Quantitative Biology at Community Colleges, a Network of Biology and Mathematics Faculty Focused on Improving Numerical and Quantitative Skills of Students

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ABSTRACT

Mastery of quantitative skills is increasingly critical for student success in life sciences, but few curricula adequately incorporate quantitative skills. Quantitative Biology at Community Colleges (QB@CC) is designed to address this need by building a grassroots consortium of community college faculty to 1) engage in interdisciplinary partnerships that increase participant confidence in life science, mathematics, and statistics domains; 2) generate and publish a collection of quantitative skills–focused open education resources (OER); and 3) disseminate these OER and pedagogical practices widely, in turn expanding the network. Currently in its third year, QB@CC has recruited 70 faculty into the network and created 20 modules. Modules can be accessed by interested biology and mathematics educators in high school, 2-year, and 4-year institutions. Here, we use survey responses, focus group interviews, and document analyses (principles-focused evaluation) to evaluate the progress in accomplishing these goals midway through the QB@CC program. The QB@CC network provides a model for developing and sustaining an interdisciplinary community that benefits participants and generates valuable resources for the broader community. Similar network-building programs may wish to adopt some of the effective aspects of the QB@CC network model to meet their objectives.

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Conflict of interest statement: This manuscript, which seeks to analyze the QB@CC program objectively, was written by the QB@CC leadership team, which may serve as a point of bias in our interpretation of the data.

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INTRODUCTION

Undergraduate biology education has often followed biology's foundation as an observational science with minimal quantitation. However, the skill sets needed to succeed in most modern-day bioscience careers have pivoted to rely heavily on quantitative skills (e.g., the ability to perform algebraic manipulations; conduct numerical reasoning; use and interpret graphs, models, and statistical analyses). This discrepancy is a call to action in modern biology education policy reforms (National Research Council, 2003; Steen, 2005; Association of American Medical Colleges–Howard Hughes Medical Institute, 2009; American Association for Advancement of Science, 2011; President's Council of Advisors on Science and Technology, 2012). In spite of such calls for reformation, biology education continues to de-emphasize quantitative skills and, like many other disciplines, often fails to make interdisciplinary connections for the students. There have been initiatives that have resulted in integrating authentic interdisciplinary experiences into biology courses, such as Project NEXUS, funded by the Howard Hughes Medical Institute (HHMI; Thompson *et al.*, 2013). However, such interdisciplinary experiences are sporadic, and students are often unable to transfer skills and knowledge from one domain to another (e.g., quantitative skills to foundational biology courses), thereby impeding success (Usher *et al*., 2010). When asked why they downplay quantitative skills, faculty teaching introductory courses cite a lack of pedagogical content knowledge (PCK), the understanding of both content and pedagogy, and feeling unprepared to effectively teach students truly interdisciplinary curricula (Shulman, 1986; National Academies of Sciences, Engineering, and Medicine, 2015; Corwin *et al*., 2019). Additionally, faculty report that varied levels of math preparedness in their students, coupled with the discrepancies in the math prerequisites or math skill levels, can reduce their willingness to incorporate math content. Varying levels of math anxiety and math self-efficacy as well as widely variable math competencies open a Pandora's box of additional foundational math content required for students to master the desired college-level quantitative skills (Ross-Gordon, 2003; Chen and Simone, 2016; Andrews and Aikens, 2018; Karpakakunjaram and Jenkins, 2019). Therefore, in preparing biology students for their careers, we must increase the opportunities for students to gain and hone their quantitative skills consistently throughout their education.

Now is the time to increase access to resources that integrate quantitative skills into courses across multiple disciplines (math and biology, in this case). Community colleges (CCs) are 2-year degree–granting institutions that offer open enrollment, have large student bodies, and are more representative of true population diversity. The majority of Hispanic and Native American students, as well as 43% of Black students, will attend a CC before earning their undergraduate degrees (American Association of Community Colleges, 2021). Additionally, though 40% of all undergraduate students are enrolled at CCs (National Science Board, 2018), ~50% of all bachelor's and 20% of doctorate graduates in science and engineering have taken course work at CCs (National Science Board, 2019). Furthermore, many students obtain training at CCs for bioscience-related technical careers (e.g., biotechnology, nursing, radiology, sonography, dental hygiene) that require on-the-job quantitative reasoning skills. Among newly hired nurses, ~60% earn associate degrees and training from CCs (Mahaffey, 2002). Currently, accreditation bodies mandate that these programs require biology courses as prerequisites. Undergraduate biology faculty limit quantitative skills–based content in their courses due to institutional and pedagogical barriers (Corwin *et al*., 2019), some of which are specific to CCs. CCs are, therefore, one of the critical centers of higher education where educational transformation may help reduce some of the abovementioned barriers and result in positive impacts on a diverse population of students.

For genuine, long-term changes to occur in course design and content, faculty need support and opportunities to implement pedagogical practices and receive feedback (Ebert-May *et al*., 2011). CC faculty have a demanding teaching workload, with no teaching assistants, which leaves little time to modify their curricula. Part-time faculty can have similarly high teaching loads along with other careers. The time investment necessary to add novel pedagogical practices such as quantitative skills to the curriculum may not be rewarded with promotion and tenure (Marsteller *et al*., 2010). Many faculty feel their curricula are already overloaded with required content, driven by learning objectives and articulation agreements with multiple 4-year institutions (Beno, 2004; Speth *et al*., 2010). Additionally, best pedagogical practices are often not sustainable due to lack of practice and local culture (Emery *et al*., 2020), and opportunities for CC faculty to join networks, discipline-based societies, or communities of practice have been limited until recently (Brownell and Tanner, 2012). Thankfully, this barrier has been gradually diminishing, especially during the global pandemic. Many discipline-based societies and networks (e.g., American Mathematical Association of Two-Year Colleges [AMATYC], American Society of Microbiology [ASM], BioQUEST Curriculum Consortium, HHMI, National Association of Biology Teachers [NABT]) now have infrastructure to intentionally include and support CC faculty within their professional development events (Holmberg *et al*., 2021).

To respond to these challenges and changing times, the Quantitative Biology at Community Colleges (QB@CC) network, a National Science Foundation (NSF)-funded Research Coordination Network for Undergraduate Biology Education (RCN-UBE) grant (award no. 1919613), was initiated in September 2019. QB@CC extends the collective efforts of building an inclusive and accessible community of practice for CC faculty, intentionally addressing barriers around PCK, time, resources, and connections. The main goals of QB@CC are to 1) engage in interdisciplinary partnerships that increase participant confidence in life science, mathematics, and statistics domains; 2) generate and publish a collection of quantitative skills–focused open education resources (OER); and 3) disseminate these OER and pedagogical practices widely, which in turn expands the network. The project is midway through building a network of interdisciplinary pedagogical practitioners who help to meet the objectives of the program. To evaluate the effectiveness in accomplishing the program's goals, we addressed the following three research questions:

1. Are interdisciplinary work groups helping to build collaborative networks?
2. Are collaborative networks generating and valuing OER practices and quantitative skills–focused resources?
3. What types of internal and external support systems are critical for the successful dissemination of QB@CC resources and expansion of the network?

