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EDUCATION ARTICLE

QUBES: a community focused on supporting teaching and learning in quantitative biology

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This letter provides an overview of the Quantitative Undergraduate Biology Education and Synthesis (QUBES) Project funded through the National Science Foundation. The project has five distinct, but interdependent, initiatives which work together to support faculty and students in the teaching and learning of quantitative biology (QB). QUBES has adopted an integrated strategy to improving the frequency and effectiveness of QB instruction that includes coordinating a broad consortium of professional stakeholders, supporting faculty development and the implementation of new teaching practices, providing an infrastructure for collaboration and access to high quality materials, establishing new metrics for faculty teaching scholarship and documenting the project outcomes.

Keywords: mathematics; biology; education; collaboration; professional development

1. Introduction

Bioscience research has become increasingly quantitative through (1) the emergence of networked computing and high throughput data collection technologies, which generates vast data sets for quantitative analysis; (2) the now standard practice of widespread use of models to explore systems and test predictions; and (3) increased research based on the mining and repurposing of archival data. These trends in research practices illustrate that quantitative skills are core competencies for career success in biology and that quantitative reasoning should be infused throughout all undergraduate bioscience curricula. Not surprisingly, these skills are emphasized in biology education policy (American Association for the Advancement of Science, 2011; National Research Council, 2003) and curriculum guidelines (American Association of Medical Colleges, 2009; College Board, 2012).

Many bioscience classrooms do not currently reflect the key role that quantitative reasoning plays in biological research (National Research Council, 2003, 2009). The disciplinary specialization of faculty members' research experience may expose them to a limited set of quantitative techniques, and the rapid evolution of tools, data and technologies makes it difficult for faculty to keep up with current quantitative biology (QB) practices. Under these circumstances, it is challenging for faculty to incorporate a wide array of quantitative

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skills to encourage students to explore diverse biological phenomena quantitatively. In addition, students are often uncomfortable with quantitative approaches, and teaching in this area requires careful development to help students develop confidence. Instruction that explicitly engages students with quantitative reasoning might involve providing multiple contexts for working with a concept or creating learning opportunities where students develop their own explanatory systems. The impacts of promoting student engagement with challenging content using effective pedagogical methods have been well documented (Cartier, Smith, Stein, & Ross, 2013; National Research Council, 2000). However, using these strategies widely across topics in biology requires confidence and proficiency with quantitative approaches and familiarity with good pedagogical practice.

