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Scaling the wall: overcoming barriers to STEM knowledge mobilization

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Improving science literacy is crucial amidst global challenges like climate change, emerging diseases, AI, and rampant disinformation. This is vital not only for future STEM generations but for all, to make informed decisions. Informal science communication efforts such as podcasts, popular science articles, and museum events are an essential part of the infrastructure for mobilizing knowledge and nurturing science literacy. However, in this *Perspective*, we emphasize the need to grow our capacity for STEM outreach in the formal K-12 classroom. While the majority of informal outreach mechanisms require audience members to seek out content, classrooms include those hard-to-reach target audiences that are not already STEM-engaged. We contrast the multitude of resources that have been developed to support informal outreach in recent decades with a relative paucity of such efforts in the K-12 formal classroom realm. We advocate for a more balanced deployment of resources and efforts between these two vital components of our knowledge mobilization and STEM engagement infrastructure. In particular, we highlight the key role of K-12 teachers as conduits for knowledge dissemination and the need for greater collaboration between scientists and teachers at individual and organizational levels. We also advocate for greater collaboration across programs in both the informal and formal outreach space, and dedicated effort to construct dissemination networks to share outreach materials at scale across disparate programs. The aim of our piece is to generate discussion about how we might refocus goals, funding mechanisms, and policies to grow the science-engaged society necessary to confront future challenges.

KEYWORDS

broader impacts, societal benefits, teacher-researcher collaboration, formal outreach, K-12 education, curriculum development

Introduction

Improving science literacy is crucial amid global challenges like climate change, emerging diseases, AI advancement, and disinformation. It is essential, not just for the next STEM generation, but for all of us to make informed decisions (Klopfer, 1969; Philipp-Muller et al., 2022). Yet, despite massive global challenges, unprecedented scientific productivity, decades of education reforms, and significant informal outreach efforts, science literacy in the US remains moderate. The US ranked 16th in science on the 2022 PISA international test for high schoolers, having risen a mere 10 points between 2009 and 2022. These minor gains were not shared equally across students, as there was a 282-point gap between the 90th and 10th percentiles—much greater than the average 254 score gap for OECD countries (OECD, 2023). As for the US adult population, the overall understanding of scientific inquiry changed little over the same period, going from 42 to 43% between 2008 and 2018 (Besley and Hill, 2020). Meanwhile, the Intergovernmental Panel on Climate Change's 6th Assessment indicates that massive economic and governmental changes must occur within the next 30 years to prevent devastating climate change impacts (Calvin et al., 2023). This demands a populace that is able to internalize urgent science-related findings and translate them into environmental values and actions on an unparalleled scale. As such, the current status quo threatens the future quality of life globally. We argue that improving the state of science literacy requires an urgent, substantial recalibration of our approach to educating the public. Our viewpoint is that this correction requires a balanced deployment of resources and efforts between informal science communication (e.g., through articles, videos, museum events, podcasts, after-school clubs, etc.) and formal K-12 STEM education in classrooms. Although we focus on the United States, and in particular outreach efforts funded by the US National Science Foundation (NSF), we believe that our conclusions and recommendations apply broadly to STEM outreach efforts worldwide. Our intention is not to provide a comprehensive programmatic analysis, but to contribute to the ongoing discourse on improving science literacy and mobilizing knowledge effectively.

Broader impacts, limited reach

Since its inception, the NSF, which funds roughly 7.8 billion dollars (National Science Foundation, 2023) of basic research annually (National Science Foundation, 2023), has strived to bridge the gap between scientific research and societal needs. A notable example is the Broader Impacts (BI) criterion— introduced into the grant review process in 1997 (Watts et al., 2015) demands scientists to demonstrate an active connection between their research, stakeholders and the broader public. However, the range of actions encompassed by BI are diverse, ranging from informal efforts like after-school clubs and YouTube videos, that rely on audience initiative, to formal classroom outreach requiring mandatory student presence and assessed learning. These efforts, often implicitly aligned closely with the concept of science *knowledge mobilization* (*KMb*), aim to foster a more scientifically-engaged society.