(A)

Grant Activities	Year 1 (Sept 2019)	Year 2	Year 3	Year 4	Year 5 (Aug 2024)
Steering Committee Meetings (Virtual, check-ins)*	→	→	→	→	→
Advisory Board Meetings (Virtual)	⇢	→	→	→	→
Recruitment and Professional Development	⇢	→	→	⇢	→
Incubator Module Development**	→	→	→	→	→
FMN Adaptations*		→	→	→	→
Dissemination and Professional Development	→	→	→	→	→
Network Website and Resources	→	→	→	→	→

(B)

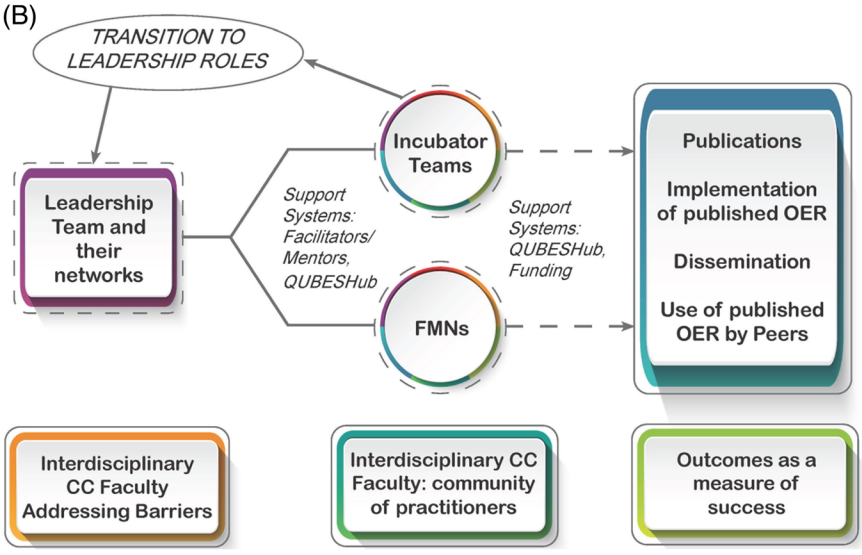

FIGURE 1. A description of the structure and critical components of the QB@CC network. (A) A Gantt chart indicating the original grant timeline for the network activities, excepting the movement of the second in-person cohort meeting to year 4 due to the pandemic. The steering committee meets through the academic year, with 3- to 4-week breaks in Summer and Winter. The hatched and solid gray arrows indicate in-person and virtual meetings, respectively. An asterisk (*) indicates biweekly virtual meetings of the steering committee and the FMNs, and a double asterisk (**) indicates weekly virtual meetings of teams until the publication of the Incubator modules. (B) Flowchart of the components of QB@CC network that represent communities of practice addressing barriers to CC faculty engaging in professional and scholarship activities. The leadership team recruits the network members (CC faculty) to participate in professional development opportunities (Incubators and FMNs) as communities of practice that result in development and dissemination of OER. The network members are supported throughout the process, i.e., the facilitators and mentors provide support during the development and implementation of OER, the QUBESHub platform supports the development and publication of the OER, and the grant funds support dissemination of the published OER at workshops and conferences. Incubator participants have also transitioned to leadership roles in the Incubators and by joining the leadership team.

Leadership Team

The core leadership team of QB@CC consists of eight steering committee (SC) members, including the principal and the co-principal investigators (PIs); seven advisory board members; and an external evaluator. Following best practices for RCN-UBEs (Eaton *et al.*, 2016), the SC members, including one of the PIs, are faculty teaching mathematics and biology from diverse CCs across the United States. In addition to the core leadership team, several professional organizations, societies, and CCs have committed to support QB@CC activities at various levels. Links to the network's leadership structure are included in the Supplemental Material.

The SC meets biweekly during the academic year to plan and track the project's activities and progress. The advisory board meets biannually to review the project's progress and guide future directions. The original grant timeline in Figure 1A is used as a guideline to plan different aspects of the program's design and goals. For example, developing, adapting, and publishing modules as OER by the Incubator teams and Faculty Mentoring Networks (FMNs) and building and maintenance of the QB@CC website are continuous activities that span the grant's lifetime, while in-person meetings are held only three times during the grant—twice in year 1 and once in year 4. The kickoff meeting for planning activities was held as an in-person meeting (Figure 1A, hatched arrow in year 1 column, advisory board meetings row) in October 2019, hosted by Montgomery College, Rockville, MD.

Incubators and FMNs

Incubator and FMNs apply change theories, such as communities of practice (Reinholz and Andrews, 2020; Reinholz *et al.*, 2021), to reduce barriers (Figure 1B) in science, technology, engineering, and mathematics (STEM) education reform and promote faculty participation in professional development (Bouwma-Gearhart, 2012; Brownell and Tanner, 2012; Kezar and Gehrke, 2015; Shadle *et al.*, 2017). Incubator teams consist of three to five math and biology CC faculty working together to develop and publish a module based on a mutually selected biology theme integrated with appropriate math skills. The selection of themes and math skills is driven by the learning outcomes of appropriate biology and math courses taught by the faculty participants (e.g., introductory biology and pre-calculus courses). Participants can join Incubators as a team or will self-organize after identifying common topics of interest based on their responses in the application. They then meet weekly until the process is complete (Figure 1A), led by experienced

facilitators. When possible, Incubator teams are coordinated by two facilitators, one each from biology and mathematics or statistics disciplines. Though implementation is not required in the Incubators, it is an essential part of the FMN structure (Figure 1B). FMN participants are interested in adopting these already published QB@CC modules and implementing their versions in their classrooms. The overall FMN structure, including basic topics and schedule, was created during the QUBES Project (Donovan *et al.*, 2015) and has been modified by many groups for their own needs. FMN groups meet biweekly (Figure 1A) through the implementation process and are led by one or two experienced mentors, so far by the members of the SC. FMN participants are required to publish their modified modules linked to the original QB@CC activity. Thus far, QB@CC has focused primarily on CC mathematics and biology faculty, but has not excluded participants from 4-year institutions.

In addition to describing the QB@CC network and structure in detail, this paper further discusses the qualitative analyses of the effectiveness of the program in building the network and meeting the goals during the first half of the grant's work. The resulting analysis and discussions reveal the strengths of the network and the limitations on the scope of this program.

METHODS

Recruiting, Onboarding, and Supporting Network Participants

Network participants are recruited by several methods: 1) personal invitations to CC colleagues from their professional networks, 2) presentations and posters at workshops and conferences, 3) publishing calls for participants in professional network newsletters, 4) current and previous participant invitations, and 5) an openly accessible survey on the QB@CC website that allows interested visitors to sign up for more information. Network participants are recruited twice a year (Spring and Fall; Figure 1A) to work in small teams as part of an Incubator or an FMN.

The first cohort of QB@CC members was recruited to participate in an in-person meeting hosted by the National Institute for Mathematical and Biological Synthesis (NIMBioS), University of Tennessee, in February 2020. At this two-and-a-half-day workshop, participants engaged in discussions about backward design principles for curricular development, developing and publishing OER, differences in the meaning of common terms used in biology and math disciplines (digit, root, function, etc.), and best practices for inclusive and equitable pedagogy. In addition, two keynote speakers, one each from the life sciences and mathematics disciplines, addressed the network about the relevance of inclusive pedagogy and increasing demand for interdisciplinary instructional opportunities in higher education and the 21st-century workforce. The participants also worked in small groups to review the modules developed by the SC members during Fall 2019 to experience quantitative skills–focused content from a student perspective. All the resources used at this workshop and the recorded keynote presentations were shared on the QB@CC site for future participants. Subsequent cohorts participate in a 1-hour virtual orientation, discussing aspects of the interdisciplinary content and pedagogy-related topics previously listed, with breakout room options for faculty discussions, and also have access to all other resources from the first in-person event as well.

