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Examination of the Delphi Method for Establishing a Quantitative Literacy Framework in Undergraduate Mathematics Course

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Abstract

The increased relevancy and importance of quantitative literacy (QL) have called for educational reform in undergraduate mathematics course offerings. However, lack of clear guidelines has led to wide variability in the content and outcomes of math courses meant to address QL. Therefore, having an expert consensus regarding content and outcomes for an undergraduate mathematics course focusing on QL would advance the quantitative literacy initiative in higher education. The authors propose the Delphi Method to aid in developing a framework based on expert opinions. The authors explain the Method and suggest the result of this process should yield a research-based framework that faculty and institutions can use as a resource for QL math courses.

Keywords

Quantitative Literacy, Undergraduate Math Curriculum, Delphi Method

Cover Page Footnote

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A Need for QL Curricular Resources

Policymakers, employers, and educators have increasingly recognized the relevance and importance of quantitative literacy (QL), also commonly called numeracy and quantitative reasoning (QR), thus leading to calls for educational reform by these stakeholders. While teaching mathematics and QL are not the same thing, with the apparent relationship between the two, much of the responsibility for reform has been placed on mathematics education (Gillman 2006). “Quantitative reasoning offerings have exploded across the country largely as a response to this call” (Gaze 2018, 2).

However, this rapid rise in QL course offerings has also led to wide variability in the content and outcomes of these courses in post-secondary institutions across the US (Gaze and Richardson 2019), so much so that some of the math courses being offered are “merely algebra alternatives and do not directly address deficiencies in quantitative literacy” (Elrod and Park 2020, 3). As such, a closer review is needed of the content of courses intended to address QL (Gaze and Richardson 2019).

These educational reform initiatives have created a substantial workload for the institutions responsible for developing new QL curricula (Gaze 2018). As Gaze remarked, “the bulk of the work remains to be done. Those tasked with completing the job will need a community of scholars sharing evidence-backed ideas. In recent issues, *Numeracy* has served as a locus for that discussion…. I hope to see much more of the same as we address this critical educational issue” (3–4). This paper examines this need for research-supported curricular resources and provides a suggestion of how one such resource might be developed for implementing QL in general education math courses.

QL Research to Build On

“It would be helpful to agree on which mathematical algorithms are necessary underpinning[s] of quantitative literacy, but this is a matter on which reasonable people differ” (Madison and Steen 2003, 91). Over the years, there have been several attempts to bring experts together for discussions regarding QL. However, these discussions have yet to result in a clear definition or set of guidelines for classroom implementation (Wallace 2019). “Practically speaking, the reason to have a fairly tight definition of numeracy is so that an institution can set a goal for what a quantitatively literate person should be able to do” (ibid., 3). However, with no such tight definition, the availability of resources for QL-focused math courses is limited. Therefore, having a framework of guidelines that academic institutions and faculty could use for a QL-focused math course that not only meets their unique needs but also ensures that it fits within the parameters of QL would likely be a welcome resource.

Previous attempts to define QL illustrate the difficulty in arriving at a universally accepted definition (Vacher 2014; Karaali et al. 2016; Sikko 2023). Perhaps this difficulty is due to QL being a broad field, much like one of its counterparts, the field of mathematics, and it may just be too expansive to be well-defined, conceptually speaking. However, like mathematics, defining specific lenses of QL could prove to be more productive. As the field of QL has evolved, scholars seem more amenable to this idea, in that it allows the concept of QL to naturally transform over time and adapt to the ever-changing needs of society. And while the purely scholastic endeavor of defining QL may be something scholars can continue to debate, or not, the need for operational definitions is essential to propelling the initiative in application and implementation settings. Perhaps the issue of a conceptual definition is less important than operational definitions needed for various lenses.

For example, one such research report (Roohr et al. 2014) completed a comprehensive review of existing frameworks and definitions to develop an approach for next-generation quantitative literacy assessment in higher education. The report proposed a framework constructed for the specific purpose of measuring the ability of students in higher education to solve practically important mathematical problems. The resulting *Next-Generation Quantitative Literacy Assessment Framework for Higher Education* is based upon a synthesized review of definitions, frameworks, and assessments, "by national and international organizations, workforce initiatives, higher educational institutions and researchers, K–12 theorists and practitioners" (ibid., 14). This framework focused on the assessment of QL at the post-secondary level, however, with the strong connection between collegiate instruction and assessment, the *Next-Generation Quantitative Literacy Assessment Framework for Higher Education* could potentially make a good starting point for developing a framework that could be used for undergraduate math courses focused on QL.

