

CDI-Type II: Collaborative Research: Preparing the Next Generation of Computational Thinkers: Transforming Learning and Education Through Cooperation in Decentralized Networks

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1. Introduction

During the past two decades, there has been a growing interest and sophistication in the study of cooperation. Research in a diverse set of disciplines, ranging from economics to psychology to organizational sociology to animal behavior to neuroscience, has contributed to a deeper understanding of the nature and possibilities of pro-social, cooperative behaviors. At the same time, new communications technologies and infrastructures have laid the foundation for new forms and opportunities for cooperation, most notably in large-scale, decentralized networks. Examples appear across many different domains, including online peer-production practices for the development of collaborative websites such as Wikipedia, cooperative supply chains in business organizations, and coordination of large-scale scientific and engineering research (Benkler, 2006).

Compared to the dramatic transformations in many parts of society, the goals and practices of the education system have changed only incrementally. Schools and other educational institutions have not taken full advantage of the new opportunities made possible by large-scale, decentralized networks and new research on cooperation (Collins & Halverson, 2009). And they are not adequately preparing students for life in a society where cooperative activity in decentralized networks plays an ever more important role in solving complex real-world problems.

Outside of formal educational settings, many of today's children and teens spend a great deal of time interacting with digital media and online communities (Ito et al., 2009). These interactions provide a base level of familiarity and literacy with cooperation in decentralized networks – but only a base level. Even as youth share and remix online, they often do it with a cut-and-paste mentality with little regard for developing deeper understanding. And few of today's youth have experience in organizing cooperative activities online (such as crowd-sourcing) or in developing their own computational creations (such as animations or simulations). These capacities are important components of computational thinking – and essential for becoming full and productive participants in tomorrow's society (National Research Council, 2010).

In this project, we propose to study and explore how cooperation in decentralized networks can serve as the basis for fundamental changes in learning and education – transforming what we learn, how we learn, where we learn, and who we learn with. The project blends theory, research, and practice. We will study the nature and patterns of cooperation in decentralized learning environments, establish design principles to guide the development of systems that foster cooperative attitudes and behaviors, and develop strategies and activities to cultivate the computational-thinking capacities that are critical for productive cooperation and problem-solving in decentralized networks.

As an experimental testbed for our research studies, we will use the NSF-funded Scratch learning network, where youth program and share their own interactive stories, games, animations, and simulations, using a specially-designed graphical programming language. We will examine how design changes in the Scratch software and website influence cooperation and learning patterns in the Scratch network, a vibrant online community with more than 400,000 registered members sharing, discussing, and remixing one another's projects. We will also conduct field experiments where we can test specific

hypotheses in controlled settings with subsets of the Scratch network. We expect that these studies will lead to broadly applicable results that contribute to the design and understanding of decentralized learning networks and virtual organizations.

Our team brings together expertise from many diverse disciplines, including computer science, psychology, child development, education, economics, and legal studies. It includes international leaders in the study and cultivation of computational thinking, the analysis and support of cooperation in decentralized networks, and the design of computational systems for creative and cooperative learning. In their own research, each PI has a history of synthesizing ideas from across disciplinary boundaries to achieve results that would not have been possible in any single discipline.

Our proposal is most strongly aligned with the *Virtual Organizations* theme of the CDI program. We focus especially on virtual organizations that provide opportunities for large numbers of participants to cooperate with one another on design and development activities. These types of virtual organizations serve as motivating and meaningful contexts for learning not only new cooperation strategies but also new computational-thinking skills, and thus provide a particularly effective framework for meeting the NSF CDI goals of “enhancing innovation and broadening participation in research and in STEM education.” By studying how young people co-create, share, and remix computational artifacts in the Scratch learning network (and iteratively modifying the network design based on the results), we will develop new insights into the design of virtual organizations to support cooperation, computational thinking, and learning. In the process, we expect to make important contributions to a range of disciplines, including education, computer science, behavioral economics, and organization science.

Intellectual Merit. This research will contribute to deeper understanding of the nature and opportunities for cooperation in large-scale decentralized networks – and design strategies for supporting cooperation in these networks. Using a novel combination of experimental and ethnographic methods, the research will provide insights into how young people cooperate in virtual organizations, their attitudes and motivations related to cooperation, and their development of computational-thinking skills and capacities necessary for productive cooperation and creative learning. We expect our findings will contribute to the design and understanding of more effective virtual organizations, particularly in the areas of learning, education, and cooperative creation.

Broader Impact. This project will leverage ideas from decentralized networks to transform approaches to learning and education. Using the Scratch learning network as an experimental testbed, it will enhance learning experiences for millions of young people, broaden participation in computing by using cooperation as a motivating context for learning, and provide opportunities for learners of different ages, gender, expertise, and backgrounds to cooperate with one another. We will disseminate research results via multiple channels across a wide range of disciplines and audiences, including researchers, practitioners, and the general public.

2. Conceptual Frameworks

2.1 Models and Levers for Cooperation

Traditional models of human behavior, based on the assumption of self-interested and selfishly-optimizing individuals, have a difficult time explaining the recent success of large-scale cooperative projects such as the development of Linux and Wikipedia. In such “peer production” projects, thousands of people around the world work together without face-to-face meetings, traditional hierarchical organization, or financial carrots and sticks.

The success of such projects has sparked interest in developing better scientific understanding of the ultimate and proximate causes of cooperation. Experiments in the fields of economics, anthropology, and

social psychology have begun to yield insights into why, when, and under what conditions people are likely to cooperate – and provide clues as to how systems might be designed to encourage and foster cooperative behavior.