All participants are provided with a support system to get started with the module work and through the semester of Incubator module creation or FMN module adaptation and implementation. Incubator teams are assigned one or two facilitators and are set up with a virtual meeting space (Zoom), a shareable Google document for module work, meeting notes, and an editable suggested schedule. Polling software determines meeting times, choosing a time that works for everyone. The FMN mentor(s) preselects a specific biology and math theme and the modules available for adaptation by that group. Each FMN member picks one of the selected modules, adapts it to fit their curriculum, implements it in their course, and then publishes the resulting adaptation in the QUBES Open Educational Resource Library as a unique resource (Donovan *et al.*, 2015), automatically linked on the QB@CC site. All published modules and adaptations are given a unique digital object identifier (DOI) with a CC Attribution-Share Alike 4.0 International license. This option allows users to make adaptations linked back to the original version, providing both authors and subsequent users credit for their efforts. In addition, the faculty participants in Incubators and FMNs can include the published information (DOI) in their professional portfolios.

When creating modules during the working meetings, faculty regularly learn content from one another, discuss pedagogical content knowledge (i.e., "this is how I would teach it"), describe their discipline-specific approaches toward quantitative topics, and discuss teaching strategies to support students' quantitative skills. The SC developed and shared a tentative timeline for developing modules as part of an Incubator based on their module development work during Fall 2019. A similar timeline was developed for adapting and implementing published modules as part of a FMN by modifying the previously existing FMN timeline. Suggested timelines for each model are listed in Table 1, but groups have the autonomy to alter and extend the schedule as they see fit.

Data Collection

Data on discipline (life sciences, mathematics, and statistics) and geographic representation of the network members, including the leadership team and Incubator and FMN participants, were collected. For the participants, data were extracted from the application form originally expressing interest to join the network. The success of module implementation and completion is collected from the QB@CC site. The link to published modules and a sample module has been included in the Supplemental Material. The data on dissemination of QB@CC resources are collected from two sources: 1) all published modules from Incubator and FMN work record the number of downloads, and 2) the network members' presentations are uploaded to a repository in the QB@CC leadership site, thus collecting information on the workshops and conferences where the QB@CC work has been shared.

Survey Data. We adopted the principles-focused evaluation (P-FE) methods to measure the impacts and effectiveness of the QB@CC network in accomplishing the project goals. The P-FE methods measure the values attributed to and use of program elements by the participants in the program (Patton, 2018). The evaluation methods include retrospective surveys (pre- and post-workshop, Incubator and FMN surveys, and focus groups;

TABLE 1. Recommended timelines for Incubator and FMN groups[a]

Week	Generalized Incubator timeline	Generalized FMN timeline
0–1	Decide on module topic	Design module implementation and student engagement plans Review backward design
1–2	Backward design of learning outcomes	Review universal design and online engagement
3–4	Create activity components that are aligned with biology learning outcomes	Review a QB@CC module and describe possible implementation strategies
5–7	Focus on math learning outcomes	Discuss assessment plans for modules
8–9	Draft components of the activity	Implement module
9–11	Analyze activity with QB@CC diagnostic tool	Discuss efficacy and future changes to adapted materials
12–14	Finalize and publish completed module	Publish adapted modules

[a]The timeline has gone through several modifications, especially due to the challenges the faculty faced during the global pandemic. Incubator teams develop and publish new modules; the FMN members modify existing modules, implement in their classes, and publish the adapted versions.

House, 1980; House and Howe, 1999) that will extract the value that the network members attribute to different programmatic elements provided by QB@CC. Survey constructs are validated through their use over time and their modifications at each stage (House, 1980; House and Howe, 1999). Evaluation of the survey tools is an iterative process, with modifications made to support the program evaluation of the QB@CC activities. Delphi methods for survey modifications (Hartman and Baldwin, 1995; Landeta, 2006) inform survey design, with feedback from the SC and advisory board based on program evaluation benchmarks and goals.

Pre- and post-workshop retrospective surveys collected data on the perceptions of participants on OER, publishing, and sharing their work as OER. Retrospective surveys were also conducted when the Incubator and FMN participants approached completion of their work. These surveys collect data on the participants' experiences with different aspects (collaborative, interdisciplinary work, teaching quantitative skills, etc.) of the module development and implementation. In addition to these surveys, the external evaluator (author S. LoRe) interviewed the participants in focus groups. Question scales were used to evaluate the perception of integral aspects of the QB@CC network activities by the network participants. Some examples of the integral aspects of the QB@CC network are interdisciplinarity, collaborative module development process, use of quantitative skills–focused resources, awareness and value of OER practices, and use of the module in the classroom. A sample set of survey questions related to use of developed modules and development of quantitative skills–based resources is provided in Table 2.

The evaluator sent the Qualtrics (www.qualtrics.com) surveys to network participants. Descriptive measures, frequency counts, and averages are employed to analyze quantitative responses. The open-ended survey responses were deductively or "focus coded" by the question topic (Merriam and Tisdell, 2016; Saldaña, 2016). The question constructs related to collaborative work and dispositions toward OER were modified from a previous version employed at a 2018 professional development workshop that emphasized quantitative skills. Survey questions are provided in the Supplemental Material.

As the Incubators and FMNs drew to a close, the project evaluator conducted virtual focus groups with each Incubator and FMN team. These focus groups occurred during the teams' meeting times, increasing the participation rates. The goal of these focus groups was to gather formative feedback about the design and implementation of curricular materials to inform the QB@CC network. The focus group questions related to module development (Incubator) or implementation in the classrooms (FMN), types of modifications to the module (FMN), plans for future use of the modules, and the perceptions of participants' institutions regarding their involvement in QB@CC activities. The program's impacts included attitudes and dispositions of the participants toward collaborative curricular design, adaptation, and implementation. The focus groups were audio-recorded with the participants' permission and transcribed before analysis. The evaluator employed deductive (focused) and inductive (open) coding techniques that involves line-by-line coding for the text of the transcription while comparatively coding the focused themes in the interview guide (Creswell and Creswell, 2013; Merriam and Tisdell, 2016; Saldaña, 2016).

RESULTS

Research Question 1: Are Interdisciplinary Work Groups Helping to Build Collaborative Networks?

Interdisciplinary Leadership Team Translates to a Holistic Interdisciplinary Network. Nearing completion of year 3 of the grant, the QB@CC network has grown from a 15-member

TABLE 2. A subset of retrospective survey questions that were given to QB@CC participants in Incubators and FMNs[a]

A Sample of Survey Questions given to QB@CC participants
1. Do you plan to use the lesson created in the Incubator in your classroom? Yes or No
a. If you selected "No," why will you not be implementing your lesson in the classroom?
2. Participating in QB@CC increased my knowledge of quantitative teaching resources.
3. Participating in QB@CC enhanced my ability to teach a quantitative biology concept in my classroom.

[a]If the response to Q1 was "No," then the participant is asked to respond to an open-ended follow-up question to explain the reasons for not implementing the module in the class. Q2 and Q3 has a scale of responses ranging from "strongly agree" to "strongly disagree" (refer to Figure 3D and the survey questions in the Supplemental Material).

