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A Framework for Strengthening The Quantitative Skills/Reasoning Support Ecosystem at Small Liberal Arts Colleges

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Abstract

We developed a framework for characterizing an institution's quantitative skills/reasoning support ecosystem to consider how various activities contribute to student success in areas connected to students' quantitative preparation. Through discussions with faculty and staff stakeholders at eight selective small liberal arts colleges, we established that the quantitative skills/reasoning support ecosystem at these institutions consists of four domains: bridge programs with a quantitative component, assessment of readiness, curricular on-ramps, and supplementary support for courses that require quantitative skills/reasoning. The framework includes questions about each domain that can be used by stakeholders in different institutional positions to reflect on existing efforts to support student success in quantitative disciplines and identify opportunities to align or change their institutional quantitative skills/quantitative reasoning support systems to better meet student needs.

Keywords

quantitative skills support, change theory

Cover Page Footnote

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Introduction

In the past few years, there has been much discussion about learning loss associated with the COVID-19 pandemic, including what seems to be a persistent decline (rather than a short-lived dip) in the National Assessment of Educational Progress mathematics scores (Grawe 2023). This decline is worrisome for those in higher education institutions because students' mathematical preparation can affect their success on many fronts if colleges are not able to meet and support incoming students wherever they are when they arrive. A 2016 National Center for Education Statistics study found that almost one-third of college students at public four-year institutions enroll in remedial math courses, the content of which varies by institution, and those who do not complete their remedial math requirements are twice as likely to drop out as those who are successful (Chen 2016). In addition to concerns about persistence generally, students' lack of facility with quantitative skills can limit their ability to pursue the major of their choice, particularly STEM and some social science fields that have become more reliant on quantitative measurement and analysis. In an effort to support student success and open doors to all majors, programs and initiatives have been developed across institutions; these initiatives are often intertwined, though not intentionally, with efforts to address the disparities in quantitative skills of incoming students.

In a 2009 article, "Change in Higher Education: Not Enough, or Too Much?", Adrianna Kezar argues that multiple initiatives at an institution, with overlapping interests but without coordination, reduce progress toward making changes or achieving goals. In our experiences at liberal arts colleges, initiatives to support students in the transition from high school to college, to foster quantitative reasoning across the curriculum, and to make STEM fields more inclusive of individuals from diverse backgrounds are often separate efforts despite related interests and concerns. Students arrive at college with a wide spectrum of quantitative skills, due in part to disparities in secondary educational opportunities and experiences. These multiple initiatives within an institution often develop different approaches to address this challenge, resulting in piecemeal or overlapping efforts that might be more effective and efficient if they were coordinated. However, supporting stakeholders in taking a slightly broader perspective is difficult because individuals and units tend to be focused on their own domains.

While conversations between programs and their stakeholders within an institution can be helpful in bringing programs into alignment, much can be learned in conversations between programs and stakeholders with similar goals across institutions. Our project brought together constituents from eight selective small liberal arts colleges all part of a consortium already discussing approaches to supporting student skill building to consider broad questions concerning support

for development of student quantitative skills/quantitative reasoning (QS/QR), including working with data, reasoning with numbers, and using mathematical models and tools within disciplines. We began by discussing issues and emergent questions around QS/QR support generally, and then engaged in focused conversations about specific approaches at these institutions. In this paper, we describe how the results of these inter-institutional discussions led to a framework for considering the QS/QR support ecosystem. This framework can be used by stakeholders to characterize existing efforts to support student success in quantitative disciplines, to identify where efforts are fragmentary or duplicative and to align work in a manner that strengthens the support available to students in a way that is sustainable for all involved. We emphasize that this ecosystem framework was developed at, and is primarily designed, for small, liberal arts colleges with full-time, traditional-aged students.

Ecosystem Framework Development

Students' math preparation and its impact on STEM career pathways have been a focus of educators and policymakers for some time, particularly at open enrollment public institutions (Couturier and Cullinane 2015; Melguizo et al. 2015). A more recent review of the impact of calculus as a barrier to STEM pathways included consideration of multiple types of institutions (Burdman et al. 2021). As selective institutions have prioritized enhancing diversity along many dimensions within the student body, students are now arriving at these institutions with a wider range of pre-college mathematics preparation; many of these institutions do not offer math courses below the level of calculus. In addition, with COVID-19 disruptions of K–12 education, finding ways to support student success with QS/QR in the transition from high school to college has become particularly pressing. Individuals or departments often do their best to address issues related to QS/QR preparation, for example by providing one-time skills review workshops for students in a particular class, but such a piecemeal approach has limits.

In our case, a constellation of faculty and staff employed by a group of selective liberal arts colleges began to engage in conversations about the need to better support student QS/QR development through regular activities of a consortium of these institutions in 2013.[1] The conversations took a number of forms and led to several informal collaborative projects. Like many grassroots change leaders, we (the authors of this paper and two other colleagues) wanted to capitalize on the connections that had developed to create change. Although our positions as director of the center for learning and teaching (MEZ) and director of quantitative skills

[1] The Liberal Arts Collaborative for Digital Innovation (LACOL) is no longer an active consortium, but information about the institutions involved can be found at https://lacol.net.

programs and peer support (LJM) made student-centered teaching and student success core to our roles at our institutions, successfully obtaining an NSF IUSE grant transformed the consortial work by providing support and formal recognition for these efforts that allowed them to move forward in a more meaningful way, consistent with what is reported in Kezar et al. (2011).

