed a *sequence* of lessons, built on researched *learning* trajectories for ratio and proportion (Civak, 2020; Stephan, 2021) and critical *contexts*. Our instructional sequence also began with contexts that positioned the students we worked with as targets of oppressive acts, and then proceeded to inquiries into how tobacco companies targeted populations with marginalized identities that many of our students did not possess. Prior reports and published resources tend to represent individual lessons, rather than carefully sequenced tasks built upon learning trajectories.

Through our work, we found that the RME design heuristics were helpful for supporting our design efforts, yet we needed to adapt two of the existing principles (the leveling and realistic principles) and add a new principle. First, our adaptation to the reality principle led us to a better understanding of the demands of selecting an appropriate anchoring, experientially-real context. Others have identified the step of determining justice-oriented contexts for a given student population and determining the mathematical topics that are relevant to that context. In addition to this, we also needed to determine whether contexts were didactically rich, meaning that problems inherent to the context lent themselves to develop a variety of models, from informal, context-bound models to more formal models. Furthermore, we needed to identify contexts that presented a variety of critical and mathematical questions; vaping for instance, had many different considerations including how to determine whether someone is vaping more, data related to teens' vaping practices, and the targeting of various groups with advertising.

Our second adaptation involved the leveling principle. Once we had determined a didactically rich, critical context, we found ourselves oscillating between posing problems with complete fidelity to the context and fictionalizing certain aspects of the situations. For example, we attempted to use real stories and actual data from social media and research articles for problem contexts, but sometimes the numbers and procedures in the reports were too complex to support students at that particular point in the mathematical learning trajectory. Thus, in order to develop a sequence that adhered to the leveling principle, we needed to fictionalize aspects of that context at times.

Finally, in addition to adapting the leveling and reality principles to design instruction with authentic critical contexts, we found the need for an additional RME heuristic. Ernest (2013) argues that the ethical considerations of problem contexts must be considered and should be the foundation for mathematization, yet none of the current RME principles provide much guidance to designers who create instructional sequences with attention to ethics and social justice. We illuminated the ways in which ethical considerations emerged for us during the design process and presented several instances when the design team encountered ethical dilemmas and the ways we resolved them. Consequently, we suggest the addition of an ethics design principle to RME and argue that, not only should instructional materials support students' development of ethical reasoning but that designers themselves must also be alert to and problematize the ethical dimensions of their designs for students.

In our description of these adaptations and additions to the RME heuristics, we must also clarify that these are proposals at an early stage of the design research project. We have developed and piloted an initial version of the instructional sequence, but we have yet to analyze the data on implementation. Thus, we are careful not to propose that the adaptations to the RME principles are final, rather they are emergent and likely to need further revision. As our work progresses, it will be important to apply and continue to revise these principles in other settings with other students, mathematical topics, and justice-oriented contexts.

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