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Starting small: using microbiology to foster scientific literacy

Amy F. Savage and Brooke A. Jude

Bard College, Annandale-on-Hudson, NY 12504, USA

In order to achieve scientific literacy for all students, Bard College recently implemented Citizen Science, a common January course for all first-year students. Structured around the question 'how do we reduce the global burden of disease?', this course uses microbiological tools to develop an understanding of potential answers.

Liberal arts and the Citizen Science program

Bard College is a selective private liberal arts institution in New York's Hudson Valley, widely known for its unique contribution to education. Bard has a strong engagement in the visual and performing arts, a vibrant atmosphere of community service, a dedication to innovative early college and college education, and a faculty representing the top talents in their fields. Bard's first-year curriculum is also unique, even among peer institutions. It emphasizes mandatory curricular components, common to all first-year students, spread over 36 weeks during the first academic year (Figure 1). In 2011, a science element was added called Citizen Science, held in January between the fall and spring semesters. The goals of this program include providing a common and immersive experience in the process of science to all students in their first year of college. The inaugural Citizen Science was focused on the question 'how do we reduce the global burden of disease?'; it was selected for presumed student familiarity with the topic, as well as the ability to execute microbiology-based laboratory experiments in a condensed timeframe. Use of microbiological topics to initiate scientific literacy, generally defined as the ability to use science-based evidence to make judgments and participate responsibly in civic affairs [1], have been utilized in other curricular initiatives [Yale University Small World Initiative, Rainforest Expedition Laboratory, and Howard Hughes Medical Institute (HHMI) Sea-Phages program] (reviewed in [2,3]). However, various elements of the Bard program, including teaching the same content to all first-year students in an immersive, block-style, condensed curriculum, distinguish it from others. Thus, Citizen Science fits stylistically with the pedagogical approach of the Bard first-year academic experience.

The purpose of a liberal arts curriculum is to provide all students with the ability to engage with complex issues in a diverse and changing world, develop a sense of social responsibility, and build practical skills inherent to all disciplines (https://www.aacu.org/leap/what_is_liberal_education.cfm). Liberal arts experiences such as these have been positively associated with inclination to inquire, lifelong learning, openness to diversity and challenge, as well as socially responsible leadership [4]. The first-year experience is structured around a common curriculum intended to provide students with broad knowledge of issues in the wider world. With the addition of Citizen Science, these include issues in science, culture, and society.

Although different in aim and execution, Language and Thinking, First-Year Seminar, and Citizen Science maintain similar goals (Figure 1). Taking place before matriculation in August, during the fall and spring semesters, and in January of the first year, these experiences are framed by large questions or themes that direct the arc of the conversations throughout that experience. Each challenges students to engage in the campus conversation on multiple scales, from individual or small group work, to large lecture experiences. Finally, because they are required of all students but are based in different liberal arts disciplines, they necessitate that students stretch themselves beyond their comfort zones and work with unfamiliar material in novel ways.

The structure of the Citizen Science program

The microbiology-based Citizen Science program is taught by PhD-level faculty, recruited worldwide.* Faculty are trained on campus as a cohort in the summer prior to the course, and engage remotely over the intervening 6 months to prepare course materials. Faculty live on campus throughout the program, collaborating on ideas and contributing to a pool of shared teaching resources. The program consists of three 4-day-long rotations focused on problem-based learning (PBL), computing, and laboratory inquiry (Figure 1). Each is intended to progress students toward the learning goals of the program from different approaches. Case studies are widely used during PBL to present students with complex problems (e.g., mechanisms of antibiotic resistance). Students regularly read and interpret current primary research alongside historical and contemporary writing, which provides social context. During the computing rotation, students actively apply commercial computer models (e.g., 'HIV Clock' or 'How Diseases Spread', SimBio, Missoula, MT, USA) as well

Corresponding author: Jude, B.A. (bjude@bard.edu).