Once we received funding, we surveyed faculty across the consortium in science and social science disciplines that used QS in introductory courses to learn what quantitative topics they felt introductory students struggled with in their disciplines. They also identified approaches they used to support students (Eblen-Zayas et al. 2020). Although our grant-funded initiative began with a focus on online modules for just-in-time support of student QS development across the curriculum, we wanted to better understand the factors influencing departmental or institutional choices about approaches to supporting student QS development (Eblen-Zayas et al. 2023).

Beginning in 2021, in an effort to gain some insight into the institutional context for QS/QR support at different colleges within the consortium, we organized a learning community focusing on institutional approaches to supporting student QS/QR development. We invited the Chief Academic Officers at institutions engaged in the NSF-funded project to identify a faculty or staff member to represent their campus in this cross-institutional learning community designed to understand how institutions were using summer bridge programs, placement exams, and tutoring programs to support student QS/QR development, topics that has been the focus of earlier consortium work. The individual identified by the Chief Academic Officer was designated the Campus Dialog Leader (CDL) for their institution. The CDLs were positioned differently in their institutions—some were science and mathematics faculty (ranging from non-tenure track to full professor) and others were coordinators of quantitative skills centers or tutoring centers on their campuses.

The learning community included CDLs from eight different institutions, as well as the project leaders, who facilitated the discussions with CDLs, and an external evaluator, who was an observer during the learning community meetings and interviewed CDLs about their perspectives at the completion of the learning community. The eight institutions are all selective, private liberal arts colleges with individual enrollments between 1,500–2,500 students. The student bodies of these institutions are generally traditional-aged college students who enroll directly after high school and live on campus as full-time students. All of the institutions are well-endowed and have significant resources for supporting students.

Initial conversations with CDLs focused on three key areas identified in earlier consortial conversations: 1) Summer bridge programs for QS/QR development and support; 2) Placement exams (departmental and institutional level) and skill assessments (course level) in the test optional admissions era; and 3) Additional

QS/QR support in disciplinary contexts, and how much is provided by faculty for their courses versus how much is provided by academic support offices. These conversations also included brainstorming what committees or venues would be appropriate for gathering institutional perspectives from relevant stakeholders. Then each CDL facilitated discussions of relevant topics on their campus, either by asking the appropriate committee (where related conversations might already be happening on campus) for input or by hosting discussions with key stakeholders. After the on-campus conversations, each CDL completed a survey that asked about major themes from their on-campus conversations and areas where cross-consortial information sharing and/or action might be helpful. Once the survey responses were submitted and synthesized, the project leaders shared the information with all the CDLs before the final learning community meeting.

An external evaluator attended all of the learning community conversations and interviewed CDLs at the end of the period about their experiences as CDLs. One of the themes from the interviews with CDLs was that although many on their campuses are passionate about enhancing diversity, increasing access to STEM majors, etc., campus interest in QS/QR was middling, despite the fact student QS/QR facility often underpins these other issues. When asked by the external evaluator, most CDLs rated their campus' overall interest in QS/QR a 3 on a scale of 1 to 5.

Building knowledge and relationships across institutions can be an important first step towards meaningful cross-institutional networks that can foster change (Gehrke and Kezar 2016; Kezar et al. 2019; Reinholz et al. 2021). The CDLs recognized the advantages of sharing information and comparing and contrasting approaches to supporting the development of student QS/QR. As one CDL noted in their interview:

> [I]t's always useful to talk to colleagues at other institutions. Most importantly, to realize we have the same problems and then hopefully get ideas from other people on, "Oh, that's interesting, that works at your institution. Maybe we could try that," . . . getting these leaders together can provide best practices. That, I think, is the ultimate benefit.

In considering ways to promote efforts to strengthen support for student QS/QR development, we recognized that having a way to categorize approaches to support is important for advancing these efforts and facilitating collaborative work that can lead to change. While we did not use the terminology of an ecosystem as part of the learning community with CDLs, as we reflected on the conversations and how to describe the various components of efforts to support students' QS/QR development, we felt that the concept of an ecosystem effectively captured the interconnected, sometimes grassroots, approaches that individuals, departments, and offices at each institution developed to support students. Just as an ecosystem is a system of interconnecting elements that are informed by their environment and often have complex interactions, STEM higher education similarly includes many

components that interconnect in complex ways and has been described as an ecosystem (Emery et al. 2019; Lee 2019). As we identified complexities and connections in the QS/QR support approaches at various institutions, we found that thinking about institutional approaches to support students' QS/QR development as an ecosystem was a useful framework. The details of the QS/QR support ecosystem looked different at each institution, but all campus ecosystems of the CDLs' institutions consisted of four major domains, described below.

About a year after the CDL learning community wrapped up, we wanted to refine our understanding of the ecosystem, so we invited CDLs (and/or other representatives of their institutions) to attend a one-and-a-half-day workshop to continue considering QS/QR support approaches. Ten faculty and staff from five of the institutions, some of whom had been CDLs, attended the workshop. At this workshop, we worked to develop a more nuanced understanding of the ecosystem, through activities that included presentations by each college about QS/QR support at their institution, identifying the relative influence of various stakeholders, and developing a plan for future action to strengthen the QS/QR support within each institution. In addition, an external evaluator hosted focus groups with workshop participants using a semi-structured protocol focused on factors that drove action planning decisions, the benefits of working with other institutions, the affordances and challenges of the liberal arts setting, as well as emergent topics.