One of the major hurdles for QL education is the lack of "clear guidelines for courses and no generally accepted measures of success. Consequently, there are no widely accepted curricular materials" (Madison 2014, 2). While some curricular resources currently exist, such as Quantway (Yamada et al. 2018)—an already-developed course with pre-determined learning outcomes—many colleges and universities are seeking to establish their own courses and programs to address QL (Agustin et al. 2012; Gaze et al. 2014; Tunstall et al. 2016). Additionally, several institutions have developed QL programs and shared their development processes as well as lessons learned (Agustin et al. 2012; Gaze et al. 2014; Tunstall et al. 2016). While these are valuable contributions toward the development of the field of QL, there is still more that can be done in the way of synthesizing this knowledge base into a framework to guide QL in undergraduate mathematics courses.

Madison (2014) suggested ten design principles for a QL course, listed below. These principles are based upon six sets of criteria: (i) AAC&U QL Rubrics and an Adaption; (ii) Mathematical Proficiency from Adding It Up; (iii) The Standards of Mathematical Practice of the Common Core State Standards; (iv) The Five Elements of Effective Thinking; (v) Research Findings from How People Learn; and (vi) Principles from Applying the Science of Learning to University and Beyond. Madison's (2014, 11–15) ten design principles for a QL course are:

1. Provide a venue for continued practice beyond the course (and beyond school).
2. Keep the material relevant to students' everyday contemporary world.
3. Use multiple contexts to practice quantitative reasoning.
4. Promote appreciation of arithmetical precision and the power of mathematical concepts and processes.
5. Help students to structure their quantitative reasoning in resolving problematic situations, including ample doses of critical reading and writing.
6. Encourage on-the-fly calculations and estimations.
7. Increase students' supplies of quantitative benchmarks.
8. Encourage students to use technology to enhance and expedite understanding.
9. Allow student interests to emerge.
10. Provide interactive classroom environment.

These principles are based on research and practice. While these are sound principles for a quantitative literacy course, they may be too broad or too general for faculty and administrators who are novices to the field of QL and may not be enough to help in the development of QL math course curricula. Madison (2014) acknowledges that while these design principles are aligned with the six sets of criteria, the alignment is far from perfect, specifically noting "two unresolved alignment issues: 1. What contextual examples should be generalized and abstracted to take advantage of the power of mathematics? 2. What are the conceptual frameworks for QR?" (21). These issues suggest that establishing a QL framework for undergraduate math courses would serve as a complement to existing QL resources, that a QL framework would work in collaboration with existing QL resources to support a holistic approach to QL math courses, and that the QL framework should strive to answer the question of what skills, content, and contexts experts agree should be included in an undergraduate QL math course.

A Call for Consensus

As suggested above, establishing a framework of guidelines as a potential resource for QL math courses would not only add to the body of research in the field of QL, but also serve as another potential tool that can be utilized in QL education. As such, the authors are advocating that establishing such a framework would be a worthwhile scholarly endeavor. Furthermore, the authors suggest the use of an established methodology for expert consensus, the Delphi method, as a means for developing such a framework based on QL expert opinions.

As mentioned, the current literature regarding QL varies greatly. Even when researchers try to develop a clear, concise definition based on summaries of current literature (Vacher 2014; Karaali et al. 2016; Sikko 2023), the results show a lack of consensus on terminology, their use, and definitions. The Delphi method is used to determine consensus amongst experts (Dalkey and Helmer 1963; Skulmoski et al. 2007). Finding consensus amongst experts regarding a framework for undergraduate QL mathematics courses will help to provide another research-supported resource to institutions and faculty alike as they move forward in this educational reform process.

Therefore, the authors suggest using this novel approach in determining a QL definition and curricular framework as it applies to undergraduate math courses through the Delphi technique in an attempt to move closer to consensus and a clearer understanding of QL, to not only propel the field of research forward but also to provide practitioners with a practical, easy-to-understand guide for developing and implementing their QL mathematics courses.

