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ARTICLE

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Incubators: Building community networks and developing open educational resources to integrate bioinformatics into life science education

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Abstract

While it is essential for life science students to be trained in modern techniques and approaches, rapidly developing, interdisciplinary fields such as bioinformatics present distinct challenges to undergraduate educators. In particular, many educators lack training in new fields, and high-quality teaching and learning materials may be sparse. To address this challenge with respect to bioinformatics, the Network for the Integration of Bioinformatics into Life Science Education (NIBLSE), in partnership with Quantitative Undergraduate Biology Education and Synthesis (QUBES), developed incubators, a novel collaborative process for the development of open educational resources (OER). Incubators are short-term, online communities that refine unpublished teaching lessons into more polished and widely usable learning resources. The resulting products are published and made freely available in the NIBLSE Resource Collection, providing recognition of scholarly work by incubator participants. In

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addition to producing accessible, high-quality resources, incubators also provide opportunities for faculty development. Because participants are intentionally chosen to represent a range of expertise in bioinformatics and pedagogy, incubators also build professional connections among educators with diverse backgrounds and perspectives and promote the discussion of practical issues involved in deploying a resource in the classroom. Here we describe the incubator process and provide examples of beneficial outcomes. Our experience indicates that incubators are a low cost, short-term, flexible method for the development of OERs and professional community that could be adapted to a variety of disciplinary and pedagogical contexts.

KEYWORDS

general education for science majors, genomics proteomics bioinformatics, integration of courses, learning and curriculum design, original models for teaching and learning, scholarship of teaching and learning, open educational resource (OER), professional development, community networks

1 | INTRODUCTION

Creating undergraduate biology educational resources in rapidly emerging, cross-disciplinary topics is an especially challenging task. Bioinformatics, an interdisciplinary field at the nexus of biology, statistics, and computer science, is a particularly relevant example that highlights both the opportunities and obstacles educators face in finding and using curricular materials in newly developing fields. On the one hand, this new, interdisciplinary field, with its wealth of freely available tools and immense datasets, is a potential gold mine for authentic student research that fully supports fundamental life science concepts. On the other hand, bioinformatics requires life science students to develop competency in a variety of scientific skills including quantitative analysis, problem solving, and handling "big data," as well as the ability to work and communicate with scientists trained in diverse disciplines. Furthermore, while calls for integration of bioinformatics into life science education have been heard for more than a decade,[1–3] the core competencies that are most important for students to acquire in this new and dynamic discipline have only recently been defined.[4,5] Compounding these challenges, relatively few life science educators are well-trained in this fast-moving area where new approaches appear frequently.[6,7] Finally, creating inquiry-based curricula in an emerging interdisciplinary field requires that faculty not only master the content, but also apply effective pedagogical approaches to design curricular tools and resources.[1] Clearly, creating exercises that actively engage students, involve authentic data and tools, and are at an appropriate level for undergraduates is a complex undertaking.

To address this educational need, we describe the conceptualization, design, and implementation of a new online collaboration environment that we call "incubators." These distributed learning communities address dual aims: to build a robust collection of engaging bioinformatics educational materials, and to support faculty in the process of integrating bioinformatics resources into their life science classes. While our work focuses on integrating bioinformatics into life sciences education, this model could be easily adapted to virtually any field of interest.

2 | BACKGROUND

The incubator platform was developed as a collaboration between Network for the Integration of Bioinformatics into Life Sciences Education (NIBLSE) and Quantitative Undergraduate Biology Education and Synthesis (QUBES).[8] NIBLSE, a National Science Foundation (NSF) Undergraduate Biology Education Research Coordination Network (RCN-UBE) formed in 2014, seeks to expand the network of educators seeking to integrate bioinformatics as an essential component of undergraduate life sciences education (see niblse.org). As a first step, NIBLSE recently published a set of core bioinformatics competencies that are recommended for all students in the life sciences (Table 1[5]). NIBLSE has also established a set of vetted bioinformatics learning resources (niblse.org) and is currently developing a set of learning and skill assessment tools. QUBES is an NSF-supported community of math and biology educators who share resources and methods for preparing students to use quantitative approaches to tackle authentic, complex, biological