If the goal is a science-invested society, the best opportunity arguably lies within formal K-12 classrooms, which offer a broad, captive audience and feature a highly systematized process where learning objectives are regularly assessed. A commonly cited study advocating for increased focus on informal outreach notes that only a small portion of students' lives are spent in a formal classroom (Falk and Dierking, 2010). The flexibility of informal outreach may also appeal to scientists, given the burdens of their primary research and academic commitments. Yet, the impact of formal K-12 classroom time is foundational for determining students' relationship with science and STEM from an early age (Hachey, 2020). Moreover, the relegation of scientists' outreach efforts to informal settings limits academic rigor and misses opportunities to assess learning. NSF-funded projects generally receive positive public ratings for societal impacts (Drummond Otten and Fischhoff, 2021), but a critical need remains for a more directed dissemination of scientific knowledge, that goes beyond general interest, and is aimed at fostering a scientifically literate and resilient society.

An additional, often disregarded caveat is that the informal space has an inherent barrier to entry, which we term the "STEM identity barrier." That is, only those who are already somewhat STEM-engaged will seek out scientific news articles or attend museum events - a phenomenon that disproportionately excludes low-income, minority ethnic groups (Dawson, 2014). This correlation underscores a trend observed in NSF-funded projects, where the BI benefits favor advantaged or STEM-aligned groups, further amplifying social inequalities (Woodson and Boutilier, 2021). Figure 1 represents a gradient of STEM identity levels required to benefit from different types of outreach. Importantly, scientific articles require the highest level of "STEM identity" (perceiving STEM as perfectly integrated into one's life). This semi-quantitative approach to measuring STEM attitudes borrows from (McDonald et al., 2019), who present a highly scalable single-item metric for quantifying and comparing STEM identity. At the other end of the audience selectivity spectrum lies the K-12 formal classroom. The mandatory nature of K-12 school means this audience includes the hard-to-reach individuals who see STEM as foreign and separate from their lives. This distinction alone should argue for greater investment in formal classroom outreach.

The last decade has seen massive growth in informal outreach investment through training programs (e.g., AAAS Mass Media Fellowships and Alda Center professional development programs); conferences (e.g., Science Talk, ComSciCon, and the University of Nebraska SciComm conference); and capacity building initiatives (e.g., the Portal to the Public and NSF INCLUDES Networks). Concurrently, the proliferation of mechanisms for growing informal audiences through blogs, video channels, podcasts, and social media further represents a strong *KMb* infrastructure for informal outreach. However, this abundance of training and support contrasts sharply with the infrastructure available for scalable dissemination of formal knowledge products. The NSF GK-12 program (1999–2011) – a unique program funding fellowships for large cohorts of scientists to build active collaborations between scientists and K-12 teachers – was dissolved (Ufnar et al., 2012). Programs like SciREN aim to integrate current research into K-12 curricula and connect teachers with researchers (Theuerkauf and Ridge, 2014), but face limitations in geographic reach, resource availability, and ensuring consistent researcher participation. Similarly, the NIH Science Education Partnership Award (SEPA) program, while different in its approach from the NSF GK-12, has played a pivotal role in enhancing science literacy among K-12 students. SEPA supports innovative educational activities, emphasizing collaborations between biomedical researchers and educators, and focuses on health and disease-related science education. Numerous SEPA-funded projects have significantly enhanced STEM education both at local and sometimes regional levels (Hernández-Matías et al., 2023). These programs, many of which have been active for several years, provide great insights into effective collaboration with educators (Santschi et al., 2024), delivering training (Chowning, 2022), and measuring impact (Baeten et al., 2020). Notably, the Teaching the Genome Generation (TtGG) program, supported by SEPA, stands out for its specific focus on preparing high school educators for the challenges of teaching genomics (LaRue et al., 2018).