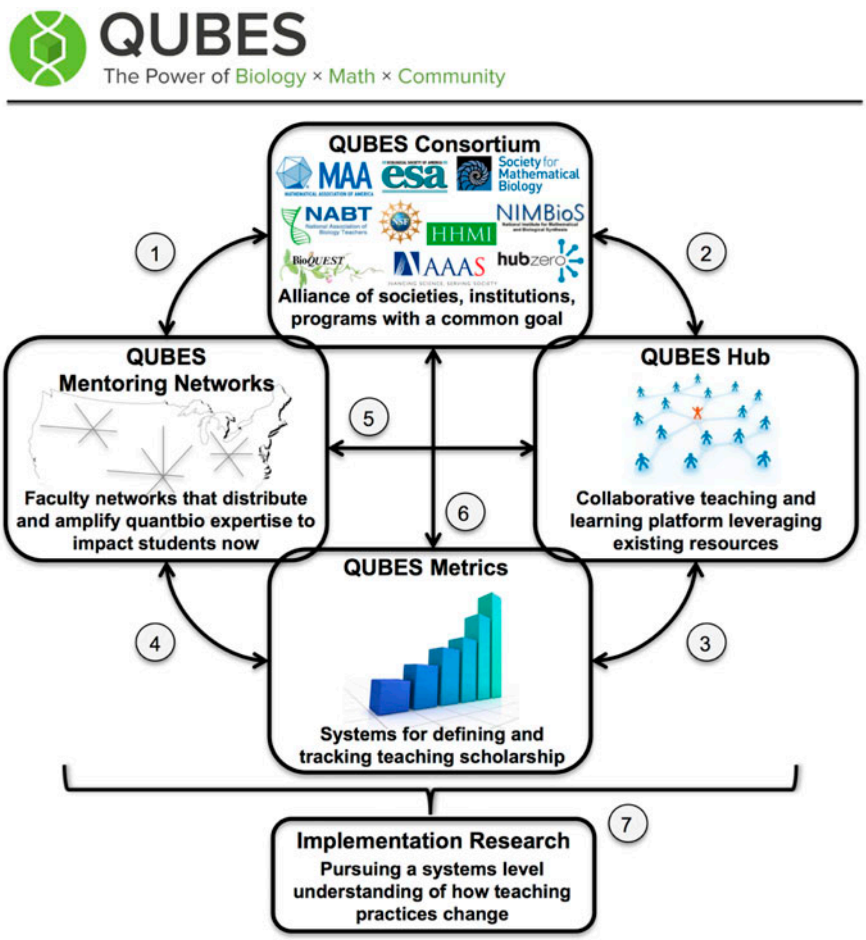

Figure 1. A diagrammatic representation of QUBES project components.
Notes: We seek to increase the frequency, quality and integration of QB. Learning opportunities in undergraduate education. This project is designed to coordinate the efforts and resources of disparate communities invested in promoting QB education (QUBES Consortium), support faculty understanding and implementation of QB concepts and teaching approaches via faculty mentoring (QUBES Mentoring Networks), increase the visibility, utility and adoption of existing QB materials, and the capacity for peer interactions around those resources (QUBES Hub), describe and track faculty contributions to QB education scholarship (QUBES Metrics) and study the features of this system that influence implementation success (QUBES Implementation Research).

To support faculty and students in their efforts to improve their quantitative proficiencies, we must raise awareness of educational research on quantitative reasoning, evidence-based pedagogies for improving student quantitative reasoning skills and resources for enhancing the integration of QB across the biology curriculum. The NSF-funded Quantitative Undergraduate Biology Education and Synthesis (QUBES, https://qubeshub.org) project is designed to address these challenges by building a collaborative community of professional societies and individual faculty to share resources and their contextual use in classrooms, develop mentoring networks and provide professional development in QB education (Figure 1).

2. QUBES history

QUBES was imagined at a workshop at Radford University in May 2013. This workshop was organized by the principal investigators of an NSF project, SUMS4Bio, that integrated mathematics into biology courses. The participants of the workshop were asked to identify critical areas of mathematical/QB education, and work on solutions to these areas of need. Our team started working on the problem of vertical integration of quantitative skills throughout the biology curriculum, when it became quickly apparent that the lack of a go-to community for resources was a major obstacle. Several organizations, for example BIO-SIGMAA (The Biology Special Interest Group of the Mathematical Association of America) and the education committee of SMB (The Society for Mathematical Biology), had long talked about a resource site, but such sites are difficult to build and quickly become outdated without an enormous effort to maintain them.

Our team consisted of tech savvy and enthusiastic faculty who wanted to deliver on a resource site that reflects the advances in sharing curricular materials. The first step was to gather the support of organizations, institutions, professional societies and faculty (hereby termed the QUBES *Consortium*; see Table 1) that are already invested in teaching quantitative techniques to our biology students. This effort to gather a consortium and to conceptualize a virtual community was funded in 2014 by an NSF RCN-UBE Incubator grant (Award #1346584) and was supplemented by funds from BIO-SIGMAA. We then planned a summit which brought together liaisons from several organizations to meet at the National Institute for Mathematical and Biological Synthesis (NIMBioS) in May 2014 in support of this common goal. At this QUBES Summit, we quickly recognized that creating a site of resources addresses only part of the challenge of changing faculty teaching practices. Other important factors influencing the adoption of quantitative approaches to teaching biology include providing the support that faculty need to be effective in classrooms and promoting the recognition of teaching scholarship in promotion and tenure.

As part of a parallel discussion, the NSF Improving Undergraduate STEM Education (IUSE) program identified QB education as a grand challenge in STEM research and education. They held a five-day Ideas Lab where participants considered strategies to integrate critical competencies in quantitative literacy into a biology core curriculum fostering the success of a diverse student population (National Science Foundation, 2014). Implementing the recommendations put forth in Vision and Change (American Association for the Advancement of Science, 2011) and preparing the future workforce were cited as important drivers for this effort. The convergence of these two workshops with overlapping membership quickly led to a collaborative IUSE Ideas Lab grant (Award #1446258, 1446269, and 1446284) focused around faculty support but addressing a wide range of factors influencing teaching culture. This paper describes the ongoing efforts of the QUBES community to improve quantitative instruction in the undergraduate biology curricula.

Table 1. QUBES Consortium.

