

The Evaluation of a Pedagogical Tool for Quantitative Literacy

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Abstract

Quantitative literacy has been identified as a critical skill necessary for statistical thinking and effective citizenship. The purpose of this study was to evaluate an instrument for determining the use of reform-oriented instructional practices that promote quantitative literacy. Data were collected from 160 US college instructors of developmental mathematics. Items in the scale were developed from a set of 10 criteria previously identified as essential for fostering quantitative reasoning and problem-solving ability. An acceptable level of reliability was obtained, and criterion validity was established in relation to instructors' beliefs, specifically perceived usefulness and personal teaching efficacy. A significantly higher level of use of all practices was reported by instructors with a degree or concentration in statistics (versus mathematics). These findings can help to inform professional development programs. Further research is needed to examine the psychometric properties of this scale.

Key Words: Quantitative Literacy, problem-based learning, scale validation, developmental mathematics, reliability, validity

1. Background

Quantitative literacy (QL) is a critical skill necessary for statistical thinking and effective citizenship. Specifically, it enables individuals to make informed and intelligent decisions about crucial issues that impact their lives such as personal finance, health, politics, the economy, and national security. As Steen (2001) noted, "Quantitative literacy empowers people by giving them tools to think for themselves, to ask intelligent questions of experts, and to confront authority confidently" (p.2). While knowledge of mathematics and statistics is important, competency in these areas is not enough. Rather, QL is about having the confidence and ability to identify and use mathematical knowledge effectively in everyday quantitative situations.

Despite the growing importance of QL, many students in the United States are entering and leaving college with quantitative skills that fall below expectations (Follette, McCarthy, Dokter, Buxner, & Prather, 2015). In a recent National Survey of Student Engagement (2015), the majority of college freshman (62%) reported that they either *never* or *sometimes* used numerical information to examine real-world problems or evaluated other people's conclusions from numerical information. College seniors fared only slightly better, with 55% reporting either *never* or *sometimes* for the same items. Changes will need to be made in mathematics curricula and pedagogy at all levels in order to improve students' quantitative literacy (Hughes-Hallett, 2003). This includes developmental math courses which are designed to assist underprepared students to engage successfully in college-level work.

2. Review of the Literature

2.1 Focus on Developmental Mathematics

The primary goal of developmental mathematics is to give students the opportunity to learn the mathematics they were supposed to learn earlier (Garofalo, 1998; Stigler, Givvin, & Thompson., 2010). Generally, this has led to attention in these courses being placed predominantly on helping students achieve computational and procedural fluency. Accordingly, learning strategies have tended to focus principally on the transmission of knowledge by the instructor and on students mastering specific tasks (Handel, 2003). Moreover, student learning has centered on the acquisition of certain skills and facts through drill and rote memorization of formulas and procedures, without much attention to conceptual understanding or context. As such, this approach does little to help develop quantitative literacy in underprepared students. As Hughes-Hallett (2003) observed, “if a course simply requires memorization, that is what students do. Unfortunately, such students are not quantitatively literate” (p.93).

2.2 Why Quantitative Literacy

Research evidence has increasingly demonstrated that doing math in a real-world context is effective at helping underprepared students learn mathematical skills and concepts (Skalicky, 2004). Burkhardt noted that for *weaker students*, QL helps them learn “mathematics more effectively, building deeper understanding, richer connections and greater accuracy” (p.153). Others have reported that students who do mathematics in context are better able to transfer the skills they learn in the course to their other courses (Wenner, Baer, Manduca, Macdonald, & Patterson, 2009). Above all, QL, with its focus on problem solving in context, enables students who tend to have a negative view of mathematics to experience it in a whole new way. That is, it challenges their notion that math is simply a collection of rules, procedures, and formulas to be remembered. In this regard, reform-based pedagogical strategies are effective in helping students acquire the requisite skills (conceptual understanding and problem solving) by actively engaging them in the learning process.