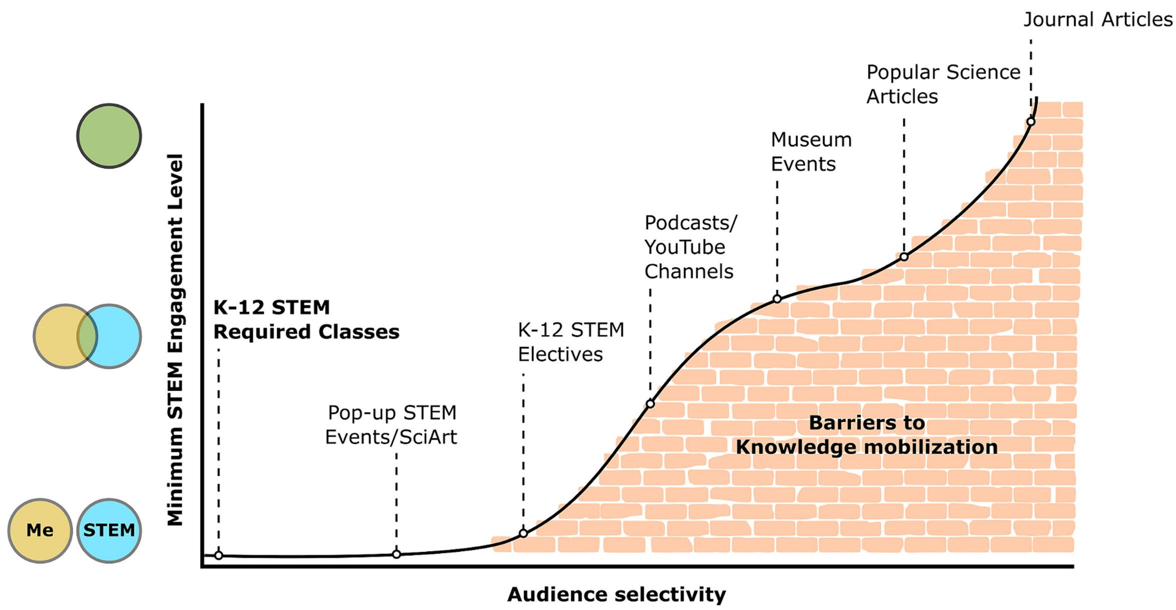

FIGURE 1
STEM identity is a barrier for certain types of outreach. This hypothetical curve represents the minimum level of STEM engagement required for audience members to seek out and/or benefit from a particular outreach effort. The Y-Axis represents STEM identity as the amount of overlap a person sees between themselves and STEM (McDonald et al., 2019). The X-Axis represents audience selectivity, maximized at the far right, as only highly STEM-engaged individuals (with complete overlap between how they perceive "Me" and "STEM") will seek out, read, and understand scientific articles. At the far left, K-12 STEM required classes (e.g., general science) have broad audiences, including students who do not see STEM as relevant in their lives at all. In between are a variety of outreach approaches requiring intermediate levels of interest and prior knowledge to be effective in improving overall STEM understanding and engagement.

While NSF maintains funding mechanisms for K-12 formal classroom outreach, such as the Discovery Research PreK-12 (DRK-12) and Innovative Technology Experiences for Students and Teachers (ITEST) programs, these programs tend to focus heavily on education research or innovation and often do not involve basic science researchers themselves, greatly limiting the scope of *KMb*. In general, the lack of cohesive dissemination networks and audience sharing across programs hinders audience development for new outreach programs. Individuals can spend years of devoted effort to build an audience from scratch and still fail to reach the wide audience the program deserves. As a result, the formal K-12 classroom is left with a disconnected web of education/outreach programs (e.g., Skype A Scientist, Data Nuggets, California Academy's Teaching Resources, and HHMI BioInteractive resources), which while valuable, only attract a small audience of teachers who are aware of and value their content.