TABLE 1 NIBLSE bioinformatic core competencies for undergraduate life scientists

C1	Explain the role of computation and data mining in addressing hypothesis-driven and hypothesis-generating questions within the life sciences
C2	Summarize key computational concepts, such as algorithms and relational databases, and their applications in the life sciences
C3	Apply statistical concepts used in bioinformatics
C4	Use bioinformatics tools to examine complex biological problems in evolution, information flow, and other important areas of biology
C5	Find, retrieve, and organize various types of biological data
C6	Explore and/or model biological interactions, networks and data integration using bioinformatics
C7	Use command-line bioinformatics tools and write simple computer scripts
C8	Describe and manage biological data types, structure, and reproducibility
C9	Interpret the ethical, legal, medical, and social implications of biological data

Note: Adapted from Reference 5.

problems (see qubeshub.org). The QUBES project, with its suite of cyberinfrastructure tools and support services, provides organizations with the opportunity to host and share their activities in an online collaborative environment. One of the central features of the QUBES infrastructure is its open education resource (OER) publishing system that makes it easy to share teaching and learning resources. The QUBES publishing system has mechanisms for authenticating its published items (digital object identifiers, metadata, and tracking attributions for adopted materials) and their impact in the larger educational community (metrics on use, number of adaptations, etc.).

The incubator strategy described here leverages the expertise of the NIBLSE community with the infrastructure and collaborative environment developed by QUBES to facilitate multiple program goals. As we elaborate below, incubators have helped to (a) expand the number of available resources aligned with the bioinformatics core competencies, (b) incorporate more educators into the network, and (c) establish supportive relationships for faculty interested in expanding the integration of bioinformatics within their programs.

2.1 | Challenges to the development and incorporation of educational resources

While OERs are well known for reducing the costs of educational materials and permitting customization,[9,10] their use and development in a new field such as bioinformatics presents several challenges. Foremost, up-to-date, reliable resources are not always readily available.[7] Furthermore, even when high-quality learning resources are available, faculty may not feel comfortable using them unless they have some practical guidance from other educators.[11,12] Indeed, biology instructors identified a lack of training as one of the primary barriers preventing further incorporation of bioinformatics into undergraduate curricula.[6]

Developing OERs in an emerging field can be a difficult undertaking (Table 2; for a review, see[13]). While experienced faculty may have developed curricular resources for their own use, they are often reluctant to share them widely. The resources might work well with proper framing in their own classes; however, because they are not sufficiently polished, are too narrowly focused, or lack sufficient documentation, other instructors would have difficulty adopting them for their own use. Furthermore, there is little incentive for faculty to improve and maintain these resources or make them available to others, since such scholarly contributions traditionally have not been recognized.[14] Consequently, developing a mechanism for faculty to refine and share such resources with the potential for peer-review publication would be invaluable for the larger educational community.

There have been a variety of efforts over the past two decades to develop new curricular approaches involving bioinformatics. Many of these programs have been highly successful, but their impact has been limited by various factors. Some programs require a major overhaul of an entire course or curriculum, for example, SEA-PHAGES.[15] Others involve attending a workshop (e.g., Data Carpentry (datacarpentry.org), BioQUEST (bioquest.org)), which often requires a commitment of time and funds that are impractical for many undergraduate instructors. In addition, after the initial enthusiasm from attending a workshop diminishes, faculty often are unable to implement what they have learned in their classrooms.[14,16] In response, projects such as the Genomics Education Partnership (GEP; gep.wustl.edu) supplement initial training with ongoing interactions as material is incorporated into the curriculum. However, these approaches are typically focused on a particular task (e.g., annotating the *Drosophila* genome) and are not widely applicable to other areas of bioinformatics. To address these limitations, we developed the incubator process (Table 2).

3 | WHAT IS AN INCUBATOR?

Incubators integrate technical and social structures developed by QUBES (qubeshub.org) to create new

TABLE 2 OER challenges addressed by incubators

Challenge	Incubator solution
There is a shortage of vetted educational resources available for undergraduate bioinformatics education.	NIBLSE incubators increase the number and visibility of robust bioinformatics resources available to the education community.
In newer or more interdisciplinary fields, it may be difficult to determine what the learning goals for a particular exercise are or how they fit into a larger framework.	NIBLSE incubators link resources to specific bioinformatics core competencies.
Students do not see the importance of learning bioinformatics or do not see how it relates to biological questions they are interested in.	Incubators allow authors to add engaging context and multiple applications to a core learning resource, allowing instructors to better adapt the resource to their students' interests.
Faculty are inexperienced or insecure about adopting new materials into the classroom.	The novice perspective is specifically incorporated during the development of the resource to ease adoption by educators with varying experience. Background and context for those new to bioinformatics are provided, allowing the resource to be more easily adopted.
Instructors may have resources that are narrowly tailored to the specific audience at their institution.	Incubators help authors produce a more robust resource, that can be adapted to use in a variety of settings.
Faculty may feel isolated and lack support for implementing bioinformatics into their courses.	Incubators allow faculty to consult with and make connections with other faculty from diverse institutions across the country who are also implementing bioinformatics into their courses. Incubators match experienced and inexperienced users.
Faculty who have created and used bioinformatics learning resources in the classroom do not have the time to polish and publish them.	Incubators run for 4–8 weeks, with a typical time commitment of 1–2 hr each week. Collaboration facilitates polishing and publication of the resource.
Faculty with unpolished educational resources lack the incentive to make them available to others.	Incubators result in a published resource in the NIBLSE Resource Collection, with a persistent DOI, as well as statistics on public views and downloads.