2.3 Reform-Oriented Practices

Research on reform-oriented mathematics has identified problem solving, defined as “mathematical tasks that have the potential to provide intellectual challenges that can enhance students’ mathematical development” (Cai & Lester, 2010, p. 1), as a primary goal of mathematics education (NCTM, 1989, 2000; Wilson, Fernandez, & Hadaway, 1993) as well as “a major means of doing so” (NCTM, 2000, p. 52). In this regard, the the NCTM report in 2000 recommended that mathematics instructions should empower all students with the ability to do the following:

- Build new mathematical knowledge through problem solving
- Solve problems that arise in mathematics and in other contexts
- Apply and adapt a variety of appropriate strategies to solve problems
- Monitor and reflect on the process of mathematical problem solving (p. 52)

Essentially, these recommendations provide a framework for designing instructional strategies that focus on actively engaging students in tasks and activities that are consistent with the propositions of constructivist learning theories (Hassad, 2011) as well as the competencies needed for QL (Turner, 2011). They include collaborative and cooperative learning, use of multiple perspectives, communicating mathematically, critical thinking, skills development, and metacognitive strategies (formative assessment, self-reflection, and feedback). Yet empirical evidence regarding the adoption and level of use of these practices by developmental mathematics instructors is lacking.

2.4 Measuring Instructional Practices

There is little research on reliable and valid scales for measuring the use of practices that promote QL and reform-oriented practices in developmental mathematics courses. Several instruments have been developed to measure the use of reform-oriented practices in mathematics courses at the K-12 level (Hamilton, McCaffrey, Stecher, Klein, Rabyn, & Bugliari, 2003; Sperling, 2009; Weiss, Pasley, Smith, Banilower, & Hech, 2003), in introductory college statistics (Hassad, 2011; Zieffler, Park, Garfield, delMas, & Bjornsdottir, 2012), and in developmental education (Pierce, 2012). These scales emphasize active, student-centered instructional practices that promote conceptual understanding and problem solving.

In the 1990s, a series of curricula for the K-12 level were developed (with grants from the NSF) grounded in a reform-oriented instructional approach, with an emphasis on conceptual understanding and problem solving. One such curriculum was the Connected Mathematics Project (CMP), a problem-based, middle school curriculum (Lappan, Fey, Fitzgerald, Friel, & Phillips, 2006). To engage students and help them make sense of mathematics, 10 criteria were used to design, select, and revise problems for CMP (Lappan & Phillips, 1998). Recently, Cai and Lester (2010) identified these 10 criteria (see Table 1) as essential for fostering conceptual understanding and problem solving.

3. Objective

The purpose of this study was to use the full psychometric process for scale development to evaluate a scale using these 10 criteria. In addition, selected instructor characteristics were explored as possible confounding factors.

4. Methods

4.1 Sample and Sampling

The 160 participants in this study were instructors at two- and four-year regionally accredited postsecondary institutions in the United States who taught developmental mathematics courses. These included full-time and part-time instructors who had full responsibility for these courses.

A purposive (or maximum variation) sampling design was used to recruit instructors for this study. This sampling method allowed for the selection of instructors who represented the full diversity of instructional practices and beliefs found among developmental or remedial mathematics instructors. With respect to this study, this diversity included a range of reform-oriented practices and strategies, which, according to the diffusion of

innovations model (Rodgers, 1995), could vary between instructors who have readily adopted these practices and instructors who rarely or ever use them.

4.2 Instrument

The reform-oriented practice scale (see Table 1) consists of 10 items that were identified as essential for fostering students' conceptual understanding and problem-solving ability (Cai and Lester, 2010). These criteria were originally developed by Lappan and Phillips (1998) and used to design a curriculum (Connected Mathematics) that has proven to be effective at the K-12 level. The 10 items were measured on a 5-point Likert scale, with values ranging from 1 (never) to 5 (always) for a total maximum score of 50.