TABLE 3. Faculty from life sciences (LS) and mathematics/statistics (MS) are equally well represented in the QB@CC network[a]

	SC members		Incubator participants		FMN participants	
Interdisciplinary representation	LS	MS	LS	MS	LS	MS
	5 (1*)	3	29 (2*)	31 (2*)	6 (1*)	4 (2*)

[a]The stakeholders in the network have been split into leadership, Incubator, and FMN teams. Incubator and FMN numbers include participants up to Spring 2022. Advisory board members are not included in this table, because some of them do not associate with a specific discipline (LS or MS). An asterisk (*) indicates the number of participants from universities.

leadership team (SC and advisory board) in September 2019, to 44 members by February 2020, to the current 85 members (June 2022). Of the 15 leaders, seven SC members and two advisory board members are from eight different CCs. Among the SC members, four are from life sciences disciplines and the other three are from mathematics and statistics disciplines (Table 3). Of the seven advisory board members, five are national leaders from CC and 4-year institutions with long track records in quantitative biology and interdisciplinary education; the other two are national leaders in professional development and in OER curricula in higher education (data not included in Table 3). This inclusive and interdisciplinary CC-focused leadership structure has been critical in successful recruitment of faculty from the life sciences, mathematics, and statistics.

The objective of building an interdisciplinary community of practitioners is strongly reflected in the equal representation of network participants from life sciences and mathematics/statistics disciplines. Of the 70 faculty participants, 35 each are from life sciences (29 Incubator and 6 FMN members) and mathematics and statistics (31 Incubator and 4 FMN members). Among the network participants, 6.67% of Incubator members (n = 60) and 30% of FMN members (n = 10) were from six different universities (Table 3), and the remaining members represent 34 CCs across the United States and a province in Canada. It is notable that one of the CC participants also teaches AP Biology at a high school.

The QB@CC network, including SC members, advisory board members, and participants, represents 24 states within the United States and one province in Canada (Figure 2). Returning members and those who transitioned to other roles in the network are not double-counted in the indicated membership numbers. As indicated earlier and in Table 3, most of the network members are CC faculty from across the two disciplines and represent 34 colleges, while the remaining members represent six different U.S. universities. The list of CCs and the universities represented in the QB@CC network is shared in the Supplemental Material.

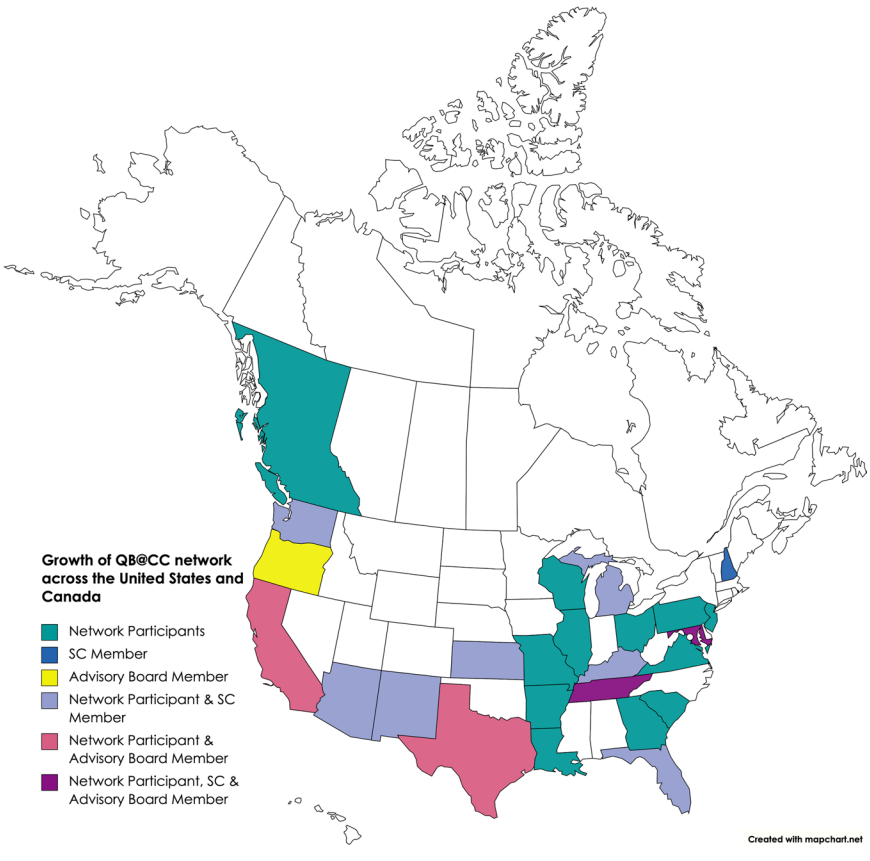

FIGURE 2. Geographic representation of QB@CC network members as of June 2022. The network is currently represented by members from 24 states in the United States and a province in Canada. The network includes participants, SC members, and the advisory board. Data were generated and imported from MapChart.net.

The QB@CC leadership team has intentionally built all project activities to reflect interdisciplinarity as the signature of the network, including the keynote speakers (one biology and one math), at the Spring 2020 in-person workshop (Figure 1A, hatched arrow in year 1 column, recruitment and professional development row), representing biology and math disciplines from CCs. The Incubator and FMN virtual workspace is a key component of the network-building and module development process, in which participants engage in rich, interdisciplinary conversations as part of their creative work. All survey respondents deeply valued the pedagogical discussions during the meetings and the opportunity to work with peers from different disciplines (Figure 3A), noted by responding either "strongly agree" (93%) or "agree" (7%) to both questions. Furthermore, 79% of respondents acknowledged that the QB@CC project provided them a rare opportunity to work with new colleagues—both across disciplines and from different CCs.