AAAS (American Association for the Advancement of Science)	**MBI** (Mathematical Biosciences Institute)
ABLE (Association of Biological Laboratory Educators)	**MCRN** (Mathematics and Climate Research Network)
BEER (International Symposium of Biomathematics and Ecology Education and Research)	**NABT** (National Association of Biology Teachers)
BioQUEST (Curriculum Consortium)	**NIMBioS** (National Institute for Mathematical and Biological Synthesis)
BIO-SIGMAA (A special interest group of the Mathematical Association of America)	**SMB** (Society for Mathematical Biology)
BSA (Botanical Society of America)	**SSE** (Society for the Study of Evolution)
ESA (Ecological Society of America)	**SUMS4Bio** (Strengthening Undergraduate Mathematics and Statistics Education for Biologists)
HHMI (Howard Hughes Medical Institute)	**TWS** (The Wildlife Society)

Notes: Consortium liaisons from several universities of various disciplines (e.g. mathematics, biology, biostatistics), sizes (e.g. teaching, R1) and locations (e.g. North-east US, South-east US, New Zealand) are also represented among the consortium members. For an updated list of QUBES consortium members, see https://qubeshub.org/aboutus/partners.

3. QUBES Hub

QUBES Hub (https://qubeshub.org) is built on the NSF-funded *HUBZero Platform for Scientific Collaboration* (McLennan & Kennell, 2010) and serves as an online portal for collaboration, development and distribution of curricular resources and pedagogy for QB education. The QUBES Hub emphasizes community building, interactions around teaching scholarship and the opportunity to establish a profile of professional activities. Communication and content development is supported by a rich array of integrated tools including wikis, discussion forums, blogs and a built-in learning management system (akin to Blackboard or Moodle). Additionally, the QUBES Hub contains a resource database capable of housing multiple resource types (e.g. assessments, concept inventories), which is equipped with a full suite of tools for annotating, reviewing, searching and creating collections of the materials. Other features include Google Drive sync support, version control, LaTeX compilation support and project management tools (e.g. calendars, to-do list managers), making QUBES Hub a productive sandbox for collaboration and curricular development. One of the most important uses of this infrastructure is the coordination of QUBES Faculty Mentoring Networks where small groups can collaborate at a distance to address shared problems around teaching QB.

Collaborations, such as Mentoring Networks, are housed on QUBES Hub using *groups* (https://qubeshub.org/groups). Groups act like semi-autonomous websites on the Hub, customized to the needs of the group, but sharing the full functionality of the shared infrastructure that was designed for use by scientific communities. Groups can have different membership rules and privacy settings making a wide range of collaborative structures possible within the QUBES community. Groups may also contain *projects* (https://qubeshub.org/projects), which provide specialized mechanisms for managing content, data, communications and workflows, and may include all or a subset of group members. For more information on the community tools available on the Hub, see https://qubeshub.org/community.

For many users, the initial engagement with QUBES Hub will involve searching for QB teaching and learning resources collected at the site (https://qubeshub.org/resources). Building on the lessons learned from a multitude of existing teaching resource repository projects, we are not simply emphasizing the quality or quantity of the resources stored at the Hub. Instead of describing QUBES resources exclusively using traditional metrics such as how many resources exist in an area or using a normative standard for resource quality, we will use the ideas of functional and critical framing. Functional framing emphasizes the ways in which particular resources support student engagement with QB (for example, describing how an online modelling simulation improved student understanding). We will also develop a more nuanced discussion space for faculty to share sophisticated criteria for evaluating, repurposing and implementing QB instructional materials (critical frames).

The functional frame contributions involve a suite of interactive software tools that provide instructors and students the opportunity to develop and deliver graphical instructional materials and modelling simulations online (https://qubeshub.org/software). These capabilities are facilitated by the inclusion of graphical user interfaces (GUIs) for developing and running programs. QUBES Hub allows these applications to run remotely on Hub computers which require only local browser software to implement. Some current examples include:

- R-Studio (https://qubeshub.org/tools/rstudio): GUI for the statistical programming language R (RStudio, 2012).
- NetLogo (https://qubeshub.org/tools/netlogo): An agent-based modeling, simulation and programming environment (Wilensky, 1999).
- Copasi (https://qubeshub.org/tools/copasi): A software application for simulation and analysis of biochemical networks and their dynamics (Hoops et al., 2006).
- QtOctave (https://qubeshub.org/tools/qtoctave): An open source GUI front-end application for GNU Octave (QtOctave Development Team, 2011).