Based on this research, PI Benkler has proposed a set of “design levers” that could influence the dynamics of cooperation within a system (Benkler, 2010). For example, Benkler points to “transparency” as an important design lever, based on research demonstrating that systems enabling participants to see what others are doing are more likely to foster cooperative activity. “Humanization” is another design lever: the introduction of elements that humanize other players in experimental settings significantly improves cooperation, even without any communication or any possibility of mutual long-term identification or reciprocity. Other design levers include: communication, solidarity, fairness, norms, trust, punishment/reward, leadership, cost, and the crowding-out effect. While most previous research on designing-for-cooperation focused on small-group collaboration, Benkler’s design levers are aimed specifically at cooperation in large-scale, decentralized networks.

In the proposed project, we will use Benkler’s design levers to guide our choices for new features and interventions in our testbed organization (the Scratch learning network) – and, in the process, refine and further elaborate the design-lever framework.

2.2 Cooperation in Learning and Education

For several decades now, educational researchers have focused a great deal of attention on the study and support of collaboration in the classroom. Cognitive and social-cultural theories alike emphasize the importance of cooperation, though for different reasons. Cognitive researchers tend to focus on how conflict and discussion can help individual learners to articulate their understanding, while socio-cultural researchers tend to stress the importance of social contexts for situating learners’ interactions in authentic practices (Sfard, 1998). Thousands of research studies have investigated causes for success and failures of group work, advantages and disadvantages of different group arrangements, and other aspects of cooperation (Webb & Palincsar, 1996). Numerous curricular designs have promoted cooperative arrangements, such as reciprocal teaching (A. L. Brown & Palincsar, 1984), jigsaw learning (Aronson, Blaney, Stephan, Sikes, & Snapp, 1978), cognitive apprenticeship (J. S. Brown, Collins, & Duguid, 1989), and communities of learners (A. L. Brown & Campione, 1994).

Some of these ideas have found their way into widespread classroom practice; indeed, cooperative learning is viewed as an all-too-rare case in which educational research has had a deep influence on educational practice (D. W. Johnson & R. T. Johnson, 2009). But, for the most part, educators and educational researchers have focused on cooperation involving only small groups of students (typically two-to-four per group). There are few examples that consider the learning of cooperation within the context of a larger group – and, even in those cases, it is often a teacher or adult who directs interactions among all members and assumes the leadership that students otherwise bring to bear in small-group collaborations.

Recent observations of social networking and gaming communities suggest that cooperation among hundreds, if not thousands, of members can be productive for learning (Gee, 2003; Greenhow, Robelia, & Hughes, 2009; Ito et al., 2009). The skills and knowledge needed to perform in such contexts are very different from what is required of learners in small collaborative groups not only because the product itself changes but also because no member alone can assume the full responsibility of creating the project.

Our proposed research is aimed at developing and studying opportunities for learning and cooperation in large-scale decentralized networks involving thousands of participants. At the same time, we are interested in rethinking how cooperation in learning environments can be re-structured to leverage the

availability of more knowledgeable peers in remote locations via large-scale decentralized networks. This is not simply a matter of involving a larger number of participants but also rethinking the nature of activities, the roles that participants assume, and the performances or artifacts that results from the cooperative efforts.

2.3 Computational Thinking

In the past few years, there has been a growing recognition of the importance of computational thinking – described by Jeannette Wing, who introduced the term in 2006, as “a way of solving problems, designing systems, and understanding human behavior that draws on concepts fundamental to computer science” (p. 33). Computational thinking is useful for understanding and solving problems in a wide range of contexts, including many science, engineering, and social-science fields, not only in the field of computer science (Guzdial, 2008; Wing, 2008). A recent report from the National Research Council (2010), based on a workshop at which PIs Kafai and Resnick were active participants, argues that “computational thinking is a fundamental analytical skill that everyone, not just computer scientists, can use” (p. vii).

Learning to program in languages like Scratch provides a strong foundation for computational thinking, helping people learn important computational concepts (such as abstraction and synchronization) as well as problem-solving and design strategies (such as debugging and iterative design) that carry over to non-programming domains. But frameworks for computational thinking need to continue to evolve as computation itself evolves. As new networked technologies transform the ways we work and learn, we need to expand our notions of computational thinking to include ideas from social, cooperative, and networked computing.

Cooperative activities can serve as an important motivation for people to become engaged in computational thinking, since social activities can attract people who would not otherwise be interested in computational ideas. Just as fascination with games can serve as an entry point for computational thinking (as youth become engaged in programming their own games), so too can cooperative computing serve as an entry point for others to become engaged in computational thinking.

2.4 Broadening Participation

There has been a well-documented drop in the number of students taking computer-science courses, and a very low level of participation by women and members of minority groups (Margolis & Fischer, 2002; Margolis, 2008; Klawe, Whitney, & Simard, 2009). Although participation in the *use* of computers has improved across the population, only a narrow slice of the population is actively involved in designing and creating with computation. Activities involving the design and testing of applications (such as games) have proven successful in improving participation of underrepresented groups in programming and computer science (DiSalvo et al., 2009; Kafai, Heeter, Denner, & Sun, 2008). In addition, the growing presence of women in social networking sites suggests that online communities could be harnessed more successfully for increasing their participation as well (AAUW, 2004; Hargittai & Shafer, 2006).

