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Developing Criteria to Design and Assess Mathematical Modeling Problems: From Problems to Social Justice

Abstract
Despite the interest in modeling and the importance of social justice, there has not been much attention to connecting modeling with social justice. To fill this gap, we developed criteria for mathematical modeling problems that embrace the characteristics of problems and social justice through three phases: literature analysis, thematic categories, and piloting. The criteria will help teacher educators when selecting modeling problems to be used in teacher preparation programs and assessing the modeling problems posed by PSTs.

Keywords
Modeling, Equity and Diversity, Teacher Education-Preservice, Problem Solving

Disciplines
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DEVELOPING CRITERIA TO DESIGN AND ASSESS MATHEMATICAL MODELING PROBLEMS: FROM PROBLEMS TO SOCIAL JUSTICE

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Despite the interest in modeling and the importance of social justice, there has not been much attention to connecting modeling with social justice. To fill this gap, we developed criteria for mathematical modeling problems that embrace the characteristics of problems and social justice through three phases: literature analysis, thematic categories, and piloting. The criteria will help teacher educators when selecting modeling problems to be used in teacher preparation programs and assessing the modeling problems posed by PSTs.

Keywords: Modeling, Equity and Diversity, Teacher Education-Preservice, Problem Solving

The purpose of this study is to develop criteria to design and assess mathematical modeling problems that embrace social justice contexts and to reflect on ways in which the criteria can be used to assess preservice teachers' (PSTs) ability to pose problems. Mathematical modeling has been emphasized since the Common Core State Standards for Mathematics (CCSSM) include model with mathematics as both content and process standards (National Governors Association Center for Best Practices & Council of Chief State School Officers [NGA & CCSSO], 2010). The CCSSM define modeling as "the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions" (p. 72). Although the emphasis on mathematical modeling grows in learning and teaching critical mathematics as described in the CCSSM, PSTs are not yet adequately prepared to design and implement effective modeling problems. The characteristics of modeling, especially linking mathematics to real-life situations and involving students into decision-making processes, are shared with social justice problems. However, there is little consideration of social justice in frameworks related to mathematical modeling. For example, frameworks for developing thought-revealing modeling activities (Lesh, Hoover, Hole, Kelly, & Post, 2000) or rubrics developed for evaluating students' processes and solutions to modeling problems (Anhalt & Cortez, 2015) address important real-life contexts in general, rather than focusing on social justice issues. Gutstein (2003), on the other hand, developed mathematics problems with real-life contexts that reveal the injustice world but did not provide criteria for developing such problems. In this paper, we describe how we initiated and piloted the criteria that help teachers pose modeling problems with social justice contexts and use it to assess modeling problems posed by PSTs.

Process of Developing Criteria for Modeling Problems with Social Justice Contexts

Phase 1: Analysis of Prior Research

Lesh and Lehrer (2003) define modeling as a "process" of developing mathematical descriptions for specific purposes in particular situations. In this sense, modeling is placed in a spectrum of problem solving because problem solving is a process that requires solvers to understand a puzzling situation and to find a solution of the situation (Baroody, 1992). Problem solving seems a broader range of mathematical processes than modeling because problem solving do not specify the puzzling situations while modeling is required to involve a real-world situation (Anhalt & Cortez, 2015). A similar relationship appears between problems and modeling problems. Although many teachers mistakenly use the term *problems* for any mathematical tasks, only the tasks satisfy certain criteria

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can be "problems." Charles and Lester (1982) argued that problems must not show an obvious way to find a solution, and Van de Walle (2003) agreed problems must not have a predictable solution. When we compared the process of modeling with that of problem solving, more similarities revealed. Pólya (2004) proposed four phases of problem solving as understanding the problem, devising a plan, carrying out the plan, and looking back, which are similar to the mathematical modeling cycle.

The difference between problems and modeling problems is their contexts: the situations of modeling problems are articulated within a specific situation in the real world while problems do not necessarily include a real-world context. Some studies focus on a specific context of modeling problems without using the term, *modeling*. Among these, the problems involving social justice have a unique characteristic because these problems not only use the context of critical parts of the real-world but also encourage students to change their perspectives and take an action to solve the real problem. For social justice, it is critical to help students "understand, formulate, and address questions and develop analyses of their society" (Gutstein, 2003, p. 40).

Phase 2: Thematic Categories to Define Mathematical Modeling with Social Justice

We reconceptualized the relationships among problems, mathematical modeling problems, and social justice problems as shown in Figure 1. Because learners choose appropriate mathematics to analyze empirical situations when working on modeling problems, a specific solution pathway should not be given during this process. Therefore, modeling problems must satisfy the crucial condition of problems and need to be included in the set of problems (Figure 1). In addition, modeling problems are more inclusive than social justice problems.