Four Domains of the QS/QR Support Ecosystem

The conversations with CDLs in the learning community allowed us to generalize campus QS/QR support efforts into four domains: bridge programs with a quantitative component, assessment of student readiness, curricular on-ramps, and supplementary support for QS/QR development in the introductory courses; the subsequent workshop allowed us to gain insight into details of support efforts at each college. The expansion of the ecosystem beyond the original three areas to include curricular on-ramps emerged from these discussions. All of the institutions had student support ecosystems that included some type of activity in all four domains, though there was an immense amount of variation in the types and levels of those activities. In an interview following these discussions, one CDL observed:

> It was especially interesting to see which elements [of quantitative skills support] were being prioritized on different campuses. . . . It was clear from the conversation that some campuses were focused more on one of those things than others . . . I found it helpful to hear that other people were kind of struggling with similar things and struggling to get buy-in from similar stakeholders.

The issue of the breadth of stakeholders involved in supporting QS/QR at an institution can be particularly challenging. The stakeholders include faculty from science and social science disciplines that teach courses using QS/QR as well as

staff in student success and academic support roles. We envision that this ecosystem framework can support conversations including the variety of stakeholders at an institution who might want to map, study, or change the ecosystem of QS/QR support. However, these conversations can be fraught if the power differential between tenured faculty and others is not thoughtfully addressed; this point was brought up both in the learning community and at the workshop by participants who were not tenured faculty members.

Four main domains within the ecosystem specifically describe institutional efforts aimed at supporting students' QS/QR development. The domains themselves are somewhat interdependent. For example, activities in the assessment of student readiness domain could help faculty and student support staff identify students who need a bridge program or a particular curricular on-ramp. And yet, the domains are well-defined enough to each have their own characteristic factors that influence student support mechanisms, presented in Tables 1–4.[2] The interplay of the factors that each institution chooses to employ describes the institution's approach to QS/QR support. To better define each factor, we have given a list of questions that stem from commonalities that emerged, or incongruencies we saw, in the summaries from CDL discussions with campus stakeholders and the subsequent inter-institutional comparisons when discussing these topics with the CDLs, as well as from the campus reports on their QS/QR ecosystems at the workshop. While the list of questions for each factor is not exhaustive, discussing these questions with other campus stakeholders can help define QS/QR support initiatives, where there might be overlapping efforts or gaps, how those initiatives fit within larger institutional efforts, and what aspects of the QS/QR ecosystem an institution might want to modify to improve student outcomes.

Bridge Programs

Summer bridge programs are usually aimed at smoothing the transition from high school to college by helping students build academic skills and social networks; some summer bridge programs continue with programming during the academic year. Programs vary in the offices and departments that sponsor the programs and the particular student populations; participant selection may be based on high school background, academic interests, or demographics (Table 1).

[2] The structure of the tables, organized by relevant factors and associated questions, was influenced by Palmer and Giering's (2023) Taxonomy of Pedagogical Innovation in Higher Education, but the content is unrelated.

Table 1
Bridge Programs: Characteristic Factors and Questions to Consider

Domain	Factors	Questions
Bridge Program	QS/QR Scope	Is the program designed to review topics that students are expected to have seen in high school, teach new topics, or apply existing knowledge to particular disciplinary contexts?
		How explicit are the QS/QR goals as compared to other program goals?
		Is the program designed to improve placement when the academic year begins or is the program supplemental to academic year courses?
Bridge Program	Population	Is the program designed for a particular population of students (first gen, interested in STEM, etc.)?
		What are the opportunity costs for the students (in terms of summer work, family caregiving obligations, etc.)?
		To what extent is the program a cohort building program?
	Program Structure	How are students selected for participation?
		Do the goals determine the length of the program or does the length of the program constrain goals?
		What are the benefits of an online versus on-campus program?
		Is there continuation of programming beyond the summer?
		How many students are served? Could the program be scaled to serve more?
	Institutional Stakeholders	What departments, offices, and programs are consulted on the design of the program?
		Who is responsible for implementation and assessment?
		What roles do faculty members, staff from quantitative resource and academic skills centers, and student affairs personnel play?

Bridge programs often consist of goals that allow students to do one or more of the following: 1) gain an early orientation to living on campus, 2) develop academic success skills (such as time management or how to use campus support resources), 3) build community with other incoming students from similar backgrounds or with similar interests, 4) earn credits by taking courses either designed to develop specific skills (writing or quantitative skills) or provide an early introduction to a potential area of study (often STEM). STEM-focused bridge programs can vary significantly in terms of goals, structure, and scope. Ashley et al. (2017), in an analysis of 30 different STEM-focused bridge programs, noted that these programs have a wide variety of goals that range from departmental goals (e.g., recruiting students into a major or diversifying students interested in the major) to psychosocial goals (e.g., increasing sense of belonging) to academic success goals.

Unlike the other domains of the ecosystem where QS/QR are often foregrounded, bridge programs may not include a QS/QR component at all or, if they do include QS/QR development, the program design may not consider the variety of contexts in which a student might apply those skills. Moving beyond niche programs that meet singular goals for particular stakeholders towards programs that are built on the engagement of many institutional stakeholders to address multiple needs, including supporting student QS/QR development, may be advantageous because bridge programs can be expensive for institutions to operate as well as have opportunity costs for students who might otherwise have work or care-giving responsibilities during the summer.