The NSF's *BI* criterion (and similar outreach requirements across funding agencies) offers a unique opportunity for change. We propose a strategic realignment of funds and efforts to prioritize *KMb* through formal K-12 classrooms, focusing on building active collaborations between STEM professionals and teachers, as exemplified by Malanson et al. (2014). The implementation of these strategies requires concerted efforts from multiple stakeholders. Scientists need incentives and training to engage with K-12 education, and education systems must adapt to incorporate current scientific knowledge into their curricula. Governmental and institutional policies should support these collaborations, creating a symbiotic relationship between scientific research and K-12 education.

Rather than placing the onus on individual researchers to devise educational programs for K-12, a more efficient strategy would be to focus on building capacity for effective knowledge mobilization through informed curricular design (through collaboration with curriculum development consultants and open access education studios or expanding teacher professional development opportunities). This approach resonates with previous studies advocating for "boundary organizations" that can act as dedicated partners, supporting the much-needed bidirectional flow of knowledge between knowledge creators and consumers (Roberts, 2009; Simeonov et al., 2021). This symbiosis, illustrated in Figure 2, will empower our school teachers, who act as the ultimate conduits for K-12 knowledge dissemination, and will better inform the iterative design of more effective curricula.

We aim not to diminish the role of informal outreach, but highlight the neglected importance of formal classroom outreach. Moreover, the outputs of this type of outreach are typically supplementary lessons and resources that enrich rather than replace the current curriculum, which maintains the need for education publishers. However, the nature of traditional, paywalled education publishing–monetized by charging schools to access resources—inherently leads to unequal outcomes, as there is up to a $16,000 difference in per-student spending across US states (United States Census Bureau, 2023). The potential for producing high-quality, open-access educational resources that achieve outreach requirements by mobilizing public-funded research knowledge offers an opportunity to radically shake up an increasingly privatized US education environment (Adamson and Galloway, 2019). Education privatization is a trend in the US and abroad (Verger et al., 2016) which limits opportunities for marginalized groups (Darmawaskita and McDaniel, 2021) and threatens our ability to respond to complex challenges as a society.

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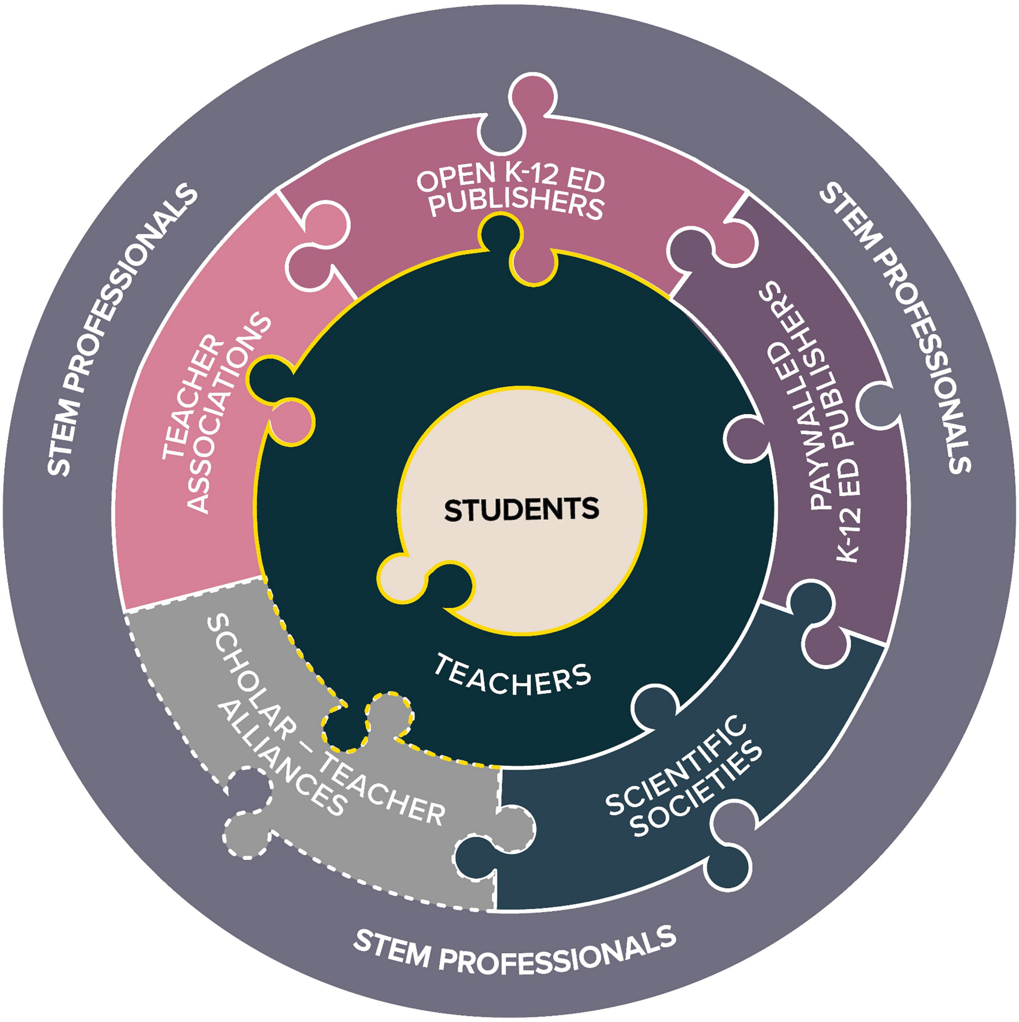

