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| Perspective

The changing landscape with respect to scientific research and education for second-level students and how they can overlap: the Kefir4All example

Liam H. Walsh,[1,2] **Cian O' Mahony,**[3] **Paul D. Cotter**[1,4,5]

AUTHOR AFFILIATIONS See affiliation list on p. 5.

ABSTRACT Have you ever deeply considered the intersections between research and education, particularly for second-level students? Traditionally, the convergence of these two realms is most often noted when considering the integration of research findings into educational practices or the involvement of, typically a small number, of students in research activities. While these practices have demonstrated efficacy, the fields of scientific research and education are evolving rapidly, necessitating a reevaluation of how we can optimize their convergence. In our discourse, we delve into these evolving trends, uncover the potential for greater integration, and, ultimately, enhance outcomes using the citizen science initiative Kefir4All as an illustrative example.

KEYWORDS citizen science, public engagement, education, fermentation, microbiology, kefir, participant voice

EMBRACING DATA-DRIVEN APPROACHES: THE CHANGING LANDSCAPE OF BIOLOGICAL SCIENTIFIC RESEARCH AND EDUCATION

Significant transformations are underway in the realm of scientific inquiry, particularly in our comprehension of complex biological processes, owing to the advent of the "omics revolution" (1). This paradigm shift signifies a transformative era marked by the rapid progress and amalgamation of diverse high-throughput technologies tailored for the study of biological systems. Furthermore, with the omics revolution facilitating interdisciplinary collaborations and data-sharing initiatives, there is an opportunity to integrate citizen science with experimental design across diverse fields, including biology, medicine, computer science, statistics, and engineering (2). Researchers from these disciplines are collaborating to leverage omics technologies to address complex biological questions and tackle healthcare challenges. Thus, the incorporation of citizen science structures into such interdisciplinary endeavors offers a rich array of topics for citizen scientists to explore, contributing to the advancement of scientific knowledge and fostering a deeper connection between research and education.

The application of metagenomics exemplifies this revolution, employing high-throughput sequencing to analyze the collective genomes of microbial communities directly from environmental samples (3). The incorporation of metagenomics into citizen science projects has enabled extensive data collection and analysis providing an unprecedented ability to answer large-scale scientific questions. A pioneering project in this regard is the Earth Microbiome Project (EMP), initiated in 2010. The EMP set out to gather and examine microbial samples from diverse global environments, engaging citizen scientists in sample collection, processing, and data analysis (4). Subsequently, a plethora of citizen science initiatives have emerged, capitalizing on metagenomics to investigate microbial diversity and ecology across various habitats and ecosystems.

Editor Sumali Pandey, Minnesota State University Moorhead, Moorhead, Minnesota, USA

Address correspondence to Paul D. Cotter, paul.cotter@teagasc.ie.

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These endeavors encompass a wide spectrum of environments, from scrutinizing soil microbiomes in urban gardens to elucidating the microbial communities linked with human health and disease. Collectively, these initiatives underscore the transition toward comprehensive, data-centric approaches in biological research, harnessing state-of-the-art technologies, and computational methodologies (5).

In parallel, education is embracing technology in biology teaching and learning, employing tools such as virtual labs, simulations, multimedia resources, and online platforms to enrich student engagement and facilitate remote learning (6). Moreover, there is a notable shift in the educational mindset, driven by the increasing recognition of the importance of nurturing a broad range of skills beyond academic knowledge (7). Educational systems are thus endeavoring to modernize and update curricula across different subjects and levels, emphasizing critical thinking, creativity, problem-solving skills, and digital literacy. The overarching goal is to make education more pertinent to the evolving needs of society and the economy.

This educational reform extends to assessment methodologies, which are moving toward more holistic forms that provide a comprehensive understanding of students' abilities and achievements, beyond mere exam results (8). STEM (Science, Technology, Engineering, and Mathematics) education initiatives have gained traction in Ireland, aiming to address skills shortages in STEM-related fields and equip students for future job opportunities (9). These initiatives include efforts to boost student engagement in STEM subjects and promote STEM careers. Consequently, there is a shift toward inquiry-based learning approaches in biology education, where students are encouraged to engage in hands-on experimentation, critical thinking, and problem-solving activities, fostering a deeper comprehension of biological concepts and nurturing scientific thinking skills (10).

