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The Promise and Complexity of Open-Source Hardware in K-12 STEM Learning: Commentary on Discussion at the 2024 National Technology Leadership Summit

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Editor's Note: From time to time, the CITE Journal *publishes commentaries that provide added context for previously published articles. This commentary provides added context for work reported in the linked article. The editors would welcome additional commentaries that build upon and advance this dialog*.

The adoption of open-source hardware (OSH) in K-12 education presents a transformative opportunity for schools to enhance hands-on learning while reducing costs. Open-source hardware refers to physical devices whose designs are publicly shared, allowing anyone to modify, build, and improve upon existing technology (Open Source Hardware Association, n.d.). The ability to customize and experiment with open-source hardware designs offers students valuable hands-on experience with science, technology, engineering, and mathematics (STEM) concepts, particularly in computer science, electronics, and engineering, without the added time constraints of engineering a complex design from scratch (Heradio et al., 2018; Weller, 2011). Although integrating OSH into hands-on lessons shows great potential and proven success in student learning, scaling this approach presents certain challenges, especially for schools with the highest need.

Integrating Open-Source Hardware into K-12 Education

Through OSH, K-12 teachers and students gain access to an extensive array of instrument designs, models, teaching aids, and tools that enrich learning, especially in subjects like science, mathematics, and engineering. These designs, which can be customized for specific classroom needs, offer an opportunity for students and teachers to build various educational tools and models using digital fabrication makerspace technologies like 3D printers and laser cutters. By engaging in the process of constructing and modifying these tools, students not only gain practical skills in using digital fabrication technology but also develop a deeper understanding of the underlying scientific and mathematical principles embedded in the designs (Brennan, 2015; Burghardt et al., 2010; Hmelo et al., 2009). This process of adapting and personalizing tools can become a hands-on, project-based learning (PBL) experience that fosters practical skills and deepens content understanding (Blikstein, 2013; Martínez & Stager, 2019).

Additionally, modifying and building OSH models encourages students to engage with the broader OSH community, connecting them to a network of researchers and makers who can provide valuable expertise and support during the design and construction process. This connection to a wider community makes STEM learning more authentic and relevant, which can foster deeper understanding and engagement with the material for K-12 students (Honey et al., 2014).

Once the models are built, teachers can embed them into classroom units or develop targeted lesson plans for student use, enabling students to directly apply theoretical concepts through interaction with physical models and kits. Engaging in such experiential learning not only strengthens students' grasp of abstract concepts but also cultivates critical problem-solving skills and fosters creativity. This approach to learning, supported by OSH, also encourages exploration and collaboration, equipping students with the skills necessary for future innovation (Bevan, 2017; Blikstein, 2013).

Schools, especially those constrained by budgets, can greatly benefit from OSH because of its cost-effectiveness. Unlike proprietary hardware, which can be expensive and restrictive, OSH allows schools to create customized, affordable solutions tailored to their curriculum needs (Baldwin et al., 2006). Teachers and students can access blueprints, build devices, and collaborate with others to improve designs that fit better within their own localized context. By integrating OSH tools and models into classrooms, educators can shift toward active, experiential learning, where students can engage more deeply in their own educational experience.

The OpenFlexure Microscope: A Model for Collaboration

The OpenFlexure microscope serves as an excellent example of how open-source hardware (OSH) can be adapted for educational purposes (Open Flexure Project, n.d.). The open flexure microscope is a low-cost, 3D-printed microscope designed for accessibility and adaptability in educational and research settings. This open-source tool can be customized and assembled with basic components, making it an effective instrument for hands-on learning in science and engineering (Collins et al., 2020).

The collaboration for testing the process of designing (or redesigning), engineering, and building the OpenFlexure Microscope for use in high school classes described in the article "Editorial: Facilitating Use of Open Hardware in K-12 Schools" is an impressive single case use (Berry et al, 2024). This project involved many partners, including university-level professors, engineering students, the principal investigator of the microscope project, contributors from the OpenFlexure online community, and staff from the university-based makerspace. These collaborators all participated in developing and building this OSH tool in support of a high school science teacher and three students.

In this example, three high school students were guided to design and build their own microscopes using LEGO blocks and other materials, following the K-12 version of the Open Flexure Microscope, developed through an OSH design by a University of Virginia engineering class (Berry et al., 2024). This allowed the students to experience "STEM-rich making" as they explored the components and functions of a microscope, experimenting with their own designs (Bevan, 2017). Moreover, through hands-on interaction with versions of the Open Flexure Microscope adapted for school use, the students engaged in both guided and open inquiry-driven learning, leading to meaningful discoveries made by the students themselves (Ramadani et al., 2021).

This scenario highlights the potential of OSH to engage students deeply in their own learning, allowing them not only to build and experiment with the hardware but also to understand and manipulate scientific tools on a fundamental level (Heradio et al., 2018). The OSH approach is highly adaptable for K-12 education, providing students with valuable, hands-on experience and fostering curiosity through iterative design and problem-solving (Blikstein, 2013; Brennan, 2015;).

However, in this example, the success of the project was supported by significant community resources and engagement, a level of support that not all schools can access. The University of Virginia and the Open Flexure community contributed materials, expertise, and time, enabling students to take on a complex project that many schools would find challenging to replicate without similar resources. Schools lacking these resources or community support often face barriers in implementing such initiatives, even with the low-cost of OSH. Without adequate funding, partnerships, and technical assistance, many students are left without the opportunity to experience this kind of immersive learning.

The Need for Makerspaces in Underfunded Schools

Unfortunately, the schools that stand to benefit the most from the low-cost of OSH are often the ones least equipped to implement it. Many underfunded schools lack the resources to set up Fab Labs or makerspaces often needed to fabricate such learning tools. Even those schools with makerspace capabilities do not often have the engineering expertise to re-design and build the hardware itself. This disparity creates a gap between students who have access to the latest technological tools and expertise and those who do not, exacerbating educational inequalities (Baldwin et al., 2006).

To address this issue, it is essential to build not only a repository of free, accessible OSH models and kits but also to establish a support network linking K-12 schools with the machines, equipment, and expertise necessary to build and customize OSH for their unique needs. Community-based Fab Labs or mobile makerspaces could offer support to schools lacking on-site resources, ensuring that students in underserved areas gain access to OSH-enhanced learning opportunities (Gershenfeld, 2005). These collaborative resources would allow teachers to integrate hands-on, inquiry-based learning into their curriculum without requiring significant school-based investments in equipment. By fostering partnerships among schools, community-based makerspaces, and universities, sustainable systems can be created to ensure that all students, regardless of socioeconomic background, can benefit from the educational advantages of open-source hardware.

Building a Bridge for Inclusive Open Source Learning Opportunities

To fully realize the potential of open-source hardware (OSH) in K-12 education, establishing a comprehensive network that connects Fab Labs and makerspaces with schools is essential. Such a network would make OSH resources, tools, and expertise more accessible to educators, particularly those in underfunded regions, thereby supporting hands-on, technology-based learning experiences. Through partnerships among community-based Fab Labs, schools, and higher educational institutions, this network could support experiential learning with OSH projects, expanding access to open-source hardware, kits, and educational materials. This approach would ensure that all students, regardless of school funding, have opportunities to engage in meaningful, hands-on STEM learning (Gershenfeld, 2005; Baldwin et al., 2006).

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