FIGURE 2
The primary scalable infrastructure for mobilizing knowledge from STEM professionals into formal (i.e., not afterschool) K-12 classrooms. Individual efforts of STEM professionals to connect with individual teachers or students are not included, as this figure illustrates the knowledge mobilization infrastructure for classroom outreach. Critically, teachers are the conduit through which resources must flow to reach the target audience of students. Tabs on the puzzle pieces indicate the direction of knowledge flow. Yellow outlines indicate bidirectional flow of knowledge with teachers. The dashed line around "Scholar-Educator Alliances" signifies the fragmented and often transient nature of platforms like NSF's defunct GK-12 and NIH's ongoing SEPA program, that provide scalable training and resources for supporting formal classroom outreach.

Laying the foundation: teachers as cornerstones of knowledge mobilization (KMb)

K-12 classrooms represent a critical frontier in shaping future generations, yet accessing and effectively engaging these spaces for *KMb* presents distinct challenges. The educational landscape, influenced by a diverse array of multicultural needs (Banks and McGee Banks, 2019), technology integration (Delgado et al., 2015), and resource availability, is diverse and intersects with political governance (Lee et al., 2022). This dynamic environment creates a bottleneck for integrating contemporary topics into school science curricula. Academic researchers and other STEM professionals, despite their expertise, frequently struggle to adapt their knowledge to the educational needs and contexts of students, with their professional demands further limiting the consistency and efficacy of educational outreach.

In formal classroom settings, teachers emerge as invaluable, yet underutilized assets in the realm of science communication. Interacting daily with students, they gain insights into individual backgrounds and interests. More than just instructors, teachers forge personal connections, instrumental in contextualizing scientific knowledge. Their expertise in conveying complex information positions them as the most crucial interface for effective knowledge dissemination.

However, the potential of teachers as collaborators in science communication is often untapped. Typical K-12 outreach scenarios have scientists presenting in classrooms with minimal coordination with teachers, failing to utilize their expertise in pedagogy and content adaptation. Initiatives such as the creation of topic frameworks by the International Microbiology Literacy Initiative (Timmis, 2023) and the Teaching the Genome Generation program (LaRue et al., 2018) showcase open-access curricula from experts in the field. Yet, a robust infrastructure for disseminating scientist-created materials to teachers is lacking.

Fully leveraging teachers for *KMb* requires a shift in approach. This means building/expanding formal collaboration channels between scientists and teachers (such as the Scientist in the Classroom program at Vanderbilt University's Collaborative for STEM Outreach), co-developing educational content with teacher input to align with curricular standards and student interests. Recognizing teachers as co-creators in the design and implementation of scientific outreach programs is vital. Supporting teacher-researcher partnerships, both logistically and financially, will foster sustainable and impactful *KMb*. We argue that bridging the gap between researchers and educators across numerous disciplines and acknowledging the unique role of teachers are crucial prerequisites to advancing *KMb* in K-12 classrooms.