opportunities for faculty scholarship, while supporting effective lesson design and promoting adoption of materials into classrooms. Each incubator is a relatively short-lived (4–8 weeks), online faculty learning community whose membership and workflows are engineered to produce teaching resources that incorporate effective pedagogies. Because the incubators run for a short period of time and only require a few hours per week, they take a smaller investment of faculty time than attending a workshop, and they have the additional advantage of providing ongoing assistance to participants. Indeed, the final products of an incubator are often implemented in the classroom by the incubator participants.

The end result of a NIBLSE Incubator is a current, vetted resource that is designed to capture student interest as well as provide skills and knowledge explicitly mapped to one or more of the NIBLSE bioinformatics core competencies.[5] In addition, incubators typically produce supporting materials to facilitate their adoption in diverse classroom contexts by instructors lacking extensive bioinformatics knowledge. To promote broad dissemination, the resource is made freely available as a scholarly publication on the NIBLSE site (hosted by QUBES) for other instructors to adapt and incorporate into their courses (see below).

4 | HOW DO INCUBATORS WORK?

Below we introduce the five steps involved in the NIBLSE Incubator model: selection of the learning resource, establishing incubator goals, identifying the incubator team, engaging in remote collaborative work, and dissemination of products (Figure 1). Here we generally describe the key features of each step and how these are tied to the successful incubation of a resource. In addition, two specific case studies of incubator implementation are included in the Appendix S1.

4.1 | Step 1: Selection of the learning resource

The incubator process begins with draft educational resources recruited from faculty with expertise in bioinformatics teaching or research. By starting with

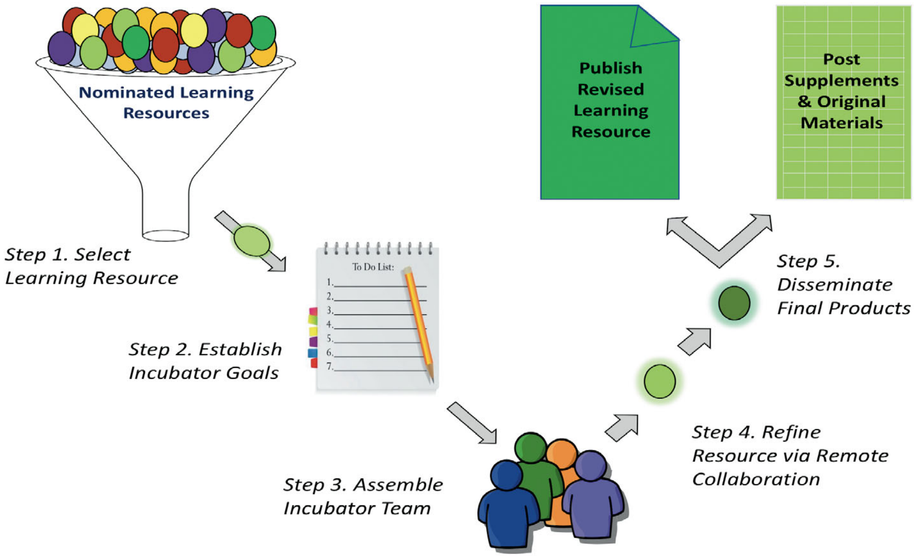

FIGURE 1 The NIBLSE incubator model. The five-step model includes (1) selecting a learning resource, (2) establishing the specific goals for refinement of the resource, (3) assembling an incubator team, (4) refining the resource through remote collaborative work, and (5) dissemination of the final products. See text for further details. (Photos are by unknown authors and licensed under CC BY-SA or CC BY-NC) [Color figure can be viewed at wileyonlinelibrary.com]

preexisting education materials, the incubators necessarily engage faculty who already have some expertise teaching bioinformatics. Consequently, the incubator work can focus on pedagogical strategies to make the bioinformatics content more accessible to both students and less experienced faculty.

