Establishing an Open-Source Ecosystem to Support Invention through Emulation

Glen Bull, Michael Littman, Jo Watts, John Maloney, and Roger Sherman

The mission of the Smithsonian's National Museum of American History (n.d.) is "to help people understand the past in order to make sense of the present and shape a more humane future" (para. 8). The history of the nation's inventions is preserved in the collections of the Smithsonian's National Museum of American History, formerly known as the National Museum of History and Technology. Reviewing the historical record of invention in American makes it clear that:

1. Inventions almost always built upon prior inventions. It was rare for an invention to emerge out of whole cloth with no precedents in the historical record.
2. Inventions were also almost always the result of collaborations among a team of inventors rather than the work of a lone individual.

This process culminated in the invention factory of Thomas Edison. In the centuries prior to 1870, the rate of technological growth held steady at 0.45 percent per year. After 1870, the rate of technological growth increased four-fold to the 2.1 percent rate of grow that has been maintained since that time. (DeLong, 2022). It is worth examining how this state was achieved.

The 19th century was an era of technological change unprecedented before or since (Hindle, 1981; Smil, 2005). The United States was transformed from a rural, agricultural nation to a technological leader. Brooke Hindle, past director of the Smithsonian's National Museum of American History, refers to this period as an "American Industrial Revolution." During his time as director of the Museum, Hindle investigated the factors underlying this transformation and summarized his conclusions in *Invention and Emulation* (Hindle, 1981).

Hindle (1981) concluded that the educational methods of the 19th century played a crucial role in the process of invention and innovation. A machinist's apprentice learned by copying the best models. A journeyman was expected to use a master work as a starting point of reference and extend it, improving upon the original. This type of emulation led to new inventions like the telegraph, which remixed and combined a number of elements to create new innovations. Hindle described the method by which mechanical knowledge was transferred from one generation to the next as "invention through emulation."

Craft guilds in Europe had an incentive to preserve the status quo to ensure that there was sufficient work for guild members. On the frontiers of a new, sparsely populated nation, the incentive was reversed. With a limited labor pool, labor-saving devices were welcome, and the barriers imposed by traditional craft guilds did not present the barriers to innovation present in more established nations.

. Roger Sherman, a curator at the National Museum of American History, commented, 'There was a feeling that this was a new country. Our governmental system was a new one. We were open to new ideas. The process of innovation and invention was encouraged and supported'. He noted that one goal of the maker movement and contemporary making is to foster a similar sense of creativity, imagination, and innovation (Hoffman and Bull, 2016). In a similar vein, Hindle asked,

> Incredibly, the newborn United States was more successful than any other nation in assuming the attitude of mind required and in transferring any desired technology. How could that possibly be? How could a thinly dispersed people, 90 percent of them engaged in agricultural pursuits, a people whose economy was still colonial and commercial, take over the most advanced technology in the world? More amazing still, how could the custodians of an empty continent, far distant from the economic power centers of Europe

> and from its busy workshops and rising factories, move on to take leadership in one line after another of mechanization and innovation? (Hindle, 1983:13)

Hindle's conclusion was that enthusiasm for mechanization and invention was incorporated at an early stage into the vision of the nation. Based on his research as director of the National Museum of American History, Hindle believed that 'invention through emulation' was the chief pedagogical mechanism responsible for this success:

> Emulation represented an effort to equal or surpass the work of others; it was more a striving for quality and recognition than a marketplace competition and seems to have emerged from the manner of instruction and improvement in the arts and crafts. There the striving was frequently spurred by contests and by constant measurement against the best models. The apprentice learned by copying the work of the master, but the journeyman had to go beyond copying. In order to become a master himself, he had to produce his own 'masterpiece'. (Hindle 1983:13)

The advent of affordable fabrication technologies such as 3D desktop printers and programmable microcontrollers have fueled a maker movement in the twenty-first century. Makerspaces introduce the technological tools used to design and build physical objects; use of the tools creates experiences that contribute to understanding of how objects work (National Academy of Sciences, Engineering, and Medicine 2018).

An understanding of the process of invention throughout the nation's history can provide guidance on ways to use these spaces to effectively support invention today. This can be asked in the context of the question, "What might invention through emulation look like in contemporary makerspaces and classrooms?" The communities established through Scratch and Snap! provide a model.

