# Tools to Support High School Students' Creativity in Scientific Research

## Creativity Support Tools for Research

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## ABSTRACT

As a creative endeavor, scientific research requires inspiration, innovation, exploration, and divergent thinking. Yet, in K-12 settings, it is often viewed as rigid and formulaic. MindHive is a web-based platform designed to facilitate student-teacher-scientist partnerships in research on human behavior. Features support research phases (e.g., question finding, study design, peer review, iteration), and their creative dimensions, including exploration, expressiveness, collaboration, and enjoyment. Interviews with teachers and students who used MindHive show how learners describe their experiences as creative agents. This work illustrates how educational technologies can broaden STEM participation by being authentic to methodical and creative aspects of STEM research.

## CCS CONCEPTS

• **Education**; • **Collaborative and social computing**; • **Human-computer interaction (HCI)**;

## KEYWORDS

Creativity support tools, Community science, High school classrooms, Technology design

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## 1 INTRODUCTION

Research is a creative and collaborative design process [2]. It requires sufficient knowledge of a content area to devise research questions that will contribute to a field; and adequate practical skills in, and understanding of research design to create studies that will generate the data necessary to answer those questions. Understanding research design at the K-12 level offers a foundation for the critical skills necessary to make informed personal and societal decisions. However, research can feel abstract to learners, who may not recognize its relevance, and feel alienated by its image as purely methodical.

We present a student-teacher-scientist-community participatory science initiative that enables teaching research design in a way that emphasizes its creative and collaborative nature. Using findings from interviews with teachers and students who used MindHive in their classrooms, we discuss how we are iterating on the platform to improve its capacity to support the creative aspects of research. This study combines perspectives from creativity support tools [29], open science [10], and STEM education, to explore how technologies can be designed to support the creative aspects of STEM, thereby inviting a broad range of learners to develop research proficiency.

### 1.1 Background and rationale

Research is a systematic inquiry into a subject that involves gathering information and data to answer questions and generate knowledge. Whether or not learners go on to pursue careers in research, understanding the nature of research is essential for evaluating claims and arguments that they will encounter in their daily lives, and upon which they will base both personal and societal decisions (e.g., Would eating less meat help to reduce climate change? How does exercise impact my sleep? How have communities in my city been impacted by migration?). Teaching research in K-12 contexts presents various conceptual, logistic and affective obstacles: Teachers must guide diverse learners in developing knowledge and skills in each of the domains and the process of research design. At the same time, teachers must ensure that learners see the relevance of their work, and find the effort to be personally and broadly meaningful. Meanwhile, learner-driven inquiry is promising for developing conceptual STEM understanding and practices, but can be logistically challenging in classroom settings, wherein teachers must manage multiple projects by students with diverse abilities and interests.

Our work builds on two opportunities to address these issues. First, we use a participatory science approach to allow learners' authentic participation in real-world research. In participatory science (also often referred to as citizen science) lay people contribute to some or all aspects of the scientific process, including proposing research questions, designing studies, and collecting and analyzing data. Participating in science can promote the public's positive attitudes toward and acceptance of science [32], as well as their identity and sense of agency as scientists [3]. Second, we build on research that highlights the creative aspects of research. Research generally consists of formulating answerable questions, designing a systematic method for gathering data to answer those questions, interpreting data to form conclusions and draw implications, and situating the contribution within a body of existing knowledge [23]. Meanwhile, creativity is commonly defined as the ability to create something that is both novel and valuable [28]. Although learners typically perceive the scientific process as linear and formulaic [6, 22], there are numerous accounts of the creative dimensions of doing science, both among professionals [15], and K-12 learners [11, 33]. These accounts demonstrate how scientific research, just as with other creative practices, involves deductive and inductive reasoning, interdisciplinary thinking, collaboration with others, iterative refinement of ideas, and importantly, the developing novel ideas by building on existing ones. Unfortunately, this creative side is not often emphasized in educational settings, which precludes learners, who may not identify with science, from benefiting from the generalizable skills that it develops for engaging critically with information.

## 1.2 Related work

A focus in Human-Computer Interaction (HCI) is on creativity support tools (CSTs) for media, architecture, and engineering [31] and creative activities among children [12]. Some CST design frameworks emphasize technology's role in supporting the practice of creative work (e.g., exploratory search, collaboration, provision of rich history-keeping, and an environment with low floors, high ceilings, and wide walls [30, 31]. More recently, [5] proposed a Creativity Support Index (CSI) that synthesizes a practice-oriented view of creativity with the emotional and dispositional dimensions of creative work [7, 24, 26]. The CSI recognizes six features of effective CSTs, those that support: (1) exploration (discovery of ideas, options, and possibilities), (2) expressiveness (i.e., communication of ideas), (3) collaboration (working with others), (4) results worth effort (satisfaction with the outcome given the effort required, (5) enjoyment (positive feelings evoked through use of the tools), and (6) immersion (i.e., absorption in a task that minimizes awareness of the tools). Existing learning designs that fuse STEM with disciplines conventionally perceived as creative (e.g. [13, 18]), often take advantage of alignments among STEM and other creative practices to promote interest and engagement in STEM [1, 14, 20, 25]. Qualitative data analysis software also include features that encourage exploration and associative thinking characteristic of creative reasoning. Yet, few designs for K-12 learners support the creative nature of experimental research.

## 1.3 MindHive: Bringing authentic brain and behavior research to the classroom

MindHive (mindhive.science) is a web-based participatory science platform and high school curriculum for human brain and behavior research [8]. MindHive offers tools for generating research questions and hypotheses; designing studies; collecting and analyzing data; and participating in, and peer reviewing studies, which are included in MindHive's public repository of studies. Together, these features help to portray science as a social and iterative process [16, 17]. Our team includes researchers in education and in human brain and behavior, high school teachers, web developers, and UX designers. In striving to make MindHive more educational, engaging, and authentic to open science, we recognized the need to also nurture learners' sense of creativity as researchers. Thus, we ask: How can a participatory science platform engage high school learners in the creative and collaborative aspects of research?

# 2 METHODS

We collected interview data from students (n=237) and teachers (n=7) who implemented MindHive during 2022-2023. Participants were from 6 high schools (2 private, 4 public) located in a large, socioeconomically and culturally diverse city (~69% nonwhite) in the northeast of the United States. Five of the courses were neuroscience electives (5 grades 11-12) and 2 were environmental science electives (1 grades 11-12, 1 grade 9). A total of 11 class sections were taught, with some of the teachers teaching multiple sections.

Students used the MindHive platform and curriculum, individually or in groups, to design studies in research areas of personal interest to them, guided by teacher-led interactive lessons and discussion. Throughout the 10 weeks of each implementation, our team hosted weekly drop-in sessions with teachers (2-5 teachers and 1-2 researchers/session), in which they shared their progress and plans. At the end of the school year, we facilitated a ~90-min session with teachers to reflect on their experiences using MindHive. We also conducted individual interviews with 21 students (3 from each class, selected based on obtained consent). These 30-min interviews asked students to describe their study's design and motivation, and to share their experiences with specific features of the platform (e.g., Show us how you used this feature. What did you like/dislike about using it? What changes would improve it?). We conducted a deductive thematic analysis of the transcribed interview recordings and meeting notes [4]. With the Creativity Support Framework [5] as a structure, we sought to qualify students' expressions of enjoyment, exploration, expressiveness, immersion, results worth effort, and collaboration through their use of the platform. Below, we describe how these features of MindHive appeared to support students' creative experiences.