Submitted materials are screened by a Resource Review Committee to identify suitable candidates that align with the core competencies identified by the NIBLSE community.[5] To standardize this process, we customized a previously published Learning Object Review Instrument (LORI[17];) to evaluate potential bioinformatics learning resources (see Appendix S1).

4.2 | Step 2: Establishing incubator goals

While the broad objectives of the NIBLSE project informed the selection of starting materials, the goals of an individual incubator are closely tied to the features of the learning resource. The LORI review process identifies the bioinformatics core competencies addressed by the learning material and provide suggestions to improve its usability and accessibility. An Incubator Managing Editor selected from the Resources Review Committee then works with the resource author to negotiate the incubator goals. These goals generally focus on addressing one or two core competencies, providing additional background or context needed by novice bioinformatics instructors, and including a richer biological context to motivate faculty and students. Some incubators also seek to develop assessment instruments to evaluate the effectiveness of the resource. While the author and Managing Editor establish the initial goals for the incubator, other members of the incubator team help shape the direction of the incubator as it progresses, particularly as it reflects each participant's teaching context and student audience.

4.3 | Step 3: Assembling the incubator team

We typically construct heterogeneous teams of 4–6 individuals to participate in an incubator. In addition to the author of the learning resource and the Managing Editor representing the NIBLSE project, an incubator team also includes a bioinformatics expert and one or two faculty members with limited experience in bioinformatics. The perspectives of both novice and expert bioinformatics instructors have proved valuable when developing the resource: Based on their experience, bioinformatics experts can recommend potential approaches to achieving the learning objectives and ensure the accuracy of all developed materials, while novices point out aspects of the materials that might be confusing to potential adopters and students. Another important benefit is that novices receive informal training in a focused environment, with minimal time commitments. The incubator team is rounded out with a representative of the QUBES project who helps with the collaborative infrastructure and establishing the norms for remote collaboration.

Incubator members have been drawn from a variety of institutions throughout the United States and beyond (Figure 2) and are typically selected from a list of NIBLSE volunteers who have previously expressed interest in participating. In some cases, the authors or the Managing Editor invite other individuals to participate (occasionally including graduate or undergraduate students) with specific expertise or interest.

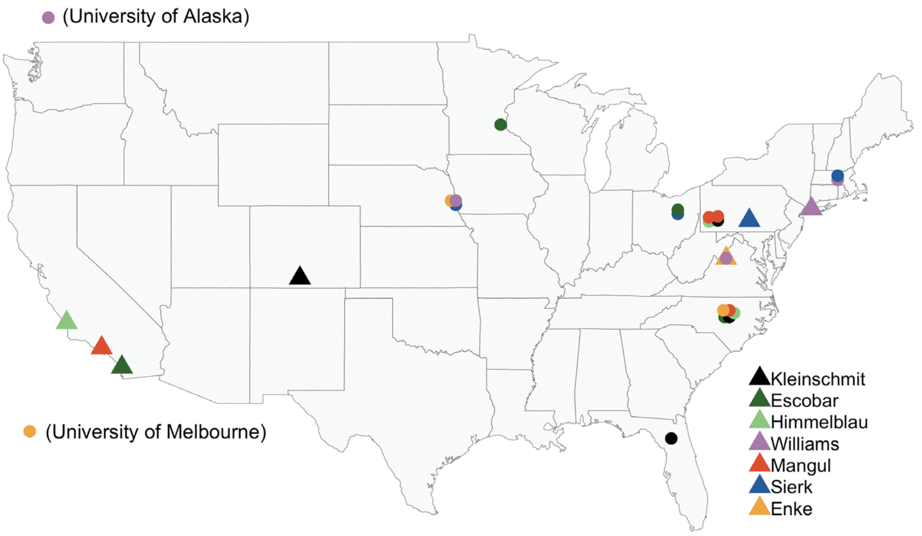

FIGURE 2 Map of incubator participants (as of June 2019). Author institutions are marked with a triangle, other incubator participants with a circle. Overlapping circles represent institutions participating in multiple incubators (but not necessarily the same individual). Each incubator also had a QUBES liaison (Sam Donovan or Hayley Orndorf from the University of Pittsburgh) who, for clarity, is not indicated here [Color figure can be viewed at wileyonlinelibrary.com]