All of the institutions represented by the CDLs have some type of bridge program (with one being early in its development at the beginning of the CDL learning community), but only about half of the bridge programs focused attention on the development of QS/QR, with most being in-person, but at least one being on-line (Eblen-Zayas and Winton 2022). Most commonly, bridge programs at these institutions focus on skill building and cohort building. Often the nature of a given bridge program seemed to be the result of which stakeholders on campus proposed and designed the program. A bridge program developed by a student affairs office focused on supporting students of particular demographic groups is going to be different from a program designed by STEM faculty concerned about enhancing pathways into STEM for students from historically marginalized groups. While both types of programs are designed to increase student success, how such a program connects with other elements of the QS/QR support ecosystem, particularly curricular on-ramps, may be quite different.

Designing a bridge program that supports student development of and success with QS/QR often requires negotiation of how various skills will benefit students in multiple realms. For those institutions that had a bridge program with a QS/QR component, there was a split with regards to whether the program was focused on a particular set of disciplines or was focused on building skills in a broadly relevant way. Nearly all of the institutions consider QS/QR as being relevant for all students (as indicated by having a graduation requirement) which suggests engaging academic support staff and faculty from a broad range of disciplines would be valuable for designing a program that can move the needle on supporting student success in multiple contexts, but in reality, the breadth of faculty and staff contributors to bridge programs varies.

Determining which stakeholders should convene the conversations, contribute to program development and implementation, and be engaged in assessment needs to be thoughtfully considered depending on the local context. Such conversations should engage constituents who are involved in other domains of the QS/QR ecosystem so connections between bridge programs and other domains are considered intentionally.

Assessment of Readiness

Identifying which students might benefit from additional QS/QR support is important for ensuring student success in a variety of social science and science courses. Now that many selective higher ed institutions are test-optional, the admissions process gathers one less piece of information that was previously used to identify students who would benefit from additional support. In the domain of assessing readiness, what information is gathered by and shared with different stakeholders (course instructors, academic advisors, academic support offices) varies considerably among the eight institutions (Table 2).

Table 2
Assessment of Readiness: Characteristic Factors and Questions to Consider

Domain	Factors	Questions
Assessment of Readiness	QS/QR Scope	Is this designed to give information about skills of the entire incoming class or to give information about students interested in taking courses in specific departments (e.g., math, chemistry)?
		What skills are assessed? What skills are not assessed?
		Are the assessments focused on placing out of introductory courses or placing students into appropriate introductory courses?
	Logistics	Is the assessment offered during the summer or when students arrive on campus?
		Are students given study materials?
		Do students learn their scores (versus placement)? If so, how is this information shared?
		What other information is shared?
	Messaging/ Advising	How is other information about student readiness (transcripts, standardized tests results, etc.) incorporated into placement decisions?
		What is the messaging about assessing readiness to students and to institutional stakeholders, and to what extent do different stakeholders provide messaging that is consistent? Does the messaging help set the students up for success?
		How does admissions talk about QS/QR readiness and placement?
	Institutional Stakeholders	Who designed the assessment? (Is it developed locally—departmentally or institutionally—or is it a widely-available test?)
		Who has access to the results?
		Do stakeholders collaborate so a few assessments can be used for multiple departments/programs? Or do stakeholders each have their own assessment?

Among the institutions represented by the CDLs, the most common tool used for assessment of QS is a math placement exam, administered by the math

department. Since the goal of such an exam is to get students into the most appropriate math course, it is not designed to measure a student's ability to apply these skills in other contexts. Beyond the math department, some departments where the discipline employs QS/QR have their own placement exams, but often these exams focus on disciplinary content knowledge and do not separately focus on QS/QR. When each department develops their own placement exam, students can find themselves having to take multiple exams before arriving on campus, which can be time-consuming, and, if the placement messaging is not carefully attended to, some students with structurally disadvantaged identities may view placement exams as defining intelligence rather than serving as a tool to promote success (DiGregorio and Hagman 2021).

Some institutions administer a general quantitative literacy assessment to all incoming students. The Quantitative Literacy/Reasoning Assessment (QLRA) was developed based on exams given at Bowdoin College, Colby-Sawyer College, and Wellesley College (Gaze et al. 2014). Some of the CDL institutions used this assessment to direct students with low scores to specified introductory QR courses, but in the learning community discussions, questions arose about whether the assessment, and messaging around it, are supportive or stigmatizing. The economics department at Carleton College experimented with using the QLRA not for placement, but to identify students who would benefit from additional support (Grawe and O'Connell 2018). The possibility of providing early connections between students and supplemental support is one benefit of assessing readiness beyond course placement.

As QS/QR become increasingly relevant across the curriculum, with a central role in some disciplines and a peripheral role in others, it is not efficient for each instructor and support staff member to engage in their own assessment of students' skills in their own courses or contexts. One workshop participant noted that placement should be broadly construed, with the aim of considering, "Can we understand where incoming students are at somehow and in a way that can be communicated and acted upon?" Another workshop participant emphasized that, "I don't only care about people finishing classes. I care about … if they thrive or not in classes, and I also care how people from different backgrounds receive any information and any advice." Assessment of readiness involves a consideration of how information is strategically shared with and communicated to students, advisors, and a number of other faculty and staff stakeholders to ensure that students make informed choices about their curricular pathways, and faculty, staff, and advisors can encourage students to use supplemental support. At some institutions, assessments and placement exams are used to recommend placement, with course options not being determined by the results. In such situations, advisors both need both key information and language to help students make course enrollment decisions to support their success.