Users will have the ability to view or analyse a data set, or run a simulation of a mathematical model by opening up an appropriate software tool for interactive exploration on the Hub with the click of a button. This has the potential to transform data analysis and simulation in the classroom, with no need for students to download and install the necessary software. HUBZeros Rappture toolkit also provides an easy way for users to develop a GUI with graphical output for simulations written in a variety of programming languages, including C/C++, Fortran, MATLAB/Octave, R, Java, Perl, Python and Tcl.

The primary aims for developing critical frames is twofold. First, we want to support implementation of QB materials that is customized, localized and contextualized to the needs of the audience. This requires providing a constellation of implementation ideas shared by a diverse and active community of users. Materials need to be shared in formats that can be easily modified, and conversations about use scenarios may turn out to be as important as the materials themselves. Second, faculty need to be able to track their contributions and measure the use of the materials they have shared. Tools for version tracking, rating, reviewing, citing and commenting will help to generate rich paradata (user supplied information about the core data). This focus on critical frames creates opportunities for the user to participate in disciplinary discourse and in doing so deepen their pedagogical knowledge.

We want the Hub to function not only as a repository of resources, but also as an online community through which new knowledge – both individual and shared – is developed. To that end, we will provide opportunities for collaborators to share information about how they used materials with students and how the materials supported learning. As additional users begin to share their experiences, we will draw from these posts to develop a framework we can use to summarize key features of materials (such as strategies to assess learning), challenges to student learning and instructional strategies that support students. We believe that users interacting with resources and with each other will not only improve the quality of individual resources and spur development of individual pedagogical knowledge, but also lead to a broader body of knowledge about what works in the problem space of undergraduate QB education, why and for whom.

4. QUBES Mentoring Networks

Many instructors understand the value of QB but feel unprepared or lack confidence to teach these skills themselves. Some instructors feel overwhelmed by the initial effort required to learn new QB at a technical or practical level (e.g. using new software, programming in a new language). Faculty development programmes can address some of these issues, but many faculty will not have the financial resources or time to attend face-to-face workshops, especially non-tenure track faculty, those at community colleges and under-resourced schools. Moreover, many faculty development programmes leave participants with new materials but very little, if any, practice developing, implementing, assessing or revising classroom strategies and materials themselves. These aspects of classroom implementation are not trivial and present a series of real hurdles even to very motivated faculty, which can erode the sustainability of reform efforts. To bridge this professional development gap, we plan to capitalize on technology to distribute existing quantitative, technical and pedagogical expertise using facilitated faculty mentoring.

Each QUBES Faculty Mentoring Network will consist of a mentor – a respected scientist with a strong track record in QB education – and faculty members with a shared interest in a specific QB topic (e.g. inferential statistics, algebraic modelling). QUBES Consortium members will help to identify mentors and cohorts of faculty interested in receiving QB mentoring. Participants will receive formal recognition through letters sent to the faculty's chair and dean, and through Consortium organizations. Capitalizing on technology-supported communication (using QUBES Hub) will make it possible to distribute the expertise of the mentor where and when it is needed to best support faculty implementation of QB materials.

During each network's operation, mentors will work with programme personnel to introduce evidence-based pedagogies, awareness/adoption of existing resources and meaningful in-class evaluation of instruction. The mentor will provide technical expertise on the QB concepts, software and existing teaching resources. The expert mentoring will be supplemented by peer interactions among cohort members, in which they will share their own expertise, resources, experiences, successes and failures via the Hub. Participants will be encouraged to present their experiences in multiple ways, such as at subsequent professional meetings or workshops, in publications, or by applying as a mentor for future networks.

Two initial mentoring networks include a POPULUS group at University of Pittsburgh and an Introduction to Biology group at the University of Radford. Each group is structured differently as pilot mentoring networks to document how different approaches may be useful in the mentoring space.

5. QUBES Metrics

One potential barrier to changing teaching practices, despite robust mentoring, is that it is difficult to evaluate the diverse aspects of teaching scholarship. Unlike the research arena, there are few widely adopted strategies for measuring faculty success in education. The expectations for faculty teaching scholarship vary widely by institution type and often within a department. For faculty with research expectations, there is often a trade-off between time allocated to teaching vs. research. It is not surprising that majority of faculty allocate flexible time towards activities that provide the best opportunity for recognition and reward. Diamond (2006) points out that reform of tenure and promotion systems will require all parties (e.g. central administration, deans, chairs and faculty) be involved in all phases of redefining the promotion and tenure process. This process is underway at the individual university level (Diamond & Adam, 1997), but the wider community of scientific professional societies and projects like QUBES can also play a role by promoting informal conversation around this topic, ranging from initiating policy discussions to providing faculty opportunities to discuss and develop this aspect of their career with their scientific peers.