There is preliminary evidence that the Scratch learning network can help attract a broader range of students to computer science. For example, the introduction of Scratch to the introductory computer-science course at Harvard led to a sharp reduction in the number of students dropping the course or receiving a failing grade, and a marked increase in the retention of female students (Malan & Leitner, 2007). There have been similar results in pre-college courses. The National Center for Women & Information Technology (NCWIT, 2008), in a case study about Scratch, calls Scratch a “promising practice” for increasing gender diversity in IT. The NCWIT study notes that Scratch “uses hands-on, active learning; it is visually appealing; it allows users to express their own creativity and to build on their own experiences; it gives immediate, understandable feedback; and it allows users to avoid syntax errors without focusing on minutiae, freeing them to focus on processes and concepts.”

Our proposed project aims to build on these initial successes with further steps to broaden participation in computer science – specifically, by putting more emphasis on concepts and activities related to cooperation and computational thinking. Just as the multimedia features of the current Scratch environment have resonated with youth culture and attracted many young people who would not otherwise be interested in computer science, we expect that the addition of new cooperation opportunities in Scratch will play a similar role in attracting a broader and more diverse collection of students to computer science. In addition, the new cooperation features in Scratch will extend opportunities for learners to work together in heterogeneous groupings, bringing together people of different ages, gender, expertise, and geographies.

3. Research Goals

- Identify design principles for fostering and cultivating cooperation in decentralized networks
- Advance understanding of how to help young people develop as computational thinkers through active participation in cooperative activities in virtual organizations
- Contribute to the educational infrastructure and knowledge base for engaging a broader and more diverse population of students in computer science
- Develop new models of learning and education that leverage the affordances of decentralized networks

4. Experimental Testbed: Scratch Learning Network

We will situate our study of virtual organizations in the context of one particular virtual organization: the Scratch learning network. PIs Resnick and Kafai, along with co-PIs Rusk and Maloney, led the development of this learning network as part of a four-year grant from the National Science Foundation (ITR-0325828). Within the network, young people create and share interactive stories, games, animations, and simulations, using the Scratch graphical programming language. In the process, participants learn core computational concepts, while also learning important strategies for designing, problem solving, and collaborating (Maloney, Peppler, Kafai, Resnick, & Rusk, 2008).

The Scratch learning network was designed specifically to support the development of computational-thinking skills. Since its public launch in 2007, the Scratch learning network has attracted more than 400,000 registered members sharing, discussing, and remixing one another's projects. Each day, members (mostly ages 8 to 15) upload roughly 1500 new Scratch projects to the website – on average, a new project almost every minute. Overall, members have contributed nearly 1 million projects to the network. Scratch is used in both informal learning settings (homes, libraries, museums, and community centers) and also school classrooms (in elementary schools, secondary schools, and even some universities, including Harvard and Berkeley). Scratch has also attracted attention in the computer-science research community: it was recently featured on the cover of *Communications of the ACM* (Resnick et al., 2009).

The Scratch learning network has special affordances that make it ideally suited for the study of cooperation and computational thinking in large-scale decentralized networks. While other virtual communities such as RiverCity (Clarke, Dede, Ketelhut, & Nelson, 2006) or Quest Atlantis (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005) have been created to showcase the possibilities for youth learning networks, they offer more scripted activities organized around curriculum topics and they reach a narrower age demographic. Large-scale tween virtual worlds such as Whyville (Kafai, 2010) attract a wider age range and offer a broader range of activities, but they do not provide the same level of cooperation or engagement with computational thinking. The Scratch learning network, with its emphasis on design-based activities and self-organized cooperation, serves as an ideal testbed for studying the type of cooperation found in commons-based peer-production environments such as Wikipedia and Linux

(and, more generally, the Free and Open Source software community), but with the added benefit of bridging into youth communities.

Unlike many researchers who study decentralized networks and virtual organizations, our team (as the creators of the Scratch learning network) is in a special position of being able to add and modify features, and collect specific data about interactions, as we study the network. As we extend the Scratch learning network in this proposed project, we have the dual goals of enhancing the cooperation opportunities for participants while also enhancing our ability to study cooperation within the network.

To implement and conduct the proposed field experiments, design interventions, and observational studies, we plan to develop a new infrastructure for the Scratch learning network, making it possible for people to author Scratch programs directly on the web (rather than in a separate, stand-alone application). We believe that this new generation of Scratch, which we call Scratch 2.0, will greatly enhance opportunities for cooperation among participants, since they can seamlessly author, share, and remix projects without constant downloading and uploading.

5. Cooperation and Computational Thinking

Networked information technologies are radically changing the ways people engage in the creation of knowledge and culture – in particular, making possible new forms of cooperation involving large numbers of people in decentralized networks. To participate fully in these new cooperative networks, people need to develop new computational-thinking skills. At the same time, cooperative activities can serve as a motivating context for learning computational-thinking skills. In this section, we discuss five forms of cooperation facilitated by decentralized networks: sharing, co-creating, remixing, crowd-sourcing, and mining. In each case, we discuss some of the computational-thinking skills associated with that form of cooperation.