Table 1. Reform-Oriented Practice Scale

The term <i>Problem</i> refers to a mathematical task that has the potential to enhance students' conceptual understand and promote their ability to reason and communicate mathematically. Please read each statement, and from the 5-point scale, clearly check one response which best represents your practice when choosing, revising, and designing a problem (task) for use in your developmental mathematics classes.
1. The problem has important, useful mathematics embedded in it.
2. The problem requires higher-level thinking and problem solving.
3. The problem contributes to the conceptual development of students.
4. The problem creates an opportunity for the teacher to assess what his or her students are learning and where they are experiencing difficulty.
5. The problem can be approached by students in multiple ways using different solution strategies.
6. The problem has various solutions or allows different decisions or positions to be taken and defended.
7. The problem encourages student engagement and discourse.
8. The problem connects to other important mathematical ideas.
9. The problem promotes the skillful use of mathematics.
10. The problem provides an opportunity to practice important skills.

5. Results

5.1 Characteristics of Participants

A total of 160 instructors who taught developmental mathematics at regionally accredited two- or four-year colleges located in 32 different states in the US submitted responses that were deemed valid. These instructors reported a considerable amount of time teaching developmental mathematics, with an average of 16 years. The median age of these instructors was 45 years, and the majority (87 or 53%) of them were women. One hundred and twenty-eight (80%) were full-time instructors. One hundred and eight instructors (68%) possessed a Master's degree, and 43 (27%) indicated they had a doctoral degree. The majority of the instructors (85 or 53%) claimed a specialization in mathematics, with 44 (27%) possessing a degree in mathematics education. The academic concentration of the remaining 28 instructors (20%) were distributed as follows: developmental education (12), education (4), statistics (6), or other (6).

5.2 Reliability Analysis

Internal consistency is the extent to which the items on a scale are interconnected or measure the same concept or construct (Tavakol & Dennick, 2011). Cronbach's alpha for the reform-oriented practice scale was .84, indicating good internal consistency. In addition, the corrected item-total correlations, which measure the significance of each item to the total scale, ranged between .34 and .64, suggesting that these 10 items are meaningfully related to the construct of reform-oriented practices.

5.3 Content Validity

Content validity, the degree to which the scale captures the construct (Polit & Beck, 2006), was measured by domain analysis and expert assessment. Cai and Lester (2010) recommended using these 10 criteria to promote the reforms envisioned by the NCTM (1989, 2001), especially in the development of students' conceptual understanding and problem-solving ability. Furthermore, others have noted the success of the curriculum (Connected Mathematics) that incorporates these criteria at the K-12 level (Cain, 2001; Klum, Capraro, & Capraro, 2007). Likewise, the U. S. Department of Education's Mathematics and Science Expert Panel awarded Connected Mathematics "exemplary" status (Klein, 2003).

5.4 Criterion Validity

Criterion validity was established by using the independent samples t-test to compare instructors' scores in the upper and lower quartiles of the reform-oriented practice scale to determine if there were statistical differences with respect to *personal teaching efficacy* and *perceived usefulness* (see Appendix A for attitudinal scale). Personal teaching efficacy is an instructor's belief about his or her ability to successfully implement an instructional strategy (Bandura, 1993; Pajares, 1992), whereas perceived usefulness is the degree to which instructors believed that using reform-oriented practices would enhance their job performances or benefit themselves or their students. The results were consistent with theoretical expectations. Instructors in the top quartile of the reform-oriented practice distribution were more likely to report higher levels of perceived usefulness than instructors in the bottom quartile (see Table 2). Similarly, those in the top quartile were more likely to report higher levels of personal teaching efficacy than those in the bottom quartile of the reform-oriented practice distribution (see Table 2).