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Beyond helping individuals make choices that are tailored appropriately, the information gathered from readiness assessments can provide a snapshot of the incoming class so that over time departments and institutions can adapt other elements of the QS/QR support ecosystem—particularly curricular and supplemental support offerings—to meet students where they are. One challenge is that different stakeholders benefit from different levels of granularity in assessments. Departments often seek assessment instruments that are narrowly tailored to their disciplinary context as that allows them to more carefully refine curricular on-ramps. However, for staff members who oversee quantitative resource centers or are responsible for providing supplemental support at the institutional level, a more general assessment of readiness can help inform quantitative resource center programming, in addition to providing faculty across disciplines with information about the foundational QS that students bring.

The tension between a desire for narrowly tailored understanding of what skills students bring to a specific course or department and an interest in capturing a broader picture of students' QS/QR can make developing institutional strategies for assessing readiness difficult. If discussions reside only within departments or only at the level of an institutional research office, assessment approaches may not meet the needs of multiple constituents and may lead to students being asked to take multiple overlapping assessments. Identifying how information from assessments can contribute to supporting successful student engagement with other domains of the ecosystem could inform decisions about what approach to use to assess student QS/QR foundations.

Curricular On-ramps

As students come in with a range of QS/QR backgrounds, ensuring that the curricular options are able to meet students at the level at which they enter college and offer pathways to desired majors and careers is important. This requires that departments and institutions continually consider the options for and structure of introductory courses that draw on QS/QR. In particular, QS/QR is relevant to many STEM and social science disciplines so considering how the curriculum helps students build and apply these skills in multiple domains is important. The HHMI Inclusive Excellence Capstone cohort included several institutions that participated in the CDL learning community, and one of the four themes that emerged from those institutions was the importance of infusing QS throughout the curriculum (DiBartolo et al. 2016). Curricular on-ramps (Table 3) at the CDL institutions include two approaches: 1) a course for incoming students who do not have some base level of QS/QR proficiency, and 2) pathways into majors requiring QS/QR fluency that account for variation in student preparation. Fewer institutions represented in this learning community had a course to address baseline proficiency (approach 1) than had carefully designed introductory sequences at the department

level that could lead into quantitative majors (approach 2). Approach 1 can be particularly challenging because rarely is it clear where in the curriculum such a course should be housed and who would teach such a course.

Table 3
Curricular On-ramps: Characteristic Factors and Questions to Consider

Domain	Factors	Questions
Curricular On-ramps	Foundational Skills Development	If there is an institutional readiness assessment, is there curricular support for those who don't achieve a minimum score? Is there a mismatch between the high school math courses incoming students have taken and the first level quantitatively rich courses at the institution?
	Course Structure	What alternative class formats (extra-time, longitudinal or extended schedule courses) to support students in developing skills for introductory courses in disciplines that use QS/QR? Do students get additional credit for additional time? Do faculty members get teaching credit for additional time? Are there student learning assistants in the classroom?
	Curricular Design	Do departments offer multiple on-ramps aimed at students with different backgrounds and interests? Are there cohort programs that aim to build community while also building on-ramps to quantitative majors?
	Institutional Stakeholders	How do faculty, student success, and ancillary support staff collaborate within the course structure? To what extent are departmental on-ramps legible to advisors outside the department? To what extent are departmental on-ramps legible to students? Is there any effort to coordinate between departments?

Even developing consensus about departmental curricular on-ramps can be challenging. At small institutions, where faculty often take great pride in their personal approach to teaching, it is not always easy to get consistency in the design and teaching of introductory STEM courses. As one of the CDLs noted in their interview at the end of the learning community, "[F]or many of us who are working on these issues, our departmental colleagues are not the right people to be talking to about this because they're not invested in it." In such situations, individual instructors are often left to address the issue of supporting student QS/QR development by changing their instructional approaches, such as embedding more quantitative development activities during class time. And some of those faculty members who want to make changes acknowledge that a barrier is their lack of training in how to teach diverse groups (Chikkatur and Valle 2023). In departments

where a majority (or influential minority) are invested in addressing the issues, curricular redesign that provides multiple pathways into the major is possible and can achieve consistent implementation and messaging. Plans at the departmental level are impacted by institutional procedures and policies that can either enhance or limit efforts to build introductory courses to meet students where they are with respect to their QS/QR. In particular, the degree of flexibility in course structure at the institutional level (e.g., allowing for compressed or extended schedules, extra meeting time, or the ability to add trailer sections onto existing courses) can shape options for those departments that are interested in making curricular changes.

For example, one approach to reinforcing foundational QS/QR used at the schools in this study is incorporating additional problem-solving sessions into some courses. In these sections, students have the opportunity to solve problems related to course material in small groups. The faculty member structures these problem-solving sessions to allow students to develop and apply their QS/QR through small group work. While "extra" instructional time with small group problem solving allows for continuing skill reinforcement, the approach gives rise to other questions. These questions include whether faculty and students receive additional credit for the extra time spent in-class as compared to a class with a traditional structure. If courses require students to do extra skill-building outside of class time, some students will end up with significantly larger workloads than peers who arrive with more preparation for those courses. Additionally the messaging around such curricular options needs to be carefully designed so that the courses are presented as legitimate on-ramps, not lesser pathways.