5.1 Sharing: connecting with an audience

Many online media platforms and social network sites, such as Flickr and Facebook, allow people to share media with the push of a button. This is a first step to participation in decentralized networks, but only a first step. People also need to develop a sense of audience, an understanding of what other people are interested in and what they can use. Many people have difficulty knowing how to share their work in a way that (1) reaches the intended audience, (2) conveys the desired message or serves the desired purpose, and (3) maps to the norms and culture of the community it is shared. In open-source networks, people need to learn to put their creations in a form that others can integrate into their own work. This requires an understanding of computational concepts such as modularity. One of our planned extensions to the Scratch learning network is to enable sharing at multiple granularities, enabling people to share not only full projects but also scripts, sprites/characters, images, and sounds. By offering multiple granularities of sharing, we hope to help young people learn about modularity, while also learning to share more effectively and productively.

5.2 Co-creating: working in networked groups

Networked technologies offer new ways for people to work together on collective projects, whether co-authoring a research paper using Google Docs, contributing to an article on Wikipedia, or working with a team of programmers to develop a large software system. But the skills required for these types of co-creation activities receive little attention in traditional computer-science curricula. At Microsoft, Begel and Simon (2008) found that first-year employees feel they have learned programming and debugging well in college, but that “their communication, collaboration, and orientation skills are not as well addressed” (p. 230). In the Scratch learning network, groups of young people, often from different parts of the world, have self-organized into “companies” to work together on programming projects that are

more sophisticated than any of the group members could have created on their own (C. R. Aragon, Poon, Monroy-Hernández, & D. Aragon, 2009). A 13-year-old girl who co-founded a Scratch game-design studio described her experiences like this: “What is fun about Scratch and about organizing a company to write games together is that I’ve made a lot of friends and learned lots of new things. I’ve learned a lot about different kinds of programming by looking at other games with interesting effects, downloading them, and looking at and modifying the scripts and sprites. Another thing I’ve learned is how to help keep a group of people motivated and working together.” As we extend the Scratch learning network, we plan to provide tools for group decision-making and version control – in part to help young people develop more advanced group projects, but also to help them develop more sophisticated ways of thinking about co-creation activities.

5.3 Remixing: building on the work of others

Remixing has taken such a widespread and central role in contemporary Internet culture that it has become, in the words of Manovich (2005), “practically a built-in feature of digital networked media universe.” In peer production and cumulative innovation, users are primarily engaged in remixing each others’ work and ideas. The Scratch learning network encourages remixing with its licensing policy: all projects are shared under the Creative Commons (CC) Attribution Share-Alike License. Members can download any project, view and modify its graphics and code, and upload modified versions back to the website. We emphasize the importance and legitimacy of remixing in the Scratch culture by highlighting the “top remixed projects” on the front page of the Scratch website. Looking ahead, we plan to provide visualizations of “remix trees,” showing the ancestors and descendents of each project, so that network participants can gain a better understanding of their role within the community, while also gaining a better understanding of computational concepts related to network dynamics and topology.

5.4 Crowd-sourcing: leveraging the networked audience

Organizations are increasingly making use of the collective inputs, or crowd-sourcing, of large numbers of people to rate products (e.g., on Amazon.com) or analyze images (e.g., on citizen science projects like Galaxy Zoo). Young people engage in a simplified version of this practice when they post on forums to ask others for help. In the Scratch learning network, one member created a project for testing people’s reaction times and then leveraged the network to collect data from people all over the world (and analyze for correlations between reaction times and level of athletic activity). Another Scratch network member created a series of animated stories and then asked other members to design and submit characters to appear in the stories (Resnick et al., 2009). As we extend the Scratch network, we plan to support crowd-sourcing activities in a variety of ways, include new match-making mechanisms to connect people seeking contributions with those interested in making contributions. In the process, we hope to help young people learn to think about distributed systems in new ways – for example, recognizing that the small efforts of many can sometimes be more effective than the large efforts of few.

5.5 Mining: making sense of the networked commons

People need tools and strategies for making sense of the proliferation of information available online. For scientists, data-mining technologies have opened up new areas of research, enabling scientists to search for patterns in climate databases, genetics databases, and other online repositories. Currently, young people do not have accessible tools to mine online data effectively, nor do they have the computational-thinking competencies needed for data-mining. As we expand the Scratch learning network, we will add tools to enable participants to mine datasets and media resources using graphical programming. In particular, we will provide ways for them to mine data in external databases related to their interests, ranging from sports statistics and media repositories to environmental databases. These new tools will also enable them to explore and visualize activity patterns within social-media sites and online communities, including the Scratch learning network itself. Through this process, we hope to help young

people develop capacities for understanding the dynamics of cooperative networks in which they are participating and contributing.

6. Research Questions

In studying ways to support and cultivate cooperation, computational thinking, and learning in decentralized networks, we are guided by the following research questions:

6.1 Attitudes and Motivation

What motivates people to want to cooperate?

How do people become engaged in different forms of cooperation?

Do different forms of cooperation attract different types of people?

What design features support people in building upon their intrinsic motivation?

How do credit and acknowledgement influence attitudes towards cooperation?

6.2 Capacities and Skills

What computational-thinking competencies are needed to engage in different forms of cooperation?

What are common trajectories for learning different cooperation skills and computational-thinking skills?

What design features support deeper conceptual understanding and reflection in cooperation activities?

6.3 Learning Networks

How can decentralized networks support cooperation among people of different ages and backgrounds?

How do ideas spread within decentralized networks of learners?

How can learners use decentralized networks to move fluidly between formal and informal learning?

7. Research Studies

To address our research questions, we will employ three distinct but complementary approaches: (1) *observational studies* of cooperation and computational thinking in the Scratch online community, (2) *design interventions* to explore how patterns of cooperation and learning are influenced by particular changes in the Scratch software and community policies, and (3) *field experiments* to test out specific hypotheses in controlled contexts.