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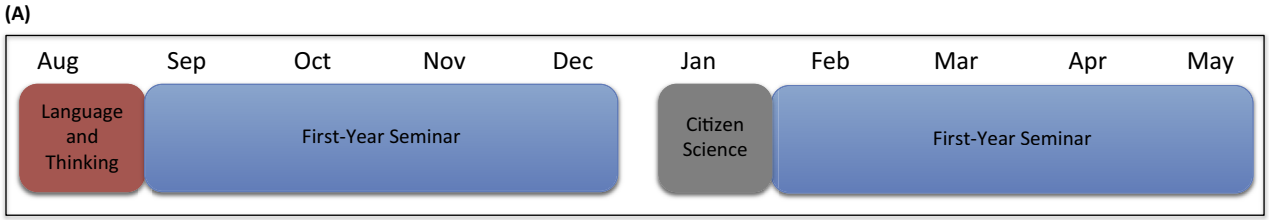
*Applications for the January 2015 Citizen Science faculty will start being accepted in April 2014, from the Bard Human Resources page. Further information about the program can be found at citizenscience.bard.edu, and questions can be directed to citizenscience@bard.edu.



(B)

	Language and Thinking	First-Year Seminar	Citizen Science
Theme	What does it mean to be human in 2014?	Studies in the human experience	How do we reduce the global burden of disease?
Grading	Satisfactory/unsatisfactory	• Standard grading A–F • Four credits/semester	Satisfactory/unsatisfactory
Class format	Small seminar style (12–16 per class)	Small seminar style (12–16 per class)	Small seminar style (17–20 per class)
Instructional time	• 4.5 hours per day • 12 instructional days	• 80 minutes per class session • 2x per week • 2 semesters	• 4–5 hours per day • 12 instructional days
Faculty	Primarily outside of Bard	Mixture of Bard undergraduate faculty and personnel outside of Bard	PhD-level scientists; primarily outside of Bard
Additional requirements	• Rostrum lecture series • Writing intensive curriculum	• Lectures • Colloquia presentations	• Faculty lectures series • Invited speaker series • Science outreach activities • Final projects

TRENDS in Microbiology

Figure 1. Calendar and description of the Bard first-year curriculum. **(A)** Timeline of the three components of the Bard first-year common curriculum, including Language and Thinking, First-Year Seminar, and Citizen Science. **(B)** Explanation of the format and administrative details for the three components of the Bard first-year common curriculum.

as freeware (e.g., FoldIt, EteRNA) to better understand how simulation can allow insight into phenomena at many scales. Many students perform bioinformatic analyses using Lasergene programs (DNAStar) and work with data from public repositories including National Center for Biotechnology Information (NCBI), whereas other classes learn to build their own Susceptible, Infected, Recovered (SIR) model in Excel. Students also spend this time analyzing data they generated and collected in the laboratory. The wet laboratory setting provides a rich opportunity for students to actively participate in inquiry-based research over a small time-frame, owing to the rapid nature of microbiological growth. Labs include isolation and enumeration of environmental microbes, examination of a viral infection (phage plaque assay), Kirby–Bauer antibiotic resistance analysis, and visualization of microbial structures; all can be completed in four daily 3-hour laboratory sessions. Exercises can also be altered based on the interest of the students and individual faculty (e.g., preparing yogurt or testing various natural products for antimicrobial effectiveness). The microbiology laboratory experiences are directly relevant to and influence the class discussions during the computing and PBL modules.

Recently, the focus in college science classrooms has shifted toward active learning [5] and increased interdisciplinarity. There has been increased effort to develop curricula that achieve higher-order student learning and successfully bridge scientific disciplines [6,7]. Although still in the beginning stages of implementation and assessment, early indications are that both science and non-science majors enrolled in courses redesigned with the above in mind perceive strong gains in skills such as the ability to use evidence, identify patterns in data, and develop a logical argument [8]. Citizen Science is distinct from a content-driven course in that the primary learning goals emphasize the habits of mind and practical responses that scientists use when encountering claims, engaging in experimentation, and evaluating evidence. Conversely, although content-driven courses might do some of these, the main element is the conveyance and expected retention of factual information specific to particular scientific disciplines. Regardless of this distinction, the Citizen Science classroom embodies many features of the educational innovations described above, emphasizing student-centered learning and active learning pedagogies to build the habits of the mind of a scientist [5]. Emphasis is placed on the development of scientific reasoning skills, and providing the context for the role of science in addressing problems of our local and global society, as discussed in the National Research Council's *A New Biology for the 21st Century* (summarized in [9]).