Table 2: Comparison of Upper and Lower Quartiles ROP by PU and PTE

Use of Reform-Oriented Practices (ROP)	N	Mean	Std. Dev.	t	df	p
Perceived Usefulness (PU)						
Upper Quartile	42	27.8	6.7	-2.21	87	.029
Lower Quartile	47	25.2	4.4			
Personal Teaching Efficacy (PTE)						
Upper Quartile	42	19.0	4.2	-3.66	78	.001
Lower Quartile	47	17.0	3.3			

5.3 Comparison of Reform-Oriented Practices by Instructor Characteristics

No statistically significant differences were observed in the use of reform-oriented instructional practices with respect to gender, age, highest earned degree, employment status, and years teaching developmental mathematics. However, statistically significant differences were found in the use of reform-based practices based on academic concentration (see Table 3). A Bonferroni correction post hoc test was run to confirm which academic concentration groups differ. The results from the test revealed differences in the use of reform-based practices between instructors with mathematics and statistics concentrations.

Table 3: Comparison of Reform-Oriented Practices by Academic Concentration

Use of Reform-Based Practices	Mean	Std. Dev.	F	p
Academic Concentration				
Mathematics	38.40 ^a	4.55	2.63	.03
Mathematics Education	39.63	5.39		
Developmental Education	39.25	5.51		
Statistics	46.75 ^a	4.03		
Education	39.83	1.94		
Other	40.14	3.34		

a. Post-hoc analysis (using Bonferroni correction): $p = .012$

5. Discussion and Implications

The results of this study provide insights into the beliefs of instructors regarding the use of reform-oriented instructional practices. That is, an instructor's sense of efficacy and their perception of the usefulness of these instructional strategies do play a role in the use of reform-oriented practices. In other words, instructors with higher levels of personal teaching efficacy and perceived usefulness are more likely to engage in reform-oriented practices. Accordingly, professional development programs can be developed to increase the use of these practices and, subsequently, enhance students' conceptual understanding, problem-solving ability and, ultimately, their quantitative literacy.

Findings regarding the effects of instructor personal or demographic characteristics were similar to those observed in the literature (Hassad, 2011; Pierce, 2012). The significant but very limited effect academic concentration had on instructors' use of these practices may be an indication that instructors' content knowledge could have an effect on the use of reform-oriented practices. Further research will be needed to be conclusive about the effects of academic concentration as well as to confirm the psychometric properties of the reform-oriented practice scale.

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APPENDIX A—Attitudinal Scale
Adapted from Faculty Attitudes Toward Statistics Scale (FATS[©])
developed by Hassad (2011)

DIRECTIONS: The survey is designed to ascertain your attitudes toward the teaching of developmental mathematics using a reform-based approach. **The reform-oriented or concept-based approach** is intended to promote conceptual understanding and problem solving rather than calculations and formulas. It involves constructivist or active learning strategies collaborative and cooperative learning, use of multiple perspectives, communicating mathematically, critical thinking, and self-reflection or metacognition.

The item scale has five possible responses ranging from *strongly disagree* through *undecided* to *strongly agree*. Please read each statement and from the five-point scale clearly check one response that best represents your agreement with that statement.

Perceived Usefulness Items	SD	D	U	A	SA
The concept-based approach to teaching developmental mathematics (rather than emphasizing calculations and formulas) makes students better prepared for work.					
The concept-based approach to teaching developmental mathematics (rather than emphasizing calculations and formulas) makes students better prepared for further studies.					
Emphasizing concepts and applications in a developmental mathematics course (rather than calculations and formulas) is a disservice to our students.					
The concept-based approach to teaching developmental mathematics is for low achievers only.					
I am convinced that the concept-based approach to teaching developmental mathematics enhances learning.					
The concept-based approach to teaching developmental mathematics enables students to understand research					
Teaching developmental mathematics using the concept-based approach is likely to be a positive experience for me.					
Teacher Self-Efficacy Items					
I will adjust easily to teaching developmental mathematics using the concept-based approach.					
Concept-based teaching of developmental mathematics may be problematic for me.					
I do not understand how to organize my developmental mathematics course to achieve quantitative literacy.					
Teaching developmental mathematics with emphasis on concepts and their applications (rather than calculations and formulas) may be stressful for me.					
I am concerned that using the concept-based approach to teach developmental mathematics may result in me being poorly evaluated by my students.					