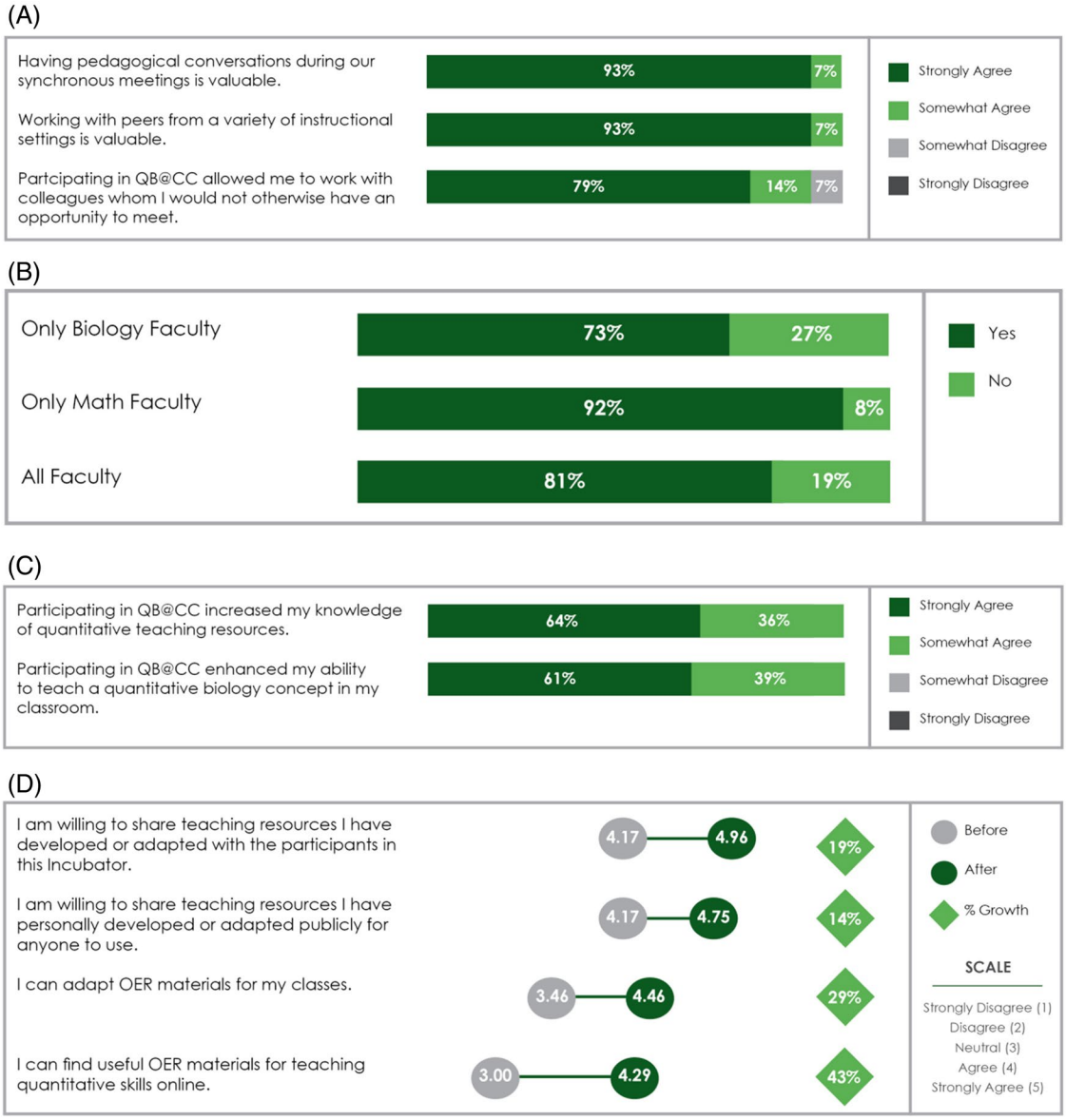

FIGURE 3. Retrospective survey data from participants. (A) Participants' level of agreement with statements about QB@CC professional development training ($n = 28$). Twenty respondents were from Incubator Cohort 1, four from Incubator Cohort 2, and four from the Spring 2021 FMN. (B) Participants' discipline-specific planned use of their modules in instruction (biology faculty $n = 15$; math faculty $n = 12$). (C) Participants' gains in knowledge of teaching resources for quantitative skills and their ability to teach quantitative biology ($n = 28$). (D) Participants' (Cohort 1, $n = 24$) ranked perception of the culture of willingness to use and disseminate quantitative skills–based teaching modules as OER before and after the in-person workshop. The gray circles indicate the average ranking in the pre-workshop survey, and the dark green circles indicate the average ranking in the post-workshop survey. The percent improvement, termed "growth," is shown in light green diamonds.

One faculty participant attributed the social support from the FMN to improving their confidence to teach quantitative topics:

> Prior to this FMN, I was very insecure about my ability to teach quantitative and math skills in my biology courses. It was comforting to know I am not the only one in this position and to find a group of like-minded individuals who also struggle, but we were able to support each other. And it was great that we were able to remind each other that it is okay if it isn't perfect the first time through; nothing is. After going through this experience, I have a lot more confidence when it comes to teaching quantitative skills in my classroom.

Additional quotes from other survey respondents (Incubator and FMN) are included in the Supplemental Material. The quotes in the Supplemental Material include respondents' reflections on the significance of the interdisciplinary Incubator teams and how this changed their perspectives on using terminologies that may have different meanings across two disciplines and be a cause of confusion for students (barrier to

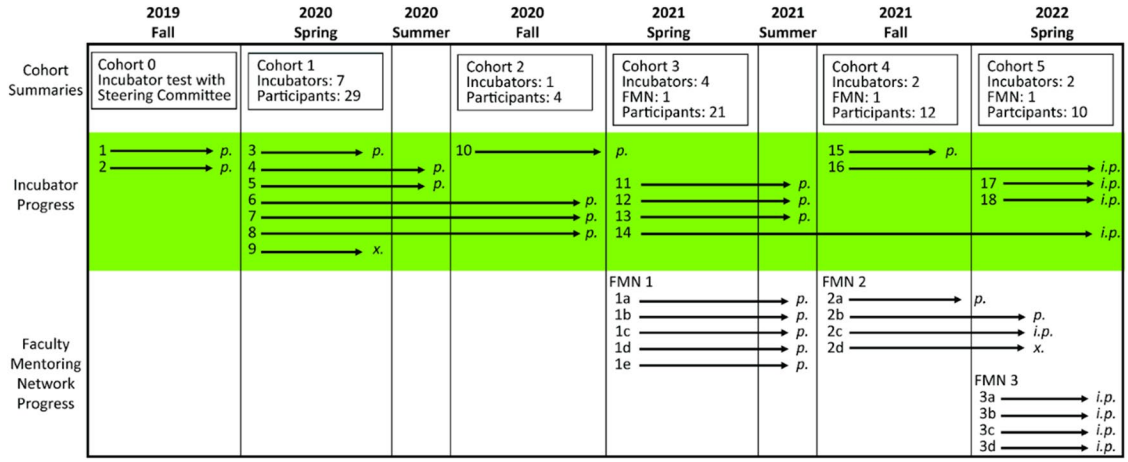

FIGURE 4. The timeline shows the module completion span for each Incubator team and FMN participant (listed as number followed by an alphabet, 1a, 2b, 3c, etc.) from Fall 2019 to Spring 2022. Each arrow represents the length of time from start to completion. Completion is defined by the publication of the module (Incubator) or an adapted version (FMN) as an OER in the QUBES OER Library. *p.*, published module; *i.p.*, module work is in progress; *x.*, the group disbanded without completing a module.

learning), the value of demonstrating application of mathematical concepts to biological processes, and the flexibility to modify a module to fit their own teaching styles.

The network has built such a positive community over these years that some of the Incubator participants have assumed leadership roles within QB@CC by facilitating and mentoring Incubators and FMNs; one of them transitioned to become a SC member. As the network expanded since Spring 2021, five of the eight Incubator teams had two co-facilitators, one each from life sciences and mathematics/statistics disciplines. The interdisciplinary co-facilitation model has strengthened the mentorship and the module development experiences of the Incubator participants and has provided leadership opportunities for faculty in the community.

Research Question 2: Are Collaborative Networks Generating and Valuing OER Practices and Quantitative Skills–Focused Resources?

The network participants have worked in smaller interdisciplinary groups of three to five members to create and publish 13 modules in Incubators, where each group coauthors a single module. In the FMNs, each faculty member ($n = 7$) modify and adapt one of the already published Incubator modules and published their version. Figure 4 highlights the timeline for publication of each module as OER. The first two Incubator groups (Cohort 0 in Figure 4) were composed solely of members of the SC piloting the process to optimize its format. Following Cohort 0's work, the QB@CC network hosted five faculty cohorts from Spring 2020 to Spring 2022 for Incubator work and three cohorts from Spring 2021 to Spring 2022 for FMN work. While faculty groups are encouraged to complete the module during one semester, most groups published their modules the following semester.