Overview of the Delphi Method

The Delphi method is a research technique used to determine consensus amongst experts (Dalkey and Helmer 1963; Skulmoski et al. 2007). Delphi may be characterized as a method for structuring group communication consisting of: individual input of information and knowledge; summary of group viewpoint/perspective; opportunity for revision of individual input; and relative anonymity of individual responses (Turoff and Linstone 2002). It is a repetitive process, in which experts are consulted at least twice on the same questions, so they can reconsider their answers after reviewing the responses of the other panel members while maintaining the anonymity of individual answers (Landeta 2006). The research participants are experts in the field in which a consensus is trying to be reached, and these experts participate in several rounds of questionnaires to establish this consensus (Skulmoski et al. 2007).

Figure 1 illustrates a common three-round application of the Delphi process. However, a review of the ways the methodology has been utilized in various research areas shows a differing number of rounds and panel sizes ranging from 4 to 171 (Skulmoski et al. 2007). “One quickly concludes that there is no ‘typical’ Delphi; rather that the method is modified to suit the circumstances and research question” (ibid., 5).

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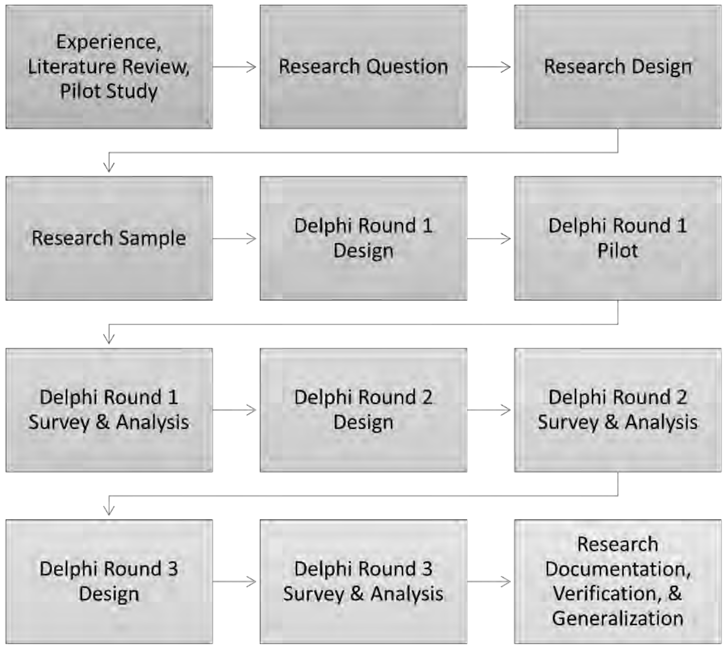

Figure 1. Skulmoski et al. (2007) Three-Round Delphi Process

"The Delphi method is a pragmatic approach grounded in the philosophical assumptions of philosopher and educator John Dewey who believed that social science research should directly relate to and inform real-world practice and decision making" (Brady 2015, 1). Thus, the results of a Delphi study are meant to inform practice and support research-based decision-making. "Dewey's pragmatism has long been considered a practical bridge between theories and methods stemming from the interpretive paradigm concerned with subjective human experiences and contextual truths and the emphasis on generalizability and objectivity common in the postpositivist paradigm" (ibid., 2). The Delphi method is one methodology that supports bridging the gap between research and application in its practical research design.

Rationale for Using the Delphi Method

The Delphi method has been used for a variety of purposes where an expert consensus is needed. It is not limited to one subject area and can be found in a variety of research fields from information technology, to the military, to social sciences, to education. The Delphi technique peaked in the 1980s, "but currently maintains a notable level of employment, relatively stable, seeming to indicate that, once the effect of fashion or novelty had been overcome, the scientific community has accepted this technique as another research technique, with present-day validity and use" (Landeta 2006, 471).

One way the Delphi method has been utilized in research on education is to determine consensus regarding elements that should be included in the contemporary curriculum. One such study in the UK (Osborne et al. 2003) sought to establish a consensus about which "ideas-about-science" should be taught in school science. This field faced a similar dilemma in which the content of science was well-established, but the recent initiative to pay more attention to teaching the nature of science and its social practices, or the "ideas-about-science," had much less unanimity within the academic community. This study sought to determine empirically the extent of any consensus amongst a community of experts using a three-stage Delphi questionnaire. The outcome of their research was a set of nine themes encapsulating key ideas about the nature of science for which there was consensus, and which were considered essential components of school science curriculum. The data gave some measure of the existing level of agreement in the community engaged in science education and science communication about the most important features of a popularized generalized account of the nature of science. Although some of the themes were already a feature of existing school science curricula, many others were not. The research findings, therefore, challenged (a) whether the picture of science represented in the school science curriculum is sufficiently comprehensive and (b) whether the balance in the curriculum between teaching about the content of science and the nature of science was appropriate.