Preliminary student self-reported outcomes from Citizen Science suggest that key features of the program (e.g., engagement with primary literature, demonstrating the social relevance of science, and increasing accessibility of science) lead to significant (self-perceived) learning

gains in several areas. These include stated program goals such as improvement in their ability to identify patterns in data ($P < 0.005$, with 73% of students reporting improvement), to recognize the appropriate use of evidence ($P < 0.001$, 83%), and understand scientific material ($P < 0.001$, 70%). These observations are comparable to those reported for full semester integrated biology courses of first-year biology majors and non-majors [8], indicating gains in this short course format.

Citizen Science can also provide a gateway for non-majors into introductory science laboratory courses. In one example, Environmental Microbiology, students have been able to move from the concepts and principles learned in Citizen Science to a semester-long inquiry-based course. Although designed to prepare biology majors for the upcoming core curriculum, non-science majors are capable of making the same gains in evaluating and analyzing scientific evidence, having begun applying these skills during Citizen Science. Structurally, the critical thinking skills learned during Citizen Science allow faculty teaching subsequent introductory courses to design their curriculum to utilize these common skills from the first day of class.

One of the stated goals of Citizen Science is to provide all students with an initial introduction to scientific literacy, as well as to instruct methods for making observations, gathering data, evaluating evidence, and determining how to best approach a question [10,11]. Additional aspects of scientific literacy include learning to read scientific work and developing the ability to evaluate scientific claims. The attributes of a post-college scientifically literate individual are not yet fully established, although Feinstein and others have examined mechanisms for providing scientific literacy to students [12,13]. In 2012, Bard College was awarded a grant from the HHMI Science Education Initiative to establish methods to effectively instill scientific literacy in any college student by designing pedagogical and curricular means of achieving scientific literacy and creating assessment instruments to gauge the success of these educational interventions. This work is necessarily re-examining the contemporary literacy concepts on which Citizen Science was initially based, and as appropriate, refining or identifying new priorities for science literacy educational initiatives. The current mechanism for providing instruction in scientific literacy at Bard College includes completion of Citizen Science as well as completion of a four-credit laboratory-based science course. Through work on the HHMI grant, pedagogical objectives of the laboratory distribution requirement are also being re-examined, with the intention of best using these two academic experiences to provide all Bard College students with the skills defined for scientific literacy.

One major question being addressed through this working group is how to provide all students with a uniform science literacy experience via a suite of various curricular choices. The rosters of laboratory distribution requirements for non-majors frequently represent a mixture of class years and majors because students can elect when over their 4 years to complete the requirement. Conversely, participation in Citizen Science during the first year of study is compulsory for all students. Importantly, this structure creates an opportunity to craft these two experiences in conversation with each other to obtain the most significant and lasting literacy outcomes. Assessment data and feedback from these early iterations of Citizen Science will certainly help shape this nascent HHMI conversation.

While many of the goals for Citizen Science are realized using microbiological themes and techniques, students also engage in the sciences more broadly during science outreach activities. Throughout the program, Bard students become the instructor in area K-8 classrooms, running activities in physics, chemistry, computer science, math, and biology, all of which supplement the school's curricula. Through these experiences, Bard first years gain skills in the communication of science and reflect on their science learning, while providing a much needed service to these schools. In January 2014, students provided science outreach to over 3000 students in six school districts.

Concluding remarks

Taken as a whole, the use of microbiological tools and concepts during Citizen Science at Bard College has proven to be a good vehicle to engage students in scientific inquiry and promote science literacy skills in college students.

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