Building bridges: the mutual benefits of teacher–researcher collaborations

Knowledge of K-12 target audience

Teachers bring an invaluable understanding of the cognitive and social–emotional development of their students, along with a mastery of academic concepts, skills, and vocabulary suitable for different age groups. Collaborating with teachers gives researchers insights into how to effectively convey complex scientific topics to young minds. This partnership alleviates the need for researchers to act as their own liaison with this unique audience, a role for which they might not be fully equipped. Moreover, teachers have an established rapport with their students, offering insights into both the educational content and the students themselves. It is unrealistic and unfair to expect all researchers to replicate this level of connection with an unfamiliar audience, making the partnership with teachers essential for effective *KMb*.

Classroom management

Teachers excel in classroom management and are skilled in anticipating and responding to the diverse behavioral, social–emotional, and educational needs of students. Researchers, often lacking in this area, can learn effective student engagement strategies through collaborations with teachers (as observed by MacFadden et al., 2022), thereby enhancing their ability to manage diverse classroom dynamics.

Student-centered pedagogy

With their training and experience in facilitating student-centered learning, teachers utilize strategies like leveraging student background knowledge, incorporating student choice, and fostering opportunities for reflection. This expertise inspires researchers to expand their repertoire of engagement strategies and become better educators.

Disciplinary STEM knowledge

Researchers offer teachers deep, specific knowledge in STEM fields, enriched by authentic research experiences and advanced methodologies. Partnerships with teachers improve access to up-to-date scientific developments, overcoming barriers like academic paywalls and technical jargon. Exchanges between scientists and teachers, therefore, can enhance teacher understanding and confidence with advanced scientific content, simplifying the integration of cutting-edge STEM content into curricula.

Diversity in researchers as role models

The increasing diversity among researchers enhances their potential as role models, especially for students from groups underrepresented in STEM. With the right platform, researchers cannot only share their scientific expertise but also their diverse personal experiences—challenging stereotypes, and inspiring a broader spectrum of students. Teachers, understanding students' backgrounds and interests, can highlight these perspectives, creating a diverse, inclusive learning environment that encourages students from different backgrounds to explore their potential in pursuing STEM fields.

Enhancing reach: building a systematic approach to formal classroom outreach

To enhance STEM education and *KMb* within K-12 classrooms will require systemic reform. While the efforts of individuals are important, a substantial and meaningful impact necessitates a more coordinated framework. Figure 2 depicts the current infrastructure available for scientists and STEM professionals to mobilize their expertise in educational settings.

A significant gap in the educational landscape is the lack of comprehensive programs like the NSF's GK-12, which provided a robust pathway for integrating scientific research into school curricula and training for early career scientists interested in pedagogy. Formal education plays a key role in dispelling misconceptions about realities like climate change (Hawkins and Stark, 2016), underscoring the need for integrating contemporary scientific discussions into classrooms. While there are a few examples of programs that found alternative funding after the defunding of GK-12, such as Metropolitan Nashville Public Schools' partnership with Vanderbilt University's Collaborative for STEM Education and Outreach (partially funded through NIH's SEPA), the majority of programs simply disappeared (Ufnar et al., 2012). This gap marks an opportunity for the NSF to reintroduce or revise the successful GK-12 program. Additionally, the Center for Advancing Research Impact in Society has echoed in multiple reports, the need for other governmental organizations around the world to adopt Broader Impacts (i.e., Societal Benefits) requirements in their granting processes.[1]

The increasing privatization of education and the rise of subscription-based EdTech services have exacerbated educational disparities. In response, open-access curriculum developers, including CK-12, OpenSciEd, OER Commons, KQED, TEDed, NASA, California Academy, PBS Learning, Smithsonian, BiteScis, Data Nuggets, and Galactic Polymath have emerged. These platforms offer

1 https://www.researchinsociety.org/

valuable resources but are still relatively disjointed and unfamiliar to many teachers. Additionally, on popular platforms like the TeachersPayTeachers portal, collaboration with researchers is rare, often resulting in materials of questionable quality and accuracy (Harris et al., 2023).