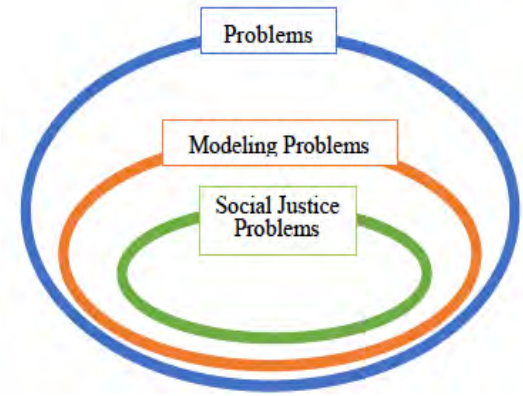

Figure 1. The relationships of problems, modeling problems, and social justice problems.

Although various types of contexts can be integrated into modeling problems, the goals of the problems of social justice is to support students not only to learn mathematics but also to actively develop their capability to read the world and become an agent of change. Thus, we placed the set of social justice problems within the set of modeling problems. The social justice problems are not defined as the tasks that just involve social justice contexts. If a task includes a social justice context only but provides a specific solution pathway, it is not a "social justice problem." Within this operationalization, we developed a draft of criteria based on the related literature, which was refined through the piloting phase.

Phase 3: Piloting and Finalizing Criteria for Mathematical Modeling with Social Justice

The third phase was to use the criteria to analyze the modeling problems that PSTs developed. We collected data from 30 PSTs in two 4-year university-based teacher preparation programs in the Midwestern United States. Participants were sophomores to seniors enrolled in K-8 teacher

preparation programs in each of their programs. The PSTs had some experience of solving modeling problems within their class before assigned the modeling problem development assignment. The criteria draft was not introduced to the PSTs although they learned the definition of modeling through reading relevant articles and discussions in class. The PSTs worked as a group of 3 people for approximately 2-3 weeks to develop their modeling problems. The first and second authors analyzed the collected 10 problems using the initial criteria and managed to reach a consensus through several discussions while finalizing the criteria.

Finalized Criteria for Social Justice Mathematical Modeling

Table 1 is the finalized criteria. The first three columns shown in Figure 1 indicate the subset relationship among problems, modeling problems, and social justice problems.

Table 1. Criteria for Modeling Problems that Address Social Justice Issues

			Criteria	Description
Social Justice Problems		Modeling Problems	Social Justice Context (Gutstein, 2003)	• The context involves unjust situations of the real world and encourages learners to be an agent of change by identifying mathematical conflicts and resolving the conflicts.
	Modeling Problems		Realistic Context, Problem, and Solution (Lesh et al., 2000; Schukajlow et al., 2012)	• The embedded context must be realistic and familiar to the target students. • The embedded problem(s) requires learners to identify variables and should likely happen in their lives. • The solution(s) must be realistic in the given real-world context.
			Multiple Representations (NGA & CCSSO, 2010)	• Multiple representations (e.g., tables, graphs, symbols, words) can be used to describe the problem situation.
			Generalizable/Transferable Knowledge (Lesh & Lehrer, 2003)	• The problem requires learners to apply their findings to other related problem solving situations. • The problem requires learners to develop mathematical knowledge that can be used in other similar situations.
			Shareable Approach (Lesh & Lehrer, 2003)	• Learners solve problems for a client outside classroom. • The problem-solving process and solutions can be shared with other people for their own use.
		Problems	Focus on Mathematics (Van de Walle et al., 2007)	• The problematic aspect should be due to the mathematics that learners are expected to learn as they solve the task. • Solving the task without using mathematics (e.g., common sense) should not be possible.
			Unpredictable Methods (Baroody, 1992)	• The task does not directly show how to solve it. • The task requires student's own method.

A social justice problem is most specific and must satisfy all seven criteria. The tasks that satisfy all criteria except for *social justice context* are categorized as modeling problems. The tasks satisfying only the last two criteria, *focus on mathematics* and *unpredictable methods*, are problems but neither modeling problems nor social justice problems. Our analysis revealed that most PSTs' modeling problems generally satisfied the criteria of problems but did not sufficiently meet other criteria. Among the criteria shown in Table 1, the most missed one was *social justice context*. None of the problems demonstrated any relevance to social justice. Additionally, the PSTs tended to ignore the characteristics of modeling problems, such as *generalizable/transferable knowledge* and *sharable approach*. Only one of the ten problems included some related features of generalizable or transferable approach.

Discussion and Implications

This study contributes to the extension of literature of mathematical modeling and social justice by demonstrating the process of designing criteria and using them with PSTs. The criteria can be used to develop and assess modeling problems. In our study, most PSTs did not address some of the other components in their problems, such as *social justice contexts*, *generalizable/transferable knowledge*, and *shareable approach*. We realized that these missing components require careful attention when introduced to PSTs. Furthermore, this study provides ideas for future research studies around modeling including social justice contexts. Hernandez, Morales, and Shroyer (2013) present a result that few PSTs identified the role of mathematics teachers as agents of change in society and assumed that one reason might be PSTs' lack of experiences or environments in which they lived and trained. Future studies can focus around changes in PSTs' awareness of social justice issues as they discuss the criteria developed in this study. The criteria have the potential for further investigations and validations in practice, which can initiate discussions among teachers, teacher educators, and researchers as they consider ways to achieve social justice through mathematical modeling.

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