The first cohort of network participants, Cohort 1, started in Spring 2020 with 29 faculty working in seven Incubator groups. All but one group completed their module, and the one group that discontinued work indicated that they could not balance their pandemic-modified teaching schedules with their QB@CC work. This information was collected by the external evaluator intentionally surveying the three participants in that group to ensure that the policies and procedures of QB@CC project were not the cause of the group's inability to complete the module. The survey sent out to these three participants is included as Supplemental Material. The remaining groups completed their modules either in the same semester ($n = 1$), during the Summer ($n = 2$), or in the following Fall semester ($n = 3$). Due to the pandemic and three Incubators from Cohort 1 extending their module development, the QB@CC leadership team decided to limit network activities to one new Incubator group for Cohort 2 in Fall 2020. During Spring 2021, Cohort 3 started with four Incubator teams and one FMN. Of Cohort 3, three Incubator teams completed their modules, while the fourth team is still working on their module. Four of the five members of the FMN successfully published their modules, while the remaining member is still working on their adaptation. Two Incubator teams were organized in Fall 2021, of which one has completed and published their module and the other is nearing completion. Two of the four members in the FMN in Fall 2021 have published their adapted versions. Currently, two Incubator teams and four FMN participants are working on their modules and adapted versions, respectively (Figure 4).

The 20 published OER modules cover a range of biological themes and faculty-valued quantitative skills (LoRe, 2019). A single module often addresses multiple quantitative skills. The two quantitative skills ranked most essential by biology faculty—graphing skills (creating and interpreting) and data interpretation from tables—are addressed in the majority of the published modules. Quantitative skills valued by biology faculty included in modules can be found in a table in the Supplemental Material. In addition, a sample list of instructional materials from a published module is included in the Supplemental Material along with a link to the modules' page on the QB@CC site.

In response to the retrospective survey on using the published modules, 81% of the respondents indicated that they will implement the module in their courses (Figure 3B). When the

respondent data were separated by discipline, 92% of math faculty indicated that they will implement their developed materials, whereas only 73% of biology faculty committed to implementing (Figure 3B). If a respondent selected "No," the common reason was that their teaching commitments changed during the pandemic and the module may not be appropriate for their current courses. One of the respondents added, "However, I will be sharing it with the faculty teaching general biology labs for them to implement." Even if not all the participants will be using their materials, more than 60% of respondents strongly agree that participation in the QB@CC activities increased their knowledge of quantitative skills–focused teaching resources and their ability to teach quantitative biology (Figure 3C).

In addition to using quantitative skills–based teaching resources, participants were asked about their change in perception of using OER and sharing their modules as open-access resources with peers. Figure 3D indicates the responses to pre and post in-person workshop surveys completed by Cohort 1. We find 19% and 14% positive change in attitude to sharing their modules within the Incubator and outside the QB@CC network, respectively. There is also a 43% gain in confidence in the ability to find appropriate OER to teach quantitative skills and 29% growth in confidence to integrate those resources into their instruction (Figure 3D).

Research Question 3: What Types of Internal and External Support Systems Are Critical for the Successful Dissemination of QB@CC Resources and Expansion of the Network?

Internal Support Systems. The QB@CC network incorporates a number of practices designed to support the success of interdisciplinary groups in creating and publishing quantitative biology modules: interdisciplinary teams of QB@CC leadership; life sciences and mathematics/statistics co-facilitation of Incubators; access to infrastructure like virtual meeting spaces, shareable working documents, and OER publications; and appropriate attributions to adapted versions of modules.

Interdisciplinary work presents a number of challenges that can derail productive collaboration. There is a language barrier that can create frustration as different disciplines use the same term to mean very different things. QB@CC orientation raises awareness of this with participants, and encourages everyone to be comfortable asking questions about terms. This is accomplished with a simple activity in which participants select a term at random and describe what it means in their discipline, and then someone from the other discipline explains what it means in their field. A surprising number of basic terms have radically different meanings (e.g., digit, root, and divide); this activity is fun and sets the expectation that the participants need to be aware of these differences. Successful interdisciplinary work relies on an atmosphere in which participants are comfortable revealing their lack of knowledge.

Focus group discussions were conducted virtually to explore the impact of the internal support systems. The focus group discussions were categorized into four discrete, but interrelated categories of reflections: overall experience being part of an Incubator, changes to their teaching methods due to participation in the QB@CC Incubator, interdisciplinary discussions of use of common terms, and the relevance of interdisciplinary experiences in higher education to better prepare students (Table 4). The quotes from the participants included in Table 4 are clear indicators of the value that is added by the internal support systems integrated into QB@CC activities, which result in a high rate of successful completion and publication of modules and their adaptations, even amid a global pandemic.

Another piece of the internal structure of the QB@CC project is the connection with the QUBES OER Library. The publication of QB@CC modules in the QUBES OER Library not only allows for dissemination, but also tracking of that dissemination through download data for each module. As of early 2022, there have been 3700 downloads of the QB@CC modules.

External Support Systems. The QB@CC activities are supported at different levels by the partner institutions and organizations of the network. These institutions and organizations, in addition to helping with sharing QB@CC events and recruitment of participants for QB@CC work, also help identify opportunities to disseminate the OER developed and published by network members. The link to the list of partner institutions and organizations is included in the Supplemental Material. The leadership team acknowledges the importance of dissemination via participation in regional and national conferences and workshops, and some SC and advisory board members are leaders in regional and national discipline-based societies to help support this. Table 4 provides a list of presentations (posters and workshops) led by QB@CC participants at various professional development events (virtual and in person). In years 1 and 2 of the grant, these were led primarily by the SC members. Since year 2, however, network participants disseminated their own work with QB@CC at six different conferences and workshops, either with their Incubator team, individually, or with SC member(s). Of the total of 25 presentations, eight were disseminated at regional professional development events (Table 4). Some of these professional meetings are discipline-specific events (NABT conference, Life Discovery Conference, AMATYC Conference), others are interdisciplinary (BIOME workshop, C^2 Summit for pedagogical advancements in STEM, Louisiana Community and Technical College System [LCTCS] workshop) or non–discipline specific events (STEM for All Video Showcase, Association of Faculties for Advancement of Community College Teaching [AFACCT], National Institute for Staff and Organizational Development [NISOD] conference).

The in-person professional development conferences and workshops held in Fall 2019 provided the QB@CC leadership team with a means to effectively reach out to CC faculty and recruit the first set of participants (Table 5). Since March 2020, most of these meetings have been held virtually. The virtual space increased CC faculty participation due to cost-effectiveness and continued virtual access to professional development resources beyond the days of the events. The QB@CC network members have been making use of these opportunities to disseminate their interdisciplinary work and share their experiences (Figure 1B).

Notable Features of Dissemination Work.

1. With the exception of two presentations disseminated by the PIs/co-PI of the grant (Workshop at the NEXUS Institute for Quantitative Biology, Improving Undergraduate STEM Education [NIQB-IUSE] grant conference, 2021: authors K.P.J.