One of the goals of QUBES is to promote faculty recognition for efforts in teaching by mirroring the scientific community's respect for research with a high impact on the field as measured by publications, collaborations, citations and community endorsement of teaching resources. Providing faculty with independent documentation of their own contributions, and the value those contributions have for others in the field, is one mechanism by which institutional review of faculty can begin to consider a wider spectrum of teaching scholarship. The Hub already has these metrics in place for resources, showing reviews and multiple usage statistics (such as number of downloads and simulations run) for a contributor's resource. The Consortium will also play an important role in providing professional outlets for materials in education journals and digital resource collections.

6. Implementation research

Like the broader post-secondary educational landscape, faculty professional development around teaching and learning is undergoing dramatic changes. These changes include an ever growing collection of evidence-based teaching practices, changes in the information and computational environment accessible to instruction and changes in the disciplinary content itself. As these changes in undergraduate STEM education continue, there will likely be new expectations that faculty describe the ways their teaching practices utilize these resources and align with these evidence-based methods (Kober, 2015; National Research Council, 2012). As such the goal is to constantly monitor and improve practice. In this environment, a significant faculty development effort like the QUBES project needs to adopt a progressive model for evaluating the way that it supports faculty. QUBES success will be measured in part by the use of activities in classrooms but also by characterizing faculty, student and community outcomes that play an important role in sustaining changes in faculty practices. Defining the implementation landscape in this way makes it possible to map specific activities, resources and strategies from the various QUBES components (Consortium, Hub, Mentoring Networks and Metrics) to identify bottlenecks, leverage points, interactions and emergent properties when used by diverse faculty groups. The QUBES assessment program will identify effective activities and interventions throughout the project, thereby providing more general insight into reforming STEM education and generating new knowledge about what limits and promotes implementation of educational reforms.

7. Getting involved

The sustainability of a community-based project like QUBES is always challenging. In order to maintain a long-term presence in QB education we must find ways to engage the research and education communities to continue to visit, use and contribute to QUBES Hub. Initially, we are reaching Hub visitors by word of mouth, and we are promoting the QUBES project at a variety of mathematics and biology conferences through workshops and booth presence. Consortium members and Mentoring Network participants will continue to spread the word about QUBES and encourage new participants.

The Hub may also provide emergent community benefits. For example, QUBES can provide letters of support for grant submission to primary investigators who use QUBES Hub as a place for maximum outreach potential. However, our goal is to get users to come back often, to contribute resources and to participate in our online community. We anticipate the typical user will most likely be the busy professor who needs something that works for their class. To go from being a commodity to a true valued resource, we must make the experience more than just a repository; the Hub must be a valuable, interactive, vibrant and fun place to visit.

As can be seen via the large reach of the QUBES project, there are many ways to get involved with this QB community. Whether you are a biology professor looking for more quantitative approaches or pedagogical best practices on a particular biology topic for your classes, or a mathematics professor wanting to show the application of a powerful mathematical tool on the biological sciences, QUBES Hub is a place to go to see what is available and what your peers in the same situation are potentially using in their classrooms. It is also a place to communicate not only with your faculty peers, but also with your students. Here are some example lists of potential ways to get involved.

Get involved as a *user* by …

- running meeting and organizational spaces for undergraduate research experiences that are shared between institutions (https://qubeshub.org/groups);
- using online software tools, thereby lowering the barrier to teaching certain quantitative concepts like data analysis and simulation (https://qubeshub.org/software);
- finding contextual classroom resources to incorporate quantitative or biological concepts into your courses (https://qubeshub.org/resources).

Get involved as a *contributor* by …

- taking part in mentoring networks, working through focused QB topics with peers *as your course is being implemented* (https://qubeshub.org/groups);
- submitting classroom materials as resources for community use and collaboration, such as lecture notes, modules and problem sets (https://qubeshub.org/resources/new);
- installing your software tools in the QUBES Forge area for online use in the classroom (https://qubeshub.org/tools).

Get involved as a *partner* by …

- becoming part of the QUBES Consortium and teaming up to address the many challenges in QB education;
- contacting QUBES for a potential business collaboration;
- supporting QUBES through hosting meetings, workshops or minisymposia.

If you would like to get involved as a partner or have any questions, you can find our contact information at https://qubeshub.org/aboutus/contact.

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