Although our research studies are situated within the Scratch learning network, they are intended to advance understanding of ways to support cooperation, computational thinking, and learning in all types of virtual organizations.

7.1 Observational Studies

Throughout the course of the grant, we will observe activities and interactions among members of the Scratch community. We will track activity patterns of particular community members and selected sub-communities, as well as analyzing overall community trends. In these studies, we will employ both qualitative and quantitative approaches, including: (1) ethnographic techniques, including interviews with members of the Scratch network, (2) analysis of projects created by Scratch members, (3) network analysis of relationships within the Scratch network, and (4) analysis of data from extensive logfiles, which will capture all interactions within the community. These logfiles will provide us with an unprecedented level of detail in analyzing how Scratch members adopt cooperation practices and respond to changes in system design.

Here are examples of the types of observational studies we plan to conduct:

- *Learning trajectories of individual community members.* Different people go through different pathways as they develop skills and capacities for cooperation and computational thinking. For example, we observed one member of the current Scratch network who created hundreds of projects with no programming scripts, then suddenly started creating projects with a large number of scripts, while other members go through a more incremental progression. We will analyze and classify different trajectories, and look for factors underlying the differences. Are learning trajectories different for members of different ages or different backgrounds? Do people typically become engaged in the five forms of cooperation in a similar order (e.g., remixing before crowd-sourcing), or are there significant differences? How do trajectories for engaging in cooperative activities relate to the trajectories for learning computational-thinking skills?
- *Comparisons among sub-communities.* We will use cluster analysis of the logfiles to identify sub-communities of Scratch members based on factors such as themes of projects, commonalities of interests, and styles of social interaction. For example, in the current Scratch network, we have identified several distinct sub-communities focused on creating different types of projects, one focusing on games, another on animations, yet another on simulations. After identifying sub-communities, we will examine similarities and differences. Are there gender differences? Age differences? Do members of different sub-communities go through different learning trajectories? If a certain sub-community includes members with a broad distribution of ages, does that affect the styles of interaction and spread of knowledge within the sub-community? If certain computational-thinking skills are less common in a particular sub-community, what are the underlying causes and what types of interventions might support the development of those skills within that group?
- *Connected ethnographies across virtual and physical communities.* While our observational studies will focus primarily on online activity, we will conduct some ethnographic studies looking at the activities of Scratch members in physical contexts as well (schools, libraries, community centers). Studies examining the connections between virtual and physical activities have proven to be very useful in virtual worlds research (see Fields & Kafai, 2010) and can assist us in understanding the diffusion of ideas and practices between informal and formal learning settings. We are interested to analyze relations between physical and virtual world activity. In some cases, young people might first become engaged with Scratch online at home and then introduce it to their teachers at school. In other cases, young people might have first learned about Scratch at school, and then introduced it to their siblings at home. Do Scratch members work on different types of projects in different settings? Do they develop different types of computational-thinking skills in different settings? Are their cooperation patterns different?

7.2 Design Interventions

Over the course of this grant, we will conduct *design interventions* to examine how our design choices influence activities and attitudes in the Scratch learning network. In these interventions, we will release new features to the Scratch network and then study (both qualitatively and quantitatively) how the changes influence cooperation, learning, and engagement with computational thinking.

In deciding on new features to release to the community, we will be guided by Benkler's design levers, such as transparency, fairness, norms, cost, and trust. For example, guided by the design lever of "transparency," we will provide participants in the Scratch learning network with more information about what other participants are doing, along with the histories and reputations of other participants. Our expectation is that people will engage in more and deeper cooperative interactions if they have a better understanding of others in the network.

Here are examples of the types of design interventions that we plan to conduct:

- *Sharing at different levels of granularity.* Currently, participants in the Scratch learning network can share full projects with one another, but there is no easy way to share parts of projects, such as sprites/characters, programming scripts, images, or sounds. As a design intervention, we will add the ability to share at multiple levels of granularity, and then study changes in cooperation patterns and engagement with computational-thinking concepts. For example, we expect that more participants will start thinking about the concept of “modularity” as they consider what types of shared objects will be easiest for others to use and build upon. We expect that people, beyond simply remixing more, will start thinking about what makes something more remixable. Also, we expect that people might start looking at one another’s projects differently, viewing a project not only as a whole but also as a collection of component parts, and thinking about how they might appropriate different parts of the project for use in their own projects.
- *Visualizations of cooperative activity.* We will add various types of visualizations to help participants in the Scratch learning network understand the nature of cooperative activity in the network and how cooperative activity changes over time. Some visualizations will show the ways in which different people contributed to large-scale cooperative efforts. For example, we will implement “remix trees” that show how a project relates to all of its “ancestors” and “descendents.” We expect that these visualizations will help participants develop better understandings of how their actions can have many indirect (and unintended) consequences, as other participants in the network build upon their work in unexpected ways. The remix visualizations could also help participants adopt a meta-level view of the network, thinking not only in terms of their own projects and actions, but also of how ideas spread through the network and how certain ideas might be viewed as belonging to the network, not any individual within it. In this way, the visualizations can help participants begin to think about networks in terms of topology and dynamics, not just collections of people and projects.
- *Making it easier to see and edit a project’s code.* When people browse projects on the current Scratch network, they must go through a rather elaborate process of downloading and uploading if they want to view, edit, and remix the code of a project. Our proposed enhancements to the network will greatly simplify this process. We expect that this will lead to a significant increase in the number of remixed projects. But will it lead to more complex or sophisticated projects? Will it lead to different styles of cooperation? And will it lead to better understanding of computational-thinking concepts? With code more easily viewable, there are certainly opportunities for better understanding of concepts related to programming. But will participants adopt a cut-and-paste mentality, making use of scripts from other projects without really understanding how they work? Based on these studies, we will iterate the design to ensure that it fosters understanding of core computational-thinking concepts.