TABLE 4. Depiction of the four major themes (Incubator experiences, changes to teaching, language of math and biology, and intersection of math and biology) coded from focus group discussions with example quotes

Incubator experiences
Participants describe their experience being a part of an Incubator.
"One thing that I thought was so cool through this cross collaboration is that I feel like this project itself really kind of epitomizes what a student who wants an associate of science degree to come out with."
"I still seem to sometimes use, you know, precise mathematical terms in biology class. I'm now realizing and I have to be, like, more careful in, like, my defined terms."
"[My] Incubator group … has just been so encouraging, because a lot of times, like, I feel, like, just out of my comfort zone."
"One of my favorite parts of the experience was being with these [instructors] we're all spread out, even at different campuses, let alone different disciplines, and so working with them, even in person, but then weekly on Zoom has been really nice."
Changes to teaching
Participants describe how their participation in the Incubator led to changes in how they teach.
"I was able to think about the specific topics that I might not cover in my math courses that are extremely important for a biology course."
"[Using real-life data sets] in our college, they're actually collecting this type of data so it's kind of very meaningful."
"I will work on my class, and assessments I'll work on making modifications similar to what others did with the math piece of it."
"I was looking at that [and] I thought really this is what my students need before they come in and do it."
Language of math and biology
Participants describe how the terminology between math and biology should be consistent.
"I appreciate the different terminology across subject matter. I realized that while I have had many math courses, many math faculties have not had any biology courses."
"I never realized that mass and weight were different and that sciences like biology use mass … I've only taught math using weight."
"I can only speak for me, but I felt I learned quite a bit about the different languages both disciplines use."
Intersection of math and biology
Participants describe the importance and benefits of integrating math and biology.
"We will develop good materials that we can use in both math and biology to strengthen quant skills for our students."
"In my actual [math] course I'm teaching as a hybrid, I had a chance to actually discuss … to tell these students you know hey like this example that we're doing here, this could be applied in like a biology class."
"Our faculty is interested in creating curriculum with some sort of modules or activities that really harmonizes both math and biology that could be used in both types of classrooms."
"I think this would work great for that because what we came up with was a math activity based on the science lesson that [Incubator group members] were working on, and I can definitely see us using it."

and V.K.; NE OER Summit, 2022: author S.P.), all other dissemination work included more than one SC member and/or the network participants. Such an inclusive culture wherein participants have strong support systems in the dissemination of their OER is critical for accomplishing the grant's objectives (Figure 1B).

2. The QB@CC network has been participating in the NSF-funded STEM for All Video Showcase virtual event since 2021. The QB@CC video showcased in the 2021 event has several of the network participants contributing to the video and received a wider, global viewership. This video has been watched more 800 times by viewers from 10 countries. The video submitted by QB@CC in May 2022 has been watched more than 200 times by viewers from five countries.

DISCUSSION

A working group consisting of CC and university faculty representing life sciences and mathematics disciplines and leaders in professional development was supported by NIMBioS, University of Tennessee, Knoxville, TN, to explore and identify barriers to integration of quantitative skills–based biology curricula in higher education. One of the outcomes of this working group's research was to address the need for a sustainable, interdisciplinary community to build quantitative skills–based resources to break the PCK barriers. Ebert-May *et al*. (2011) identified that support and opportunities are needed for faculty to implement pedagogical practices and receive feedback for genuine, long-term changes to occur in course design and content. In the absence of such support and opportunities, it will be impossible to build a sustainable, interdisciplinary community, and both teaching and learning of course content will continue without interdisciplinary connections (Usher *et al.*, 2010). The QB@CC project was initiated to provide the support and opportunities, especially for CC faculty, for the transformation of the pedagogical structures to facilitate and weave the interdisciplinary connections into the curricula of life sciences, mathematics, and statistics.

Leadership Culture Facilitates the Success of Interdisciplinary, Collaborative Networks

Life sciences and mathematics faculty are distinct communities with unique ways of thinking about quantitative topics, pedagogical practices, training, and discipline-specific languages. QB@CC leadership includes both disciplines to ensure program design benefits all stakeholders equitably. All the SC members, with the exception of one, are CC faculty with a four-to-three split across life sciences and mathematics disciplines. Given that the primary focus of the network is to build a community of practitioners with a significant representation of faculty from the CCs, reflection of such representation in the leadership team

TABLE 5. Dissemination of QB@CC resources at various professional development events includes a good representation of discipline-based, CC-focused, leadership-centered conferences and workshops

Dissemination of QB@CC work at workshops/conferences		
Year 1 (September 2019–August 2020)	**Year 2 (September 2020–August 2021)**	**Year 3 (September 2021–August 2022)**
1. AMATYC Annual Conference 2. 2019 Annual Professional Development Conference: NABT 3. ASM Conference for Undergraduate Educators 4. BIOME Institute 2020	1. Life Discovery Conference 2. C2 Summit for pedagogical advancements in STEM[a,b] 3. AMATYC Annual Conference 4. Annual Professional Development Conference: NABT 5. AFACCT[a,b] 6. Spring 2021 Workshop of NIQB-IUSE (NSF award: 1821274)[b] 7. Innovations Conference: League of Innovation 8. Washington Mathematical Association of Two-Year Colleges[b] 9. Tennessee Mathematical Association of Two-Year Colleges[b] 10. STEM for All Video Showcase[a] 11. BIOME Institute 2021: Workshop presentation	1. Life Discovery Conference 2. NISOD Fall 2021 Conference 3. Michigan Mathematical Association of Two-Year Colleges[b] 4. 2021 Annual Professional Development Conference: NABT 5. Workshop and posters[a] 6. LCTCS Workshop[a,b] 7. STEM for All Video Showcase 8. NISOD Spring 2022 Conference 9. NE OER Summit[b] 10. BIOME Institute 2022: workshop presentation[a]

[a]Presentations made by network participants either as Incubator teams or collaboratively with SC member(s) or independently.
[b]Presentations at regional conferences or workshops.

was critical to provide a welcoming space for their colleagues to participate in the QB@CC activities. Moreover, a strong CC representation at the leadership level has been critical in identifying and relating to 2-year institution–specific issues and needs. For example, as CCs are open-enrollment institutions, students enter higher education with different levels of preparedness (Karpakakunjaram and Jenkins, 2019), especially in quantitative skills. Variable preparedness makes instruction more challenging, thus making PCK a critical barrier to including quantitative skills in biology curricula or biological themes into mathematics and statistics curricula.

The interdisciplinary leadership team facilitated recruitment of CC faculty from life sciences, mathematics, and statistics and thus grew a strong interdisciplinary community of practitioners. An overwhelming majority of participants in the QB@CC network are faculty from CCs (56 of 60 Incubator participants and seven out of 10 FMN participants; Table 3). Life sciences, mathematics, and statistics are equally represented by the network's membership. Though the CC faculty in the leadership team represent eight states, their professional networks had a far-reaching effect that allowed for a wider geographic representation, with participants from across 24 different states of the United States and one province in Canada. The interdisciplinary Incubator and FMN cohorts often discuss common terms used in different contexts across disciplines, which may impede students from transferring skills from one discipline to another. The Incubator and FMN designs provide a safe space for interdisciplinary conversations to occur and brainstorming ways to resolve pedagogical issues. The shared values of growth mindset, patience, and camaraderie help participants work through hurdles related to discipline-specific language and ways of thinking about integrating quantitative skills or biological themes into their curricula. Such opportunities to interact with colleagues from different disciplines have been highly valued by the participants, as evidenced by their feedback on the retrospective surveys.

The diverse structure of the leadership team, with its representation from CCs, universities, professional development, and OER proponents, provides a cohesive and stable foundation for the QB@CC network. Inclusion of such diverse stakeholders is critical to the success of an RCN (Eaton *et al.*, 2016) and for the growth of the membership. In spite of the pandemic, only one Incubator team (three members) from Cohort 1 dropped out of the network, and not for reasons related to QB@CC network's design or the expectations for completion of project-related work. Among the leadership team, only two SC members—one life sciences and one mathematics faculty—left the network due to changes in their roles at their institutions. One other SC member transitioned to the advisory board due to a change in job status. All open SC positions were filled by other CC colleagues. The leadership team intentionally set a culture of inviting the participants to take up responsibilities following the completion and publishing of their Incubator and/or FMN. Such a model encouraged six participants to assume a co-facilitator role in a subsequent Incubator cohort, and one Incubator participant joined the SC membership.