4.4 | Step 4: Engaging in remote collaborative work

The activities of the incubators are coordinated using the QUBES cyberinfrastructure, along with third-party tools such as Google Docs and Zoom video chat sessions. A private online group space is built on QUBESHub to organize materials and communication, with the QUBES project representative initially providing an orientation to effective uses of these tools for remote collaboration. Each incubator group maintains a regular schedule of synchronous video meetings (usually an hour-long session every week or two) for the duration of the incubator (generally 4–8 weeks). These meetings are used to provide background and training, share progress and feedback on resource development, and otherwise coordinate the work of the group. Development tasks are generally distributed among participants for drafting and then shared back for discussion and feedback. Striking the proper balance between synchronous and asynchronous tasks has proved important for balancing engagement and accountability with the flexibility needed to accommodate participants' regular teaching, research, and service commitments.

4.5 | Step 5: Dissemination of final products

The incubator products are published using the QUBES open education platform. To publicly recognize the important scholarly contributions of incubator participants, QUBES publications receive digital object identifiers (DOIs) to make them easier to reference and cite in lists of professional activities. Additional benefits of the QUBES publication platform include collecting standard metrics (number of views and downloads; Table 3), as well as automatically tracking attributions when new versions or adaptations of resources are released.

While a completed incubator serves as a standalone published activity, incubators can also serve as stepping stones to further professional activities. For example, two incubated resources[19,20] have gone on to be accepted for publication in *CourseSource*,[24,25] a peer-reviewed journal of teaching and learning materials. Resources can also serve as the basis of professional developmental opportunities, furthering their dissemination and implementation. For example, one incubated resource[19] served as the foundation of a QUBES Faculty Mentoring Network (FMN), where 12 faculty members from a variety of institutions worked together online to adapt and integrate the resource into their classrooms. To support and guide this process, the initial author of the resource in concert with NIBLSE leadership and QUBES support collaborated with the FMN participants throughout the semester as they implemented the activity in their courses. These activities, produced in the first three years of operation, clearly illustrate the potential for incubators to further the development and dissemination of bioinformatics learning resources.

5 | DISCUSSION

We have described a novel community-based strategy, called incubators, for the development of bioinformatics OER for the life sciences community. Incubators are a cost-effective mechanism (with regard to both time and money) to accomplish multiple faculty- and curriculum-development goals: they produce polished, vetted

TABLE 3 List of completed incubators[a]

Resource title, submitting author and institution	NIBLSE competencies	Number of participants (institutions)	Downloads (views) since publication
Needleman Wunsch Exercise[18] Michael Sierk Saint Vincent College	C2. Computational concepts	6(5)	1,005 (1,063) 2016-10-13
Bioinformatics: Investigating Sequence Similarity[19b] Adam Kleinschmit Adams State University	C2. Computational concepts C4. Bioinformatics tools C5. Data retrieval C8. Data types	6(5)	349 (1,894) 2017-06-05
RNAseq Data Analysis Using Galaxy[20bc] Matthew Escobar California State University-San Marcos	C1. Role of bioinformatics C2. Computational concepts C3. Statistical concepts C5. Data retrieval	5(5)	97 (582) 2017-11-13
Using DNA Subway to Analyze Sequence Relationships[21] Jason Williams Cold Spring Harbor Laboratory	C1. Role of bioinformatics C2. Computational concepts C4. Bioinformatics tools C5. Data retrieval C8. Data types	7(6)	202 (922) 2018-05-30
Introduction to Command Line Coding Genomics Analysis[22] Ray Enke James Madison University	C1. Role of bioinformatics C7. Scripting C8. Data types	6(4)	136 (575) 2019-06-07
Introduction to the UNIX Command Line[23] Serghei Mangul University of California, Los Angeles	C7. Scripting	4(4)	29 (250) 2020-01-22

[a]The submitting author of the resource and their home institution, NIBLSE core competencies addressed by the learning resource (see Table 1), number of participants (and represented institutions) in the incubator, and number of downloads and views of the learning resource since the incubated resource was published on QUBES until April 2020 (tracked via the QUBES-hosted NIBLSE Learning Resource Collection website) are indicated.
[b]Incubated learning resource later published in *CourseSource*.
[c]Incubated learning resource later featured in a Faculty Mentoring Network (Bring Bioinformatics to Your Biology Classroom) hosted by NIBLSE and QUBES (12 participating faculty and institutions).

learning resources; provide training and support to faculty who are inexperienced in teaching bioinformatics; and expand the number of faculty that are incorporating bioinformatics into their life science courses.