7.3 Field Experiments

Investigations of certain research questions require greater structure and control than is possible in design interventions with the entire Scratch learning network. Traditionally, there have been two basic classes of field experiment approaches. One approach is to take controlled, structured experiments into the field (Henrich et al., 2004). This has the benefit of isolating motivational responses in cultural and ethnographically-known subpopulations, and therefore enriching our understanding of cooperation generally. A second approach is to interject controlled interventions into the normal flow of activity of a randomly selected portion of the population (Coleman, 1996). We plan to build affordances that would allow us to conduct both types of field experiments. By constructing special-purpose projects, we plan to recruit participants to lab-like experimental settings, and connect the results to the rich data we already have about the participants and their practices in the field. We also plan to develop alternative versions of

some new features and release them into the normal flow of work of subpopulations within the Scratch community, and observe and measure responses to design interventions in these “natural” settings.

In some cases, our experiments will involve variations of social-dilemma games traditionally used in behavioral-economics studies. We will put special effort into modifying these activities so that they are age-appropriate for youth participants in the Scratch network and, just as importantly, consistent with the learning principles and values underlying the Scratch network.

Here are examples of the types of field experiments that we plan to conduct:

- *How do community norms influence social dynamics?* We plan to conduct a field experiment to study whether the content and tone of notification messages influence the social dynamics around remixing and collaborating. When a Scratch member’s project is remixed, the member will be randomly assigned to receive one of six messages (or, for the control group, no message at all). Members in one category will receive a “grateful” notification saying “Congratulations! Your project has been remixed. Sharing your work is a generous thing to do and a great thing for the Scratch community.” Members in another category will receive a “neutral” notification saying simply “Your project was remixed.” Members in other categories will receive messages focusing on reputation (“People respect your work and get inspired by it!”) or fairness (“The community is about sharing and it is fair to let others use your projects”). We will investigate whether the difference in notification messages influences people’s attitudes and behaviors related to remixing and collaborating – for example, do people who receive the more positive notification messages write more positive comments on remixed projects? We will also study the “plasticity of virtue,” investigating the persistence of any behavioral change.
- *How do people’s differences influence cooperation?* There is some evidence that experimental subjects in different countries respond differently to certain aspects of behavioral experiments (Hermann et al., 2008). There are conceptual arguments as to why practice and culture should in principle influence proclivity to cooperate, or development of the virtues of cooperativeness, over time (Nissenbaum & Benkler, 2006). We plan to develop age-appropriate versions of public goods games, trust games, and prisoners’ dilemma games, segregate them as special features of projects so that they do not mix with the general reputational and interaction models of the Scratch community as a whole, and study the behavior of participants in these settings as a function of differences such as country of origin, age, and gender – and as a function of the history of an individual’s cooperative practices in the Scratch community itself.
- *What forms of communication support and encourage cooperation?* To explore the design lever of “communication,” we will make available new forms of communication when participants in the Scratch network remix one another’s projects. Remixers will have the option to send a private message (from a list of provided options) to the original author of the project, expressing appreciation or admiration for the work. We will give this option to a subset of Scratch participants, and follow the pairs (remixers and remixed) over the course of several months, to study how different communication options influence cooperation patterns.

8. Timeline

Year 1: Baseline Studies; Pilot Field Experiments; Development of Experimental Testbed <i>September 2010 – August 2011</i>
<ul style="list-style-type: none">- Collect baseline data- Analyze existing cooperative patterns and practices- Identify initial set of design interventions- Launch internal project wiki and public blog- Convene in-person Advisory Board meeting for feedback on conceptual approach and plan- Pilot first wave of field experiments- Develop Scratch 2.0 experimental testbed infrastructure
Year 2: Studies of Attitudes and Motivation; Revisions to Testbed <i>September 2011 – August 2012</i>
<ul style="list-style-type: none">- Pilot and refine Scratch 2.0 infrastructure changes- Run second wave of field experiments focused on attitudes towards cooperation- Implement and study design interventions focused on motivation for cooperation and learning (including visualizations of cooperative activity; modular sharing of objects)- Ongoing postings of initial ideas and approaches; online consultations with advisory board
Year 3: Studies of Capacities and Skills; Initial Analysis of Findings <i>September 2012 – August 2013</i>
<ul style="list-style-type: none">- Conduct observational studies focused on cooperation and computational thinking (modularity and sharing; initial analysis of learning trajectories)- Run third wave of field experiments (including forms of communication that support cooperation)- Convene in-person Advisory Board meeting to discuss preliminary findings and potential applications to other network initiatives- Post preliminary findings
Year 4: Analysis of Learning Network; Dissemination <i>September 2013 – August 2014</i>
<ul style="list-style-type: none">- Refinement of analysis- Presentations at conferences across disciplines (learning sciences; science education; computer science; educational computing, organization science; psychology)- Publishing in journals and online forums- Followup networking with Advisory Board members and other leaders of educational and network initiatives

9. Project Team and Advisory Board

The multidisciplinary team for this project includes leaders in the fields of educational-software design, human-computer interaction, educational research, and organization science, with extensive and unique expertise in the design and study of large-scale decentralized networks.