Critical Internal and External Structural Support Systems Facilitate Successful Growth of the Network

Positive Attitude and Value Add to the Interdisciplinary Work Of CC Faculty. Tuition costs, which account for a large proportion of higher education revenue (State Higher Education Executive Officers Association, 2019) and include textbook costs, disproportionately impact access to affordable higher education for students from lower socioeconomic backgrounds (National Center for Education Statistics, 2019). Several faculty surveys have identified removing textbook costs for students (Delimont *et al.*, 2016; Ozdemir and Hendricks, 2017) and providing equal access to the course resources for all students from the first day (Jung *et al.*, 2017; Ozdemir and Hendricks, 2017) as primary, student-centered reasons to adopt OER for their

courses. However, surveys done by Bliss *et al.* (2013) and Hilton *et al.* (2012) indicate that a low percentage (33% and 7.5%, respectively) of faculty actually customize the OER to fit their course needs. The time demanded for identification, review, and customization of OER was also identified as a major barrier by a large proportion of 39 CC faculty who were surveyed by Lantrip and Ray (2021). As part of the Incubators and FMNs, QB@CC participants are provided strong support systems over 12 to 14 weeks to develop and publish or customize, implement, and publish their resources. This process allows them to break the barrier of time taken to fit an OER to their courses, which is reflected in a very high percentage of QB@CC participants (81%, $n = 27$) indicating willingness to implement their modules. Such positive feedback on using OER aligns with the workshop survey responses indicating a change in faculty perception of sharing curricular resources with colleagues within and outside their disciplines and institutions. The accessibility of resources such as professional development workshop presentations from the in-person meeting and activities and discussions during virtual orientations resulted in faculty participants expressing higher growth in confidence to identify OER related to teaching quantitative skills (43%) and use of such OER (29%) in their courses. Such opportunities scaffolded into Incubator and FMN work had a large positive impact on the network participants, as evidenced by more than 60% of the survey respondents ($n = 28$) indicating an increased confidence to identify and use quantitative skills–based resources.

When the faculty realize and acknowledge that their investment of time and subject matter expertise into the interdisciplinary work will result in resources they can use in their courses, it results in higher rates of completion of their modules. This is evidenced by the publication of 20 modules that include adaptations of Incubator modules that were already published. Publishing their developed modules and adapted versions is an additional professional incentive to faculty. Each of these publications is assigned a unique DOI that can be included in professional portfolios and used as part of promotion or tenure documentation.

Successful Dissemination of Resources and Expansion of the QB@CC Network. The SC members valued piloting the module development process in advance of recruiting the first Incubator participants. This allowed the design and implementation of support systems for participants to have seamless experiences developing and publishing their modules. The support system included setting up virtual meeting spaces (Zoom); a shareable and real-time editable document template (Google doc); a tentative and editable timeline, including tasks to be completed between weekly meetings; and step-by-step guidelines for publishing a completed module. The feedback shared by Incubator and FMN participants in focus group interviews is a testimony to the value added by these structural support systems to the success of the network. In the focus group interviews, participants often discussed the unique opportunities provided by QB@CC activities: for example, interdisciplinary, cross-institutional, weekly interactions included discussions about the nuances of using common terms in life sciences and mathematics, but in different contexts (e.g., digit, root, and divide). QB@CC has been interdisciplinary since its inception, with strong leadership from experts in both mathematics and biology education. This "baked-in" interdisciplinary culture has created a space where faculty of different backgrounds are comfortable working together. Creating such professional spaces as part of an internal support system contributed to higher success rate of module completion, publication, and dissemination.

The BioQUEST Curriculum Consortium, the grantee of the QB@CC project grant, has been a leader in providing quantitative skills–focused professional development for higher education faculty for more than 36 years. Their professional development practices are built around the 3Ps of problem posing, problem solving, and peer persuasion (Peterson and Jungck, 1988). Over three decades, BioQUEST has been a transformational agent in quantitative biology (Kezar and Gehrke, 2015) and currently manages the cyberinfrastructure platform QUBES, where the QB@CC resources reside along with many other partner networks, and hosts more 11,900 users (Akman *et al.*, 2020). Such a large network of users on QUBES has been leveraged to disseminate QB@CC resources and to increase the visibility of the community. In addition, the download numbers (3700 times) indicate a large interest in the published QBCC resources.

Discipline-specific societies and networks play a critical role in supporting the career growth of faculty through offering timely and relevant professional development workshops. Historically, due to lack of institutional support and lack of professional recognition and gains (Marsteller *et al.*, 2010; Holmberg *et al.*, 2021), CC faculty have either ignored or were minimally engaged with discipline-based societies and their events. Brownell and Tanner (2012) acknowledged that professional societies and networks may not have the supportive infrastructure to encourage CC faculty to participate in their professional development events. However, there are exceptions to this pattern. Networks like AMATYC exclusively serve CC faculty in mathematics, and societies like NABT have a significant representation of CC faculty in their community, including in their leadership structure. At the annual professional development conference organized by the NABT, ~7% of workshops and 23% of posters are presented by faculty from CCs (Holmberg *et al.*, 2021). Some of the SC and advisory board members are active leaders in several discipline-based societies (life sciences and mathematics) and have played a critical role in reaching out to peers in these networks and recruiting faculty to engage in the QB@CC project. Such connections to wider networks have also helped in supporting QB@CC members to join national and regional discipline-based societies and disseminate their work in the professional development workshops and conferences. It is encouraging to note that, as the network grows, more participants are becoming engaged in the dissemination of QB@CC work, and we predict this trend to increase.

Challenges in Participant-Focused Grant Funding and Data Analysis

QB@CC is an RCN-UBE grant with large funding for participant support, but limited funding to conduct specific program-level evaluations. We recognize that such a funding structure prevents us from collecting survey data on student gains from engaging with QB@CC-developed modules and faculty gains in terms of interdisciplinary PCK. In addition, the smaller sample size of retrospective survey responses has been

a barrier to statistically analyzing the survey data for any meaningful conclusions. Thus, the current report includes descriptive analysis of the survey data and qualitative discussion of focus group interviews. The QB@CC leadership team hopes to have a sufficient survey sample size by the end of the grant to perform statistical analyses that will help to draw further conclusions on the effectiveness of the QB@CC program. At this point, analyzing the outcomes within the limits of the grant's goals and objectives, we could conservatively conclude that the network has a strong and resilient membership and has made effective progress, in spite of the pandemic, since March 2020.

CONCLUSION

Though biology undergraduate education has often downplayed the necessity of quantitation, faculty must respond to its increasing importance by widely integrating quantitative skills–based components into life sciences education. Analysis of the network's growth; interdisciplinary and CC representation in the network; development, publication, and dissemination of modules as OER; feedback from participants; and a low rate of membership loss indicate that QB@CC is achieving these goals. The QB@CC project empowers these faculty with interdisciplinary pedagogical content knowledge and a supportive network for interdisciplinary teams to thrive, create, and disseminate curricular resources. QB@CC is unique as the first and the only federally funded network organized and led almost exclusively by CC faculty and leaders, where many first-generation, low-income, and underrepresented student populations are served (American Association of Community Colleges, 2021). This network has grown and thrived in spite of the unexpected challenges associated with the global pandemic. The growth of the network to a strong 85-member community in less than 3 years, more than two within the pandemic, is a commendable example of resilience and sustainability and an indicator of the strong commitment of the leadership team. We recommend that the structure of the QB@CC network and the strategies adopted to build the community be replicated by any higher education transformation program that intends to build a grassroots network. We also hope for this project's inclusive and interdisciplinary approach to positively impact STEM students and equip them with the essential skill sets to succeed and accomplish their academic and career goals.

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