BRIDGING RESEARCH AND EDUCATION: THE TRANSFORMATIVE POTENTIAL OF CITIZEN SCIENCE

In light of these transformations, we advocate the prioritization of citizen science programs. Citizen science projects empower non-professional volunteers to participate in authentic scientific research by engaging in hands-on data collection, observation, and analysis (11) (Fig. 1). Numerous citizen science initiatives have been established worldwide such as the Global Learning and Observations to Benefit the Environment (GLOBE) program, Zooniverse, eBird Schools, Project Noah, and SciStarter Classroom which have successfully facilitated citizen science within educational systems.

These initiatives while varied in scope and approach have allowed students to apply biological concepts learned through the curriculum to real-world scenarios, deepening their understanding of biology and cultivating essential scientific skills. Despite the success of these initiatives, citizen science is often overlooked within educational systems (12). This oversight can be attributed to several factors, including traditional educational paradigms, resource constraints, and a lack of awareness of citizen science.

As evidenced by the changing landscape within scientific research and education trends outlined above and our recent completion of the Kefir4All citizen science initiative (13), which focused on kefir-related research, there is immense potential for citizen scientists to engage in scientific learning and discussion within school systems (Fig. 1). Our project provided science education and communication in both formal and informal settings, with workshops integrated into school curricula and support provided for citizen scientists conducting fermentations at home.

Through our endeavor, we underscore the transformative potential of citizen science in bridging the gap between research and education (Fig. 1). By presenting the perspectives of both a scientific researcher and a teacher, both novices in the realm of citizen science, before and after their participation in the Kefir4All project, we illuminate the profound impact and enriching experiences that such initiatives can offer. Reflecting as the lead educator involved in the Kefir4All project, Cian O'Mahony noted, "I initially viewed citizen science as a valuable opportunity for students to engage in an external