Mitchel Resnick, Professor of Learning Research at the MIT Media Lab, specializes in the development and study of new technologies that expand the range of what young people can design, create, and learn. His research group developed (with NSF support) the “programmable bricks” that were the basis for the LEGO MindStorms robotics kits, and the Scratch software and website that are the basis for this proposed project. He co-founded the Computer Clubhouse network of after-school learning centers and the NSF-

funded PIE Network of museums. Resnick earned a BS in physics from Princeton in 1978, and a PhD in computer science from MIT in 1992. He was awarded an NSF Young Investigator Award in 1993.

Yasmin Kafai, Professor of Learning Sciences at the Graduate School of Education at the University of Pennsylvania, focuses on youth's learning of programming as designers of interactive games, simulations, and media arts in schools and afterschool programs. She has pioneered research on games and learning since the early 90's and more recently on tween participation in virtual worlds. She has also been influential in several national policy efforts, including contributing to the report *Tech-Savvy: Educating Girls in the Computer Age* (AAUW, 2000) and co-authoring the upcoming National Educational Technology Plan for the US Department of Education. Currently, she is a member of the steering committee for the National Academies' workshop series on "Computational Thinking for Everyone." Kafai is a recipient of an Early Career Award from the National Science Foundation, a postdoctoral fellowship from the National Academy of Education, and the Rosenfield Prize for Community Partnerships.

Yochai Benkler is Berkman Professor of Entrepreneurial Legal Studies at Harvard University and faculty co-director of the Berkman Center for Internet and Society. Benkler is a leading theorist of collaboration and cooperation in digital networks, with a focus on how peer production and sharing can have transformative effects on the economy and society. His book *The Wealth of Networks: How Social Production Transforms Markets and Freedom* (2006) received best book awards for 2006 from the American Political Science Association and the American Sociological Association. His current work, funded by the Ford, MacArthur, and Kauffman Foundations, is focused on understanding the micro-foundations of human cooperation, emphasizing the development of online platforms for conducting both experimental and observational research into questions of human cooperative motivation and practice. He is a member of the advisory board of the MacArthur Foundation's Digital Media and Learning Initiative.

John Maloney, Research Specialist at the MIT Media Lab, has been the lead developer and programmer for the Scratch project initiative since the start of the project in early 2003. Prior to joining the MIT Media Lab, Maloney worked for Alan Kay at Apple Computer and Walt Disney Imagineering. Maloney earned BS and MS degrees in computer science from MIT in 1981 and a PhD in computer science from the University of Washington in 1991. In the proposed project, Maloney will serve as co-PI, leading the development of the Scratch 2.0 experimental testbed.

Natalie Rusk, Research Specialist at the MIT Media Lab, researches and develops technology-based programs that build on young people's interests. She is a core member of the Scratch design team, and leads the development of educational materials for the Scratch network. She co-founded the Computer Clubhouse after-school program and established the Learning Technologies Center at the Science Museum of Minnesota. She served as Network Director of the NSF-funded PIE Network, a collaboration with six museums to develop a new generation of hands-on science activities. She served on the National Academies' Oversight Group on Learning Science in Informal Environments. She has a Master's degree in Interactive Technology from Harvard Graduate School of Education, and is pursuing her PhD in Child Development at Tufts University. As co-PI in the proposed project, Rusk will collaborate on the research studies, focusing on the motivational and educational aspects of the interventions.

We have a team of experienced graduate students in computer science, education, and economics who will assist us with collecting, processing, and analyzing the large quantitative and qualitative datasets generated in the study.

Andrés Monroy-Hernández, PhD student and Research Assistant at the MIT Media Lab, leads the development of the Scratch website and online community. His research focuses on the design and analysis of social platforms to support creative and collaborative learning. He holds a bachelors degree in

Computer Science from Tec de Monterrey in México and a Master's degree from the MIT Media Lab. Before coming to MIT, he worked for four years as a software engineer on library-automation projects. In the proposed project, Monroy-Hernández will focus especially on developing social-media applications of Scratch 2.0 and studying how design decisions on Scratch 2.0 influence cooperation within the online community.

Michael Moore, PhD student and graduate researcher in the Penn Graduate School of Education, has studied how fan communities participate in public discourse through digital media production. In particular, he has looked at how video game communities respond to marketing messages through textual poaching and remixing. His current research focuses on the relationship between creative production in Do-It-Yourself (DIY) online communities and economic transactions and perceptions in tween virtual worlds. Moore holds a Master's degree in Communication Studies from Georgetown University and an undergraduate degree in economics from Wharton.

We have assembled an **Advisory Board** of internationally recognized experts from multiple disciplines. The Advisory Board will meet in-person twice: in Year One to provide feedback on the conceptual approach and project plans, and then in Year Three to discuss preliminary findings and potential applications to other virtual organizations. Board members will also be consulted periodically for advice on design interventions, field experiments, and interpretation of results. **Iris Bohnet**, a behavioral economist and professor at Harvard University's Kennedy School of Government, specializes in research to improve decision-making in organizations and society. **Kevin Clark**, associate professor at George Mason and director of the Center for Digital Media Innovation and Diversity, researches the development of online learning environments, the role of gaming and media in learning, and the use of technology in broadening STEM participation among underrepresented groups. **Gerhard Fischer**, professor and director of the Center for Lifelong Learning and Design at University of Colorado at Boulder, researches social computing, creativity, and design in distributed communities. **Andrea Forte**, assistant professor at Drexel University's College of Information Sciences and Technology, studies social computing and learning sciences, with a focus on information production and creation among youth. **Mizuko (Mimi) Ito** is a senior research scientist at UC Irvine and the lead author of a multi-site ethnographic study of youth communities and participation in social networking sites. **Thomas Malone**, professor at the MIT Sloan School of Management and director of the MIT Center for Collective Intelligence, studies how new organizations can be designed to take advantage of the possibilities provided by information technology.