To address these challenges, concerted efforts are needed to build credibility, grow teacher audiences, increase collaboration and co-promotion across curriculum portals, and foster two-way knowledge-sharing with educators. NSF's Research Experiences for Teachers (RETS) programs can play a pivotal role, by focusing on capacity building through hands-on experiences for K-12 teachers, equipping them with techniques and technologies for their courses. The teachers gain from lab experience and professional development, while their hosts learn to identify jargon and develop new strategies for communicating their research. This fosters mutual respect, targeted outreach, and opportunities for teacher training and feedback. The NSF RETS sites are geographically limited, with approximately 10 sites funded per cycle (National Science Foundation, 2021). Other programs like NOAA's Teacher at Sea Program (National Oceanic and Atmospheric Administration, 2023), NASA's STEM Gateway Program (National Aeronautics and Space Administration, 2023), and the NIH's Summer Research Education Program (National Institutes of Health, 2023) offer similar opportunities for educators to develop skills and collaboration. Increased awareness and sharing of educational products of these opportunities for both educators and researchers would magnify impact.

Universities, researchers, and scientific societies should consider forming partnerships with open-access curriculum developers and actively promote collaborations with educators. Co-promoting aligned projects and improving the searchability of quality resources are crucial. While platforms like Open Educational Resources (OER Commons) and PBS Learning Media centralize content, their limited usage and cumbersome content addition for developers remain challenges. Interoperability and user-friendliness when using these repositories is critical, necessitating greater collaboration between organizations.

Echoing ARIS/NABI's recommendations, professionalizing the *BI* ecosystem (ARIS, 2020), and creating funding opportunities for university-affiliated outreach support centers, nonprofits, and social enterprises are essential. These entities can help build the capacity needed to effectively facilitate the transfer of knowledge from academic journals into the public domain through formal education channels, thereby growing a more STEM-engaged society.

Conclusion

Enacting changes in our economic and legislative systems to confront looming threats, like pandemics, climate change, pollution, and mass extinction, may take decades, but they hinge on an immediate need: enhancing science literacy. Rapidly scaling up public engagement and comprehension of science is crucial for catalyzing long-term systemic changes. We must adopt a holistic STEM outreach approach that considers STEM identity barriers, and rebalances our strategies for outreach and knowledge mobilization. Significant progress has been made in informal science outreach, but these efforts often fail to reach uninitiated audiences. It is time to greatly expand our outreach efforts in formal classroom education and curriculum development. To achieve this, we must craft new puzzle pieces to enhance the knowledge mobilization landscape and make it easier for researchers to connect with and inspire K-12 students. Empowering teachers as the primary agents of knowledge dissemination is imperative. Their expertise in interacting with students, fostering curiosity, and shaping curricula makes them invaluable and underutilized partners for knowledge dissemination. Collaborations between researchers and K-12 teachers can also play a pivotal role in promoting inclusivity and broadening early STEM participation. A long-term solution to this puzzle, however, will necessitate systemic change to expand curriculum development and dissemination based on authentic research. This demands dynamic collaborations among researchers, educators, curriculum developers, and dissemination networks, making STEM more accessible and relevant to our younger generations and laying the groundwork for an informed citizenry to tackle increasingly complex challenges.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

MW: Conceptualization, Project administration, Visualization, Writing – original draft, Writing – review & editing. SR: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. CG: Writing – review & editing. JW: Conceptualization, Writing – review & editing. AM: Conceptualization, Funding acquisition, Project administration, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

MW was the founder and CEO of Galactic Polymath Education Studio, where SR was the lead curriculum developer. As an open-access K-12 education publisher, Galactic Polymath aims to help build the capacity we argue for here. JW was on the Council of Experts for NSF's Center for Advancing Research Impact in Society.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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