Additionally, the Delphi method has been utilized in developing a best practices framework for faculty professional development (Mohr and Shelton 2017). With the growth in online enrollment, higher education institutions need to prepare faculty throughout their teaching career for learning theory, technical expertise, and pedagogical shifts for teaching in the online environment. This study used the Delphi method to gain consensus from a panel of experts on the essentiality of professional development items to help faculty prepare for teaching in the online environment. Best practices were identified after four survey rounds developed consensus. Consisting of essential professional development and institutional/organizational strategies for supporting faculty teaching online, these results are significant for planning new or improving existing faculty development programs that enhance teaching and learning in the online classroom.

The Delphi method has also been used in a variety of ways in math education research. One study (Muñiz-Rodríguez et al. 2017) used the Delphi method to establish a competence framework for secondary mathematics student teachers in Spain. Although a generic framework for teaching competencies already existed for all school subjects in Spain, the initial teacher education programs curriculum did not specify which competencies secondary mathematics student teachers should acquire during their initial teacher education. Building on existing models and international frameworks, a preliminary list of competencies was developed, and the Delphi method was employed to determine a comprehensive framework of 33 competencies for secondary mathematics student teachers that could be validated. Another study (Manizade and Mason 2011) used the Delphi methodology to design assessments of teachers' pedagogical content knowledge focused on a specific area of middle school geometry and measurement. A diverse panel of 20 experts reached a consensus after three rounds of surveys. The initial survey items were derived from research literature in the relevant fields, and as the Delphi progressed, new categories emerged which concluded in the production of the study's resulting assessment. The researchers go on to suggest the potential use of the Delphi methodology to design and validate other instruments in different fields.

These examples of the Delphi method's usage in other curricular matters demonstrate how it could be a useful methodological approach to developing a QL framework through expert consensus. Additionally, these examples support the validity of the methodology and its acceptance in the research community.

Defining Expertise

The selection of the participants is key to the success of a Delphi study, as the results of the study rely on the knowledge and cooperation of the panelists, so it is crucial to include individuals who are likely to provide valuable ideas (Gordon 1994). Often, in studies such as public opinion polls, the sample is meant to be representative of a larger population, so that statistical analysis of the data collected can be used to make inferences about the larger population. However, in a Delphi study, the sample is meant to consist specifically of knowledgeable persons in the field, so the results of the study demonstrate consensus amongst experts about the issue at hand. In a Delphi study, participants should meet four requirements: i) knowledge and experience with the issues under investigation; ii) capacity and willingness to participate; iii) sufficient time to participate in the Delphi; and iv) effective communication skills (Adler and Ziglio 1996; Skulmoski et al. 2007).

The first essential task is to identify how potential participants will be selected. One approach is conducting literature searches to identify individuals who have published on the subject being studied. Another approach is seeking recommendations from institutions or associations, as well as recommendations from other experts in a process known as daisy chaining. However, there are shortcomings to each of these approaches. Literature searches only identify people who have published on the topic of interest and miss those who may have something to contribute but have not published. Recommendations are limited to only those known to the institutions, and daisy chaining has the potential disadvantage of identifying cliques. Therefore, Gordon (1994) recommends forming a matrix of required skills to ensure the required skills are represented.

The defining feature of an expert is a person who is significantly knowledgeable about and/or experienced in the field, and as a means to qualify an individual's knowledge and experience, a matrix should be developed to identify individuals who made significant contributions to the field of QL. The matrix should utilize all suggested strategies of identification, including literature searches, institutional/organizational recommendations, and daisy chaining to compile a list of potential participants, such that each potential participant meets at least one criterion and that collectively all criteria are represented in the group of experts selected to participate.

Establishing a Consensus

An initial instrument should be constructed based upon a thorough "review and synthesis of existing frameworks, definitions, and assessments of quantitative literacy, quantitative reasoning, numeracy, or mathematics" (Roohr et al. 2014, 2). This instrument could employ either a quantitative or qualitative paradigm. Alternatively, the instrument could employ a mixed-methods paradigm, combining both quantitative analysis and qualitative analysis. However, in any approach taken, the instrument should provide for experts to be able to make suggestions to add to subsequent iterations of the instrument.