10. Results from Prior and Current NSF Support

The proposed collaborative research project builds on the results of several successful NSF-funded projects conducted by PIs Mitchel Resnick and Yasmin Kafai over the past decade. These projects have allowed them to develop a strong foundation in the prime areas of the proposed research: computational thinking, virtual worlds, learning in both formal and informal contexts, and broadening participation for women and underrepresented minorities.

Resnick and Kafai, along with co-PIs Rusk and Maloney, collaborated on a previous NSF-funded project, "Developing a Media-Rich Networked Programming Environment for Community Technology Centers in Economically Disadvantaged Communities" (ITR-0325828; 09/15/03-08/31/08; \$1,999,435), which supported the initial development of Scratch and the study of how Scratch can support the development of technological fluency. Since its launch in 2007, Scratch has been used by millions of youth and translated into 50 languages around the world. Scratch was awarded the Eliot Pearson Award for Excellence in Children's Media in 2008 and the Kids@Play award for Best Informal Learning Experience in 2009. Kafai and Resnick and their colleagues published numerous journal articles, book chapters, and conference papers based on this NSF-funded research (e.g., Kafai, Peppler, & Chiu, 2007; Maloney et al., 2008; Monroy-Hernández & Resnick, 2008; Peppler & Kafai, 2007; Resnick et al., 2009).

Earlier, Resnick was PI on several other NSF-funded science-education projects, including “Beyond Black Boxes: Bringing Transparency and Aesthetics Back to Scientific Instruments” (CDA-9616444; 01/01/97-12/31/00; \$880,658), focused on the development of new technologies to enable young people to build their own scientific instruments; “The PIE Network: Promoting Science Inquiry and Engineering through Playful Invention and Exploration with New Digital Technologies” (ESI-0087813; 03/01/01-02/28/05; \$2,078,635), working with a network of museums to develop a new generation of public programs integrating art and technology; and “The Virtual Fishtank” (ESI-9627672; 09/15/96-08/31/99; \$598,472), focused on the development of a major museum exhibit to help the general public learn important ideas from the sciences of complexity.

Kafai is currently the lead-PI on a CreativeIT grant “Computational Textiles as Materials for Creativity” (CISE-0855868; 08/01/09-07/31/12; \$309,397) with Leah Buechley (MIT) and Kylie Peppler (Indiana University), in which they investigate the design of an online community for sharing and evaluating e-textile designs among underserved youth. She was one of the first researchers to study creative production and participation in Whyville.net, a tween virtual world with more than 5.4 million registered players (ROLE-0411814; 09/15/04-08/31/07; \$441,674). The findings of this work have been presented at numerous national and international conferences and resulted in more than a dozen publications in peer-reviewed journals, including a special issue for *Games & Culture* and a book edition “Beyond Barbie and Mortal Kombat: New Perspectives on Gender and Gaming” together with C. Heeter, J. Denner and Jen Sun (MIT Press, 2008).

Kafai was also a co-PI with the American Association of University Women (AAUW) on the NSF-grant “Bridging the Gap” (PGE-0220556; 09/15/02-11/30/05; \$218,708) which synthesized findings from more than 400 studies that addressed gender equity issues in STEM areas sponsored in the last ten years. One of the findings relevant to this study is that the territory of online interventions had not been mined in substantial ways to address gender and minority disparities. The final report “Under the Microscope: A Decade of Gender Equity Interventions in the Sciences” was published in 2004 by AAUW.

11. Dissemination

Our research team has an exceptionally strong track record for getting our ideas, activities, technologies, and strategies disseminated nationally and internationally. Millions of young people are currently using technologies based on our research (including Scratch and LEGO MindStorms robotics kits) in both formal and informal educational settings. We have also developed educational programs with a broad impact: the Computer Clubhouse network of after-school learning centers, founded by two members of our team, has expanded to 100 sites in 20 countries, reaching 20,000 young people in low-income communities (Kafai, Peppler, & Chapman, 2009; Rusk, Resnick, & Cooke, 2009). Our team also has a strong record for disseminating ideas and research findings to a wide variety of audiences – through academic publications and conference presentations for researchers, workshops and curricula for practitioners, and popular books for the general public.

In this project, we plan to continue to share our research findings with researchers and practitioners across multiple disciplines, including computer science, education, psychology, law, and economics. Members of the project team regularly make presentations at leading academic conferences and industry symposia, such as AERA (American Educational Research Association), CHI (Computer-Human Interaction), CSCL (Computer-Supported Collaborative Learning), HICSS (Hawaii International Conference on System Sciences), CSCW (Computer Supported Cooperative Work), ICLS (International Conference of the Learning Sciences), and SIGCSE (Technical Symposium on Computer Science Education).

We plan to set up a public blog to distribute and discuss findings with researchers, educators, and others interested in issues related to cooperation and learning. In addition, we plan to make active use of social media tools such as Twitter and Facebook to bring attention to the latest updates on our research.