Altering curricular on-ramps to provide additional QS/QR support for students who enter needing that support provides a unique opportunity to examine and then collaborate with other campus stakeholders invested in student success. Involving staff with expertise in teaching QS/QR may help faculty develop approaches to separate where students struggle with disciplinary knowledge from where they struggle with underlying QS. Further, these staff often oversee the campus quantitative resource center, and through that structure support peer tutoring on campus. Therefore, they could help recruit and train peer learning assistants equipped to facilitate development of foundational QS/QR, freeing the faculty to focus on course planning and implementation (Barrasso and Spilios 2021). Cross-campus collaboration around QS/QR support could also promote conversations around QS/QR transfer between disciplines, in the form of informal efforts or formal communities of practice. While centering on useful pedagogy to promote skills transfer, conversations also can be helpful in revealing consensus about foundational skills for inclusion in classes to help students improve QS/QR needed across the curriculum.

Supplemental Support

Even in the most carefully designed courses and curricula, some students will have difficulty with the material. At the CDL institutions, the modes of supplemental support available to students might include: course-based support beyond instructor office hours including some form of help session or tutoring hours run by students who took the course previously and organized by the instructor or the department; a STEM Center or a Quantitative Support Center that provides drop-in hours, workshops, or one-on-one tutoring; or a patchwork of support that includes both course/departmental support (such as facilitated study sessions) and centralized support (such as peer tutoring) that varies by course level or department (Table 4).

Table 4
Supplemental Support: Characteristic Factors and Questions to Consider

Domain	Factors	Questions
Supplemental Support	Design	Is support tied to a course? To a department? Centralized?
		Is support asset- or deficit-based?
		What skills does supplemental support help develop that will serve students in managing their work in more advanced courses?
		Are just-in-time workshops offered?
	Personnel	Is support primarily provided by other students? By professional staff?
		Are professional staff within departments or in centers?
		Who selects, trains, and provides on-going professional development for peer tutors?
	Messaging	How is help-seeking normalized?
		If support is departmental or course-based, how are inconsistencies across contexts managed?
	Institutional Stakeholders	How do faculty engage with the campus supplemental support structures and personnel?
		How do students find their way to the appropriate supplemental support?

Supplementary QS/QR support may be an important element of a student's development of agency and belonging in a STEM field; however, this support may be siloed, with each department taking its own approach, or centralized in a unit that is not included in discussions of curriculum or pedagogy. Conversations between faculty and those providing the support are key to having the support personnel understand the expectations for students in various classes. At some institutions, faculty ask students who have taken their particular section of a course to be tutors because of their familiarity with the particular instructor's approach to

the course, but these students may not be trained to provide coaching for more general QS/QR development.

While QS/QR are relevant in many different disciplines, faculty do not always think of these skills as being separable from the disciplinary content, and therefore they tend to see QS/QR support as their individual responsibility. While some QS/QR may be employed in specific ways within a discipline, working with data, constructing and using graphs, and numerical reasoning are foundational skills that are broadly relevant and student development in these areas can be supported by individuals who may not be experts in the discipline. We have found that faculty at the institutions represented by the CDLs tend to prioritize providing individual support to students, followed by referring students to peer tutors affiliated with the course, rather than referring students to relevant staff members (Eblen-Zayas et al. 2020). While course-based interventions give faculty members the greatest amount of control, sometimes faculty members are not prepared, or do not have the time, to support students who lack a certain minimum level of facility with foundational QS/QR. Designing support approaches that are not solely reliant on faculty who are already teaching the courses is desirable.

While institutions have come to view writing as a skill that is relevant to most disciplines offering support to both faculty and students in a single campus writing center, each institution has its own approach to centralized support for QS/QR. For example, one institution in this cohort had a long-standing center offering support to students in the form of course-based tutoring or just-in-time workshops, while another is beginning a program of peer support that focuses on transferrable QS/QR. In both of these cases, however, the faculty that teach courses supported by the center do not reliably engage with the center. *A Handbook for Directors of Quantitative and Mathematics Centers* (Coulombe et al. 2016; Schuckers et al. 2017) provides a wide variety of expectations and approaches to providing QS/QR support through quantitative support centers. Among the differences are the relationship between center staff and faculty, the types of support offered (workshops, peer tutoring, professional support, etc.) and the level of centralization for professional development for students and faculty.

Holistic examination of the goals of providing supplemental support, as well as the methods through which students receive this support—just-in-time workshops, regular drop-in hours, collaborative study sessions, individual tutoring, etc.—can strengthen the network of support. Ensuring that stakeholders understand how the support they provide fits within the network of support as well as other domains of the ecosystem is important. Additionally, stakeholders might want to consider the messaging to students about when and how to access different types of support.

Concluding Remarks

Considering QS/QR support as an ecosystem has the potential to serve as a framework that campus stakeholders can use to coordinate and consider changes to improve support efforts at small colleges. Taking stock of what approaches to student support are currently in use in each of the four domains, and which individuals or units are responsible for those approaches, can be a valuable first step. Often this initial reflection can identify places where there are gaps or redundancies in support efforts; deciding how to address such issues is the next step. One theme that emerged from campus dialog leader and workshop participant discussions of QS/QR support at their institutions was the tension in considering what elements of support should be centralized and when support was better left to distributed efforts.