Scratch is a blocks-based educational computing language developed at M.I.T. Snap*!* is an advanced blocks-based language inspired by Scratch developed at the University of California, Berkeley. John Maloney, who wrote the first implementation of Scratch (in Smalltalk), comments,

> When I was growing up in the 1970's, there was a lot of making going on. Magazines like *Popular Electronics* and *Popular Mechanics* were full of instructions for things you could build yourself. There was ham radio and model rocketry. There were electronics kits you could buy and solder together, like the two-transistor radio I got for Christmas one year. There were also educational kits like the Radio Shack 50-in-1 electronics kit.
>
> Looking back, my entire life and career path have been shaped and enriched by being exposed to maker culture during my formative years. I feel fortunate to been exposed to making while I was growing up, and to have been born to parents who encouraged and supported it.
>
> Scratch and MicroBlocks are my attempts to help today's young people discover the joys of making and creative problem solving. (Maloney, 2022)

By any measure, the outcomes have been successful. Scratch has become the most widely used children's language today, and it is currently the 22nd most popular computer language overall according to the TIOBE index (https://www.tiobe.com/tiobe-index/). Snap! is currently used by more than a thousand high school computer science teachers to teach Advanced Placement Computer Science (APCS) courses.

The most notable aspect of these languages is the communities built around them. Millions of Scratch projects have been shared on the forums maintained by the Scratch Foundation. A significant number of these projects are ones that have been remixed, incorporating code from another project.

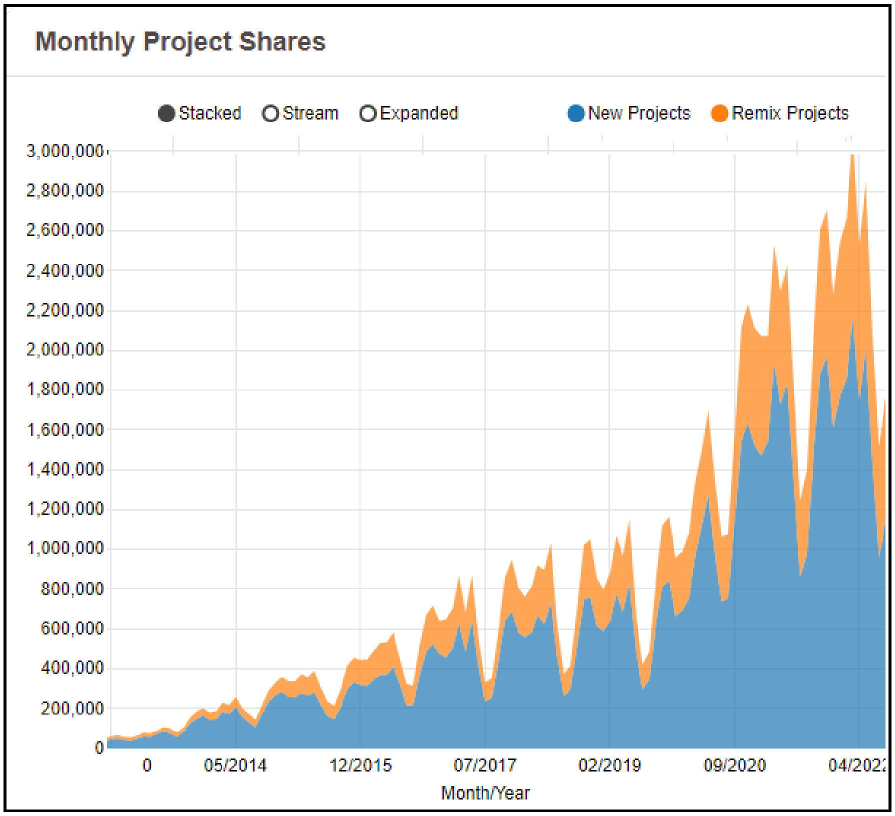

Figure 1. Number of New and Remixed Scratch Projects (https://scratch.mit.edu/statistics)

Students on the Scratch forum invent through emulation. They identify a project that they admire and emulate it through creation of their own version. The new invention is then shared back to the community. During this process, there is extensive dialog in which techniques and methods are discussed, often with support from the originator of the initial invention.

The initial template for ecosystem built around physical objects rather than software might emulate some of the successful characteristics of the Scratch ecosystem:

1. An initial repository of objects should provide models for students to emulate.
2. There should be support for students who attempt to use makerspaces to reconstruct and improve upon existing objects in the repository.
3. There should be provision for exemplary student-created inventions that improve upon the original to be reposted to the repository.

Physical designs are time consuming to evaluate. To thoroughly test a design, it is necessary to actually fabricate the components and build it. That could potentially be even more time consuming than evaluating code or an academic paper.

One strategy for mitigating this issue could consist of creation of a collection of CAD model repositories. An open repository could enable students to submit models even in preliminary form. This could provide a forum to enable experienced users to provide advice and assistance. Designs that are mature could be migrated to a separate repository of fully-reviewed designs. Students who successfully make the transition would essentially follow the same path as the nineteenth century apprentice who successfully made the transition to journeyman status after submission of a fully-reviewed work.