During the initial implementation period, we have learned several important lessons for successful completion of an incubator (outlined in Table 4). First, the value of an overall curricular framework cannot be overstated. The NIBLSE core competencies have proven invaluable to guide the selection of needed resources for incubators and communication with potential authors and incubator participants. A commitment to engaging and active pedagogy has also been important. In addition, setting specific goals for each incubator at the outset is essential. We prefer that the Incubator Managing Editor work with the submitting authors to establish the incubator's goals prior to forming the incubator team. This allows the incubator to start quickly and reduces ambiguity about the focus of the incubator as volunteers are recruited to participate.

Second, a defined process for seeking volunteers and forming groups is essential. When recruiting incubator participants, we clearly articulate the opportunities for

TABLE 4 Tips for carrying out a successful incubator

• Build resources around a Framework (competencies and pedagogy)
• Recruit participants with multiple viewpoints (expert, novice, instructor, student)
• Keep the group small (4–7 people)
• Keep the time defined (e.g., 1 hr weekly meetings for 6 weeks)
• Establish goals for the resource early
• Define tasks for each participant at each meeting
• Acknowledge contributions of participants (publication/DOI/authorship)

authorship and emphasize that incubator participation is a way to engage in professional activities related to teaching and learning, in addition to potentially enhancing their own teaching. When forming incubator teams, we favor relatively small groups to facilitate logistical details such as finding meeting times, establishing trust, and being accountable to the group. Given that overburdened instructors are slow to volunteer for work that hasn't been traditionally recognized as a valued professional activity, it is critical to maintain a list of interested faculty volunteers so that each incubator can be launched promptly. In our case, incubator participants were primarily drawn from NIBLSE members who had expressed an interest in participating in an incubator. Other participants were nominated by a NIBLSE member and individually invited to participate based on their expertise and interests, and in some incubators, highly motivated undergraduate and/or graduate students have contributed a valuable student perspective on the appeal and accessibility of a learning resource. Having an organized Managing Editor to keep the group focused and making ongoing progress is obviously important.

While participating in an incubator requires a commitment of effort by each participant (in addition to their other professional responsibilities), the overall time commitment is significantly lower than an onsite workshop: Each incubator has a flexible schedule, does not require travel, and is spread out over several weeks, which gives participants more time to process each round of revision and development (unlike the compressed time frame of a workshop). At the same time, the incubator has definitive deadlines and an end point, which encourages participants to focus on achieving discrete tasks between meetings. In this way, incubator participation does not become another ongoing, open-ended professional responsibility to manage in an already hectic schedule.

5.1 | Incubators provide a unique combination of supporting features for the development of curricular resources

While several analogous efforts have achieved success in developing learning resources and fostering a broader educational community, the incubator process described here is unique in its combination of supporting features. Most comparable is the VIPEr (Virtual Inorganic Pedagogical Electronic resource; ionicviper.org) project that serves the inorganic chemistry educational community by "developing materials to bring current research into the classroom, building community through cyber-technology, and testing materials and technology in the classroom and assessing student learning" (ionicviper.org[26];). As with NIBLSE, VIPEr recognizes that educators need to engage in ongoing discussion about the effective use of resources in different contexts, difficulties others have encountered, and possible solutions. However, while VIPEr has a mechanism for posting teaching resources and hosting discussion forums, it does not employ an online, collaborative process to develop resources for publication.

Similarly, the Bioinformatics Education Dissemination: Reaching Out, Connecting, and Knitting-together (BEDROCK) project (http://bioquest.org/bedrock/) created "problem spaces" that included background information, data (typically molecular sequences), and classroom activities to engage students in exploring the data. While BEDROCK hosted workshops to bring educators together and train them in how to use the problem spaces in their classrooms, a robust infrastructure for collaborating and interacting online was not available.

5.2 | Future plans

Future plans for the NIBLSE Resource Collection are to expand the number of resources to provide greater depth in offerings. This will require offering a greater frequency of incubators and soliciting additional raw materials from current and future NIBLSE members. In concert with QUBES, we also have plans to increase the availability of commenting and discussion tools associated with each resource. Our vision is that these tools will further facilitate faculty engagement and thereby strengthen the dynamic community of bioinformatics educators created by NIBLSE. Finally, NIBLSE is actively developing assessment materials linked to the core competencies that can be used to assess the impact of the resources in the NIBLSE collection. Future incubators could then revise the existing learning resources in response to the data collected from these assessment tools.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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