Decentralized approaches to QS/QR support bring up concerns about duplicating efforts, developing redundant resources, and whether localized support will be legible to those outside the unit, particularly for students who traverse different courses, departments, and locations on campus. As one workshop participant noted:

> I think there's a lot to be said for keeping in mind the student experience of getting the help as well, especially for first term students, especially students who are less prepared. They're terrified to walk in the door of the building they've never been in before, let alone find the right office, and the right number, and the right person, so I think in that sense, the single point of entry, whether it's a physical space, an app, it doesn't matter what if we can say everyone is telling them, "Go there" . . . [so students] don't have any extra mental work to do to figure out how to get help.

Our work did not query student perceptions of the ease of navigating the QS/QR support ecosystem, but CDLs and workshop participants were interested in improving the convenience of accessing appropriate support.

With regards to centralization of efforts, many of the institutions involved in these discussions have an individual with a role dedicated to QS/QR support, and in some cases, they are charged with coordinating that support across the campus. However, that person is often a member of the staff without much power to set institutional priorities. On campuses that do have such a staff person, that individual often engages with students taking a broad array of courses and can identify themes in the types of experiences that impact student QS/QR success; although they have the benefit of a broad perspective, these staff members are often not in an institutional role that allows them to influence strategic directions or make decisions with impact beyond their constrained sphere of influence.

Research shows that networking across institutions can be particularly helpful for those involved in promoting grassroots change by providing opportunities for individuals to learn, brainstorm, and develop strategies for next steps in a space that

has more safety and emotional support than one's own institutional context (Kezar and Lester 2009; Kezar et al. 2019), and both CDLs and workshop participants expressed appreciation for the opportunity to learn from other institutions and bring those perspectives back to their own colleges. Ultimately, however, finding ways to build coalitions, identify points of convergence, and align efforts within the institution is needed. Small institutions have some advantages; they can be more agile and pilot small-scale initiatives more easily. Additionally, at small institutions, it is easier to identify programs or initiatives that could be part of a larger effort to make change in the QS/QR support ecosystem than at a much larger institution. Schools or colleges within a larger university may find this ecosystem framework is useful to analyze support approaches and bring together stakeholders within their unit. Even if stakeholders and potential collaborators are identified, individuals who lead particular efforts may worry about the loss of control over their initiative or losing resources for their specific work, and this can diminish the willingness to engage collectively (Kezar 2009).

One of the CDLs noted, "I don't know how you do it, but I think if you want to get people to subscribe to a common solution, you have to get them to see that it's a common problem." Encouraging alignment of QS/QR support efforts requires getting many stakeholders on board to identify concerns and then to prioritize those concerns. This ecosystem framework offers a starting point for organizing conversations to identify shared interests across departments and programs and decide what collective efforts would strengthen approaches that bolster student success with QS/QR across the curriculum.

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References

Ashley, Michael, Katelyn M. Cooper, Jacqueline M. Cala, and Sara E. Brownell. 2017. "Building Better Bridges into STEM: A Synthesis of 25 Years of Literature on STEM Summer Bridge Programs." *CBE—Life Sciences Education* 16(4): es3. https://doi.org/10.1187/cbe.17-05-0085

Barrasso, Anthony P., and Kathryn E. Spilios. 2021. "A Scoping Review of Literature Assessing the Impact of the Learning Assistant Model."

International Journal of STEM Education 8: 1–18. https://doi.org/10.1186/s40594-020-00267-8

Burdman, P., M. Baker, and F. Henderson. 2021. "Charting a New Course: Investigating Barriers on the Calculus Pathway to STEM." *Just Equations.* http://justequations.org/resource/charting-a-new-course-investigating-barriers-on-the-calculuspathway-to-stem

Chen, Xianglei. 2016. *Remedial Coursetaking at U.S. Public 2- and 4-Year Institutions: Scope, Experiences, and Outcomes* (NCES 2016-405). Washington D.C.: U.S. Department of Education.

Chikkatur, Anita, and Stephanie Valle. 2023. "Rethinking 'Damage-Centered' Research and Individual Solutions: Cultural Humility as a Framework to Increase Student Diversity in Undergraduate STEM Departments." *International Journal for the Scholarship of Teaching and Learning* 17(1), 19. https://doi.org/10.20429/ijsotl.2023.17119

Coulombe, Grace, Mary B. O'Neill, and Michael E. Schuckers, eds. 2016. *QMaSC: A Handbook for Directors of Quantitative and Mathematics Support Centers*. Scholar Commons, University of South Florida. https://digitalcommons.usf.edu/qmasc_handbook/

Couturier, Lara K., and Jenna Cullinane. 2015. "A Call to Action to Improve Math Placement Policies and Processes: Six Policy Recommendations to Increase STEM Student Aspirations and Success While Decreasing Racial and Income Gaps." *Jobs for the Future*. https://files.eric.ed.gov/fulltext/ED559677.pdf