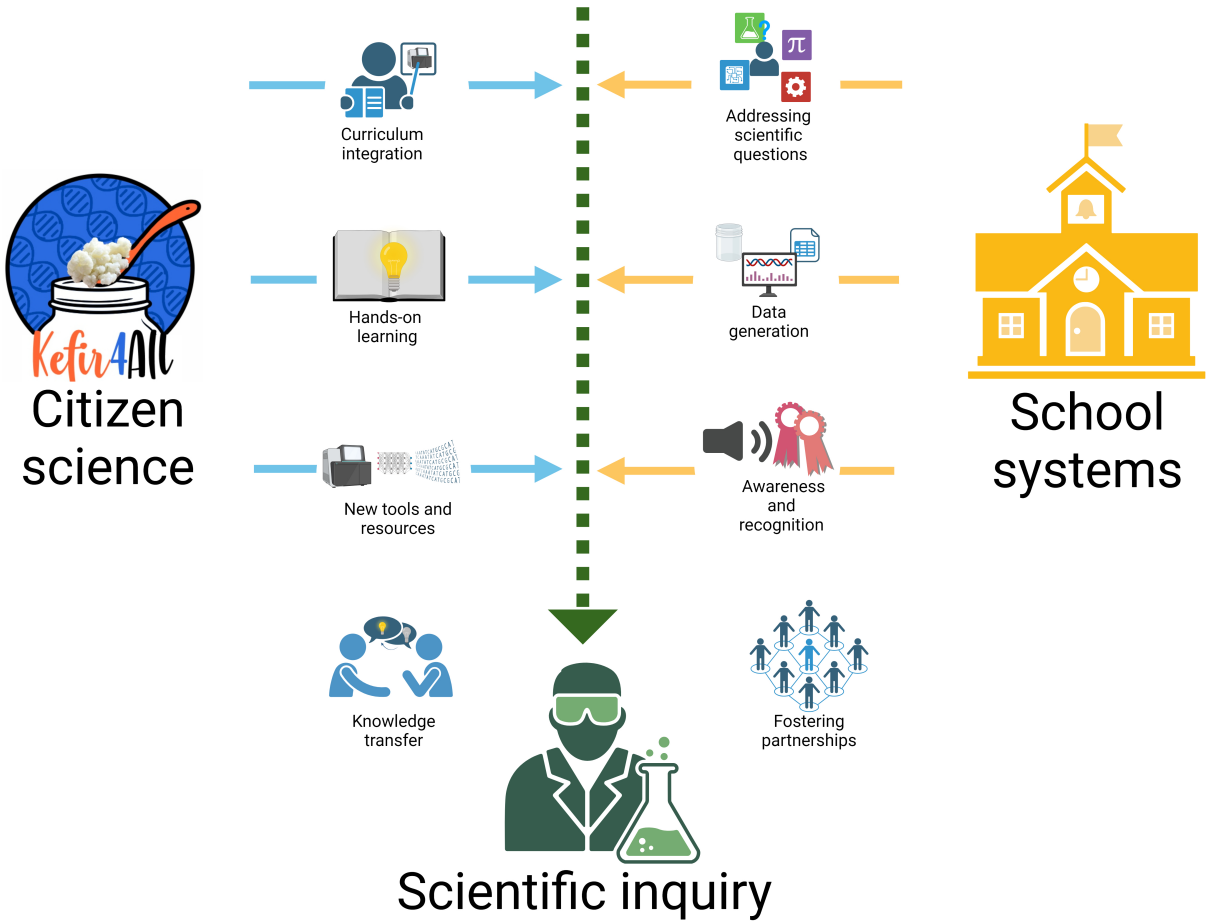

FIG 1 Dynamic interactions and mutual contributions between citizen science initiatives (blue elements), school systems (yellow elements), and scientific inquiry (green elements). Contributions include data generation, hands-on learning, and the availability of new tools and resources. Arrows depict the flow of contributions between the three domains, showcasing how each initiative informs and supports the others. Dashed lines represent intersections, signifying areas of mutual benefit and opportunities for shared learning and advancement.

research endeavor" . Participation at the school level is not something that is widely promoted or conducted yet in Ireland. As an educator, I did have initial reservations about the time commitment involved and felt too that this could be a hurdle to recruiting teachers as leaders of citizen science projects. In the Irish education system, experienced teachers are often promoted to middle management positions, which bring an increasing level of responsibility and administration. The role of lab technician does not exist in most state schools and so this role is fulfilled by the science teacher. However, recent curricular changes at second level education in Ireland, with a now established research project at age 14 (14) and a proposed research project worth 40% of the terminal state exam in the sciences (15), make exposure to science outside of the classroom more attractive to teachers and their students. This is particularly pertinent in a school system where university matriculation is competitive and dependent entirely on results in these terminal state exams. Further to participation in the project, there were a number of key benefits of and learning from our involvement in the project. These included access to some equipment and resources not readily available in the second-level school laboratory. The exposure to and partnership with "real" scientists was something they felt was of particular importance and benefit to their students. The study of the scientific method is a key part of the school science curriculum but is one that is often difficult to bring to life in the school setting. Participation in Kefir4All gave me direct exposure to valuable and accessible research from the project design stages right through to publication in Scientific journals. Experience with Kefir4All and the shared

learning from the project, including tweaks in the experiment design and reporting, helped enormously to reduce and share the time burden. On a personal level, as a science teacher for over 20 years, running the project in my school, linking it with academic research, and visiting the research center was a reinvigorating experience and a great refresher of the work of a sfcientist.