The instrument should be modified for each iteration of data collection. This modification consists of: removing items that have reached consensus for inclusion after each round, as once consensus has been reached, the item will become part of the resulting framework; leaving items that did not reach consensus for inclusion in the framework for further deliberation in future rounds; adding the additional expert-suggested items for consideration in each of the next rounds. By the end of the last round, only items that reached consensus by the experts for inclusion in the framework should be included in the resulting framework.

The instrument can be administered using various formats, but the most common is the use of electronic software. Data collection should occur over several rounds, each round using a modified version of the initial instrument. For each of the survey iterations, the same deployment method should be employed, for consistency. And all responses should be kept secure to ensure confidentiality of responses. After each round of data collection, the results should be analyzed such that items that reached consensus for inclusion in the framework be removed from the instrument and the items suggested by experts should be added prior to the instrument being deployed for the next round. Additionally, the data analysis of each round should be provided to the experts before the next round to allow them to compare their own responses with the group from the previous round. The purpose of this is to allow the experts to determine if their opinion has changed based on the collective responses of their peers, or if their opinion remains unchanged. After the final round, the results should be analyzed for the final results to determine if any additional items have been found to reach consensus for inclusion in the framework.

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Data analysis would depend on the instrument used and data collected. For analysis of qualitative data, techniques such as content analysis can be used, and for analysis of quantitative data, central tendencies and levels of dispersion are typically computed (Hasson et al. 2000). "This enables participants to see where their response stands in relation to that of the group. However, the level of measurement will influence the types of statistical tests undertaken, for example the standard deviation does not apply to ordinal or nominal data so returning such information back to participants is misleading" (ibid., 1012).

Strengths and Weaknesses of Delphi

The Delphi technique provides an alternative to the traditional group opinion based on direct interaction, thus: reducing the influence of some undesirable psychological effects, such as inhibition, dominant personalities, etc., among the participants; increasing extensive consideration due to the repetition; producing statistical results; focusing on the relevant feedback; and providing flexible methodology and simple execution (Landeta 2006).

However, as with most methodologies, there are limitations. Some of those potential limitations include potential research bias that influences responses, researcher error in newly added questions based upon the synthesis of panel suggestions from the previous round, and respondent fatigue over the several rounds of surveys, leading to less care in response (Mohr and Shelton 2017). Additionally, participation is voluntary. Therefore, the results of the study are unlikely to capture all expert opinions in the field, which is a generally accepted reality of Delphi studies.

The Significance of a QL Framework

Quantitative literacy was not born out of discovery or exploration, but out of necessity (Karaali et al. 2016). Thus, as researchers and practitioners alike attempt to describe this need, many words and phrases (with varying definitions) took root, yet similarities can be found among these alternatives. Not surprisingly, it has been hard to determine a singular definition, let alone a framework, for this broad need that experts are trying to describe. While much work has been done to clarify the response to addressing the societal need for quantitative skills, there is still a lot of work to do.

As with most fields of study born of policy rather than research, developing the field of study can be difficult, but with a clear framework, it can be easier to conduct research to inform policy and practice. Additionally, as a field of study with a focus on implementation and practice, there is still a great need for resources and guidelines for practitioners to implement QL in the classroom. Studies have shown a need for curriculum development and resources around QL (Agustin et al.

2012; Gaze and Richardson 2019; Elrod and Park 2020). Thus, a framework for undergraduate QL math courses would add to the body of research and provide another resource for the implementation of QL in college mathematics.

Establishing a framework for undergraduate QL math courses would offer guidance to math faculty who may be unfamiliar with the important aspects of QL and how it differs from traditional mathematics courses. The field of QL consists of such a broad range of concepts and definitions, that having a consensus among experts regarding content and context for a QL mathematics course will help to provide another research-supported resource to institutions and faculty alike, thus helping the QL educational reform movement continue to advance. The results of such a study would not necessarily produce a singular standard upon which to base all QL math courses. Rather, the resulting framework would be the development of a potential resource based on expert opinions through an established methodology, which not only adds to the body of research in the field of QL, but also serves as another potential tool that can be utilized in QL education.

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