DiBartolo, Patricia Marten, Leslie Gregg-Jolly, Deborah Gross, Cathryn A. Manduca, Ellen Iverson, David B. Cooke III, Gregory K. Davis, et al. 2016. "Principles and Practices Fostering Inclusive Excellence: Lessons from the Howard Hughes Medical Institute's Capstone Institutions." *CBE—Life Sciences Education* 15, no. 3: ar44. https://doi.org/10.1187/cbe.16-01-0028

DiGregorio, G., & J. Ellis Hagman. 2021. "Towards Student-ready Mathematics Departments: Creating a Mathematics Placement Experience within an Asset Framed Approach." *PRIMUS* 31(10): 1089–1105. https://doi.org/10.1080/10511970.2020.1810184

Eblen-Zayas, Melissa, Ellen Altermatt, Laura J. Muller, Jonathan Leamon, and Sundi Richard. 2020. "Supporting Student Quantitative Skills across Introductory STEM Courses: Faculty Approaches and Perceived Needs." In *2020 Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2020.pr.Eblen-Zayas

Eblen-Zayas, Melissa, and Lin Winton. 2022. "Building a Social and Academic Online Bridge to Quantitatively-Rich College Coursework." *Numeracy* 15(1): Article 3. https://doi.org/10.5038/1936-4660.15.1.1408

Eblen-Zayas, Melissa, Laura J. Muller, and Janet S. Russell. 2023. "Possibilities and Pitfalls of Practitioners in Trying to Apply Change Theory as Viewed through the Lens of Reinholz, White, and Andrews' 'Change Theory in STEM Higher Education: A Systematic Review.'" *International Journal of STEM Education* 10(1): 53. https://doi.org/10.1186/s40594-023-00446-3

Emery, N., J. M. Maher, & D. Ebert-May. 2019. "Studying Professional Development as Part of the Complex Ecosystem of STEM Higher Education." *Innovative Higher Education*, *44*, 469–479. https://doi.org/10.1007/s10755-019-09475-9

Gaze, Eric C., Aaron Montgomery, Semra Kilic-Bahi, Deann Leoni, Linda Misener, and Corrine Taylor. 2014. "Towards Developing a Quantitative Literacy/Reasoning Assessment Instrument." *Numeracy* 7(2): Article 4. https://doi.org/http://dx.doi.org/10.5038/1936-4660.7.2.4

Gehrke, Sean, and Adrianna Kezar. 2016. "STEM Reform Outcomes through Communities of Transformation." *Change: The Magazine of Higher Learning* 48(1): 30–38. https://doi.org/10.1080/00091383.2016.1121084

Grawe, Nathan D. 2023. "COVID Learning Loss: A Call to Action." *Numeracy* 16(2): Article 3. https://doi.org/10.5038/1936-4660.16.2.1450

Grawe, Nathan D., and Kristin O'Connell. 2018. "Using the Quantitative Literacy and Reasoning Assessment (QLRA) for Early Detection of Students in Need of Academic Support in Introductory Courses in a Quantitative Discipline: A Case Study." *Numeracy* 11(1): 5. https://doi.org/10.5038/1936-4660.11.1.5

Kezar, Adrianna. 2009. "Change in Higher Education: Not Enough, or Too Much?" *Change: The Magazine of Higher Learning* 41(6): 18–23. https://doi.org/10.1080/00091380903270110

Kezar, Adrianna, and Jaime Lester. 2009. "Promoting Grassroots Change in Higher Education: The Promise of Virtual Networks." *Change: The Magazine of Higher Learning* 41(2): 44–51. https://doi.org/10.3200/CHNG.41.2.44-51

Kezar, Adrianna, Tricia Bertram Gallant, and Jaime Lester. 2011. "Everyday People Making a Difference on College Campuses: The Tempered Grassroots Leadership Tactics of Faculty and Staff." *Studies in Higher Education* 36(2): 129–151. https://doi.org/10.1080/03075070903532304

Kezar, Adrianna, Emily Miller, Samantha Bernstein-Serra, and Elizabeth Holcombe. 2019. "The Promise of a 'Network of Networks' Strategy to Scale Change: Lessons from the AAU STEM Initiative." *Change: The Magazine of Higher Learning* 51(2): 47–54. https://doi.org/10.1080/00091383.2019.1569973

Lee, W. C. 2019. "Pipelines, Pathways, and Ecosystems: An Argument for Participation Paradigms." *Journal of Engineering Education*, *108*(1), 8–12. https://doi.org/10.1002/jee.20241

Melguizo, Tatiana, Johannes Bos, George Prather, Holly Kosiewicz, Kristen Fong, and Federick Ngo. 2015. "Assessment and Placement Policies and Practices in Developmental Math." https://pullias.usc.edu/wp-content/uploads/2023/11/USC-Community-College-Project-Report.pdf

Palmer, Michael S., and Judith A. Giering. 2023. "Characterizing Pedagogical Innovation in Higher Education." *Innovative Higher Education*, 1–21.

Reinholz, Daniel L., Isabel White, and Tessa Andrews. 2021. "Change Theory in STEM Higher Education: A Systematic Review." *International Journal of STEM Education* 8(1): 37. https://doi.org/10.1186/s40594-021-00291-2

Schuckers, Michael, Mary B. O'Neill, and Grace Coulombe. 2017. "Providing Open-Access Know How for Directors of Quantitative and Mathematics Support Centers." *Numeracy* 10(1): Article 2. https://doi.org/10.5038/1936-4660.10.1.2