From a research perspective, before embarking on the Kefir4All Project, our research team perceived citizen science as a promising approach to involve the public in expansive scientific undertakings. The intricacies of conducting and documenting milk kefir or water kefir fermentation processes under very many growth conditions and household environments over a span of 21 weeks were not feasibly reproducible within laboratory settings. However, there were concerns about maintaining participant interest and motivation over time. Despite initial reports of limited knowledge about microbiology and fermented foods among participants, we observed robust participation rates during the first 6 weeks of the study. Citizen scientists who participated in our surveys also noted enhancements in their scientific knowledge, expanded vocabulary, and increased interest in the subject matter. Furthermore, citizen scientists returned over 500 samples, providing an unprecedented opportunity to study evolutionary trends in fermenting microorganisms within the milk and water kefir microbiome over time. Lead investigator Liam Walsh noted, “On a personal level, as a scientific researcher, receiving direct feedback on my research efforts and witnessing how they contributed to the scientific knowledge and curiosity of the citizen scientists was profoundly rewarding". It provided a unique perspective on the broader impact of my work and reinforced the importance of engaging with diverse communities in scientific endeavors.

ADVANCING CITIZEN SCIENCE PROGRAMS IN EDUCATIONAL SETTINGS: FUTURE DIRECTIONS AND STRATEGIES

While citizen science holds significant promise for engaging secondary school students in scientific research, further efforts are needed to optimize its implementation within educational settings. The collaborations established between scientists, educators, and citizen scientists during Kefir4All sparked further discussions on the design of future projects and methods aimed at meeting scientific objectives and educational standards. It was unanimously agreed that public engagement (PE) activities, already established in most research institutions, could substantially enrich citizen science initiatives by nurturing partnerships with local communities, schools, and organizations to align projects with community needs. This could be achieved through targeted outreach efforts, ensuring a participant voice within citizen science-related discussions. Such collaborative approaches would foster a more informed and open dialogue between researchers and lead educators during the project’s design stage. By doing so, concerns such as time burdens for educators could be thoroughly documented, and proactive solutions could be implemented.

Citizen science initiatives also stand to gain considerable advantages by harnessing technology and incorporating gamification strategies to enrich the participant experience and appeal to the competitive nature of schools and school students. This could involve integrating user-friendly digital platforms and applications that make participation more accessible and engaging and streamline the reporting required by educators and citizen scientists. Notably, in this regard, the citizen science project Noah has effectively utilized mobile technology to collect ecological data by encouraging citizen scientists to publish and discuss wildlife photographs of organisms within their natural habitat (16).

In addition, recognizing the valuable contributions of volunteers is essential; this could be achieved through various means such as issuing certificates of appreciation or presenting awards to standout participants. Moreover, offering opportunities for multiple site visits or providing exposure to research facilities can further deepen participants’ engagement. During the Kefir4All project, only 4% of respondents in the final evaluation survey, which was completed by citizen scientists at the project’s

conclusion, indicated that the various activities and merchandise distributed during the project failed to sustain their ongoing interest (13).

Finally, to ensure sustained engagement and foster continued interest in citizen science, researchers must go beyond the conclusion of the study by implementing comprehensive end-stage debriefing and consultation processes. These additional steps involve actively engaging with participants to discuss their experiences, gather feedback, and address any concerns or questions they may have. By facilitating open dialogue and providing avenues for reflection, researchers can enhance the overall experience for participants. Moreover, this post-study engagement allows researchers to gather valuable insights that can inform the design and implementation of future citizen science projects, thus contributing to ongoing improvements in the field. Funding bodies should also consider providing grant opportunities to empower citizen scientists to pursue independent research emphasizing the importance of leadership roles in coordinating and facilitating such initiatives. By integrating these elements and acknowledging the potential of citizen science, we can strive to cultivate a culture within school systems that not only encourages participation in citizen science projects but also nurtures a sense of belonging within the scientific community and promotes openness in scientific research (Fig. 1).

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AUTHOR AFFILIATIONS

[1]Teagasc Food Research Centre, Co. Cork, Ireland
[2]School of Microbiology, University College Cork, Cork, Ireland
[3]Douglas Community School, Cork, Ireland
[4]APC Microbiome Ireland SFI Research Centre, University College Cork, Cork, Ireland
[5]VistaMilk SFI Research Centre, Teagasc, Co. Cork, Ireland

AUTHOR ORCIDs

Liam H. Walsh http://orcid.org/0009-0002-9054-1910
Paul D. Cotter http://orcid.org/0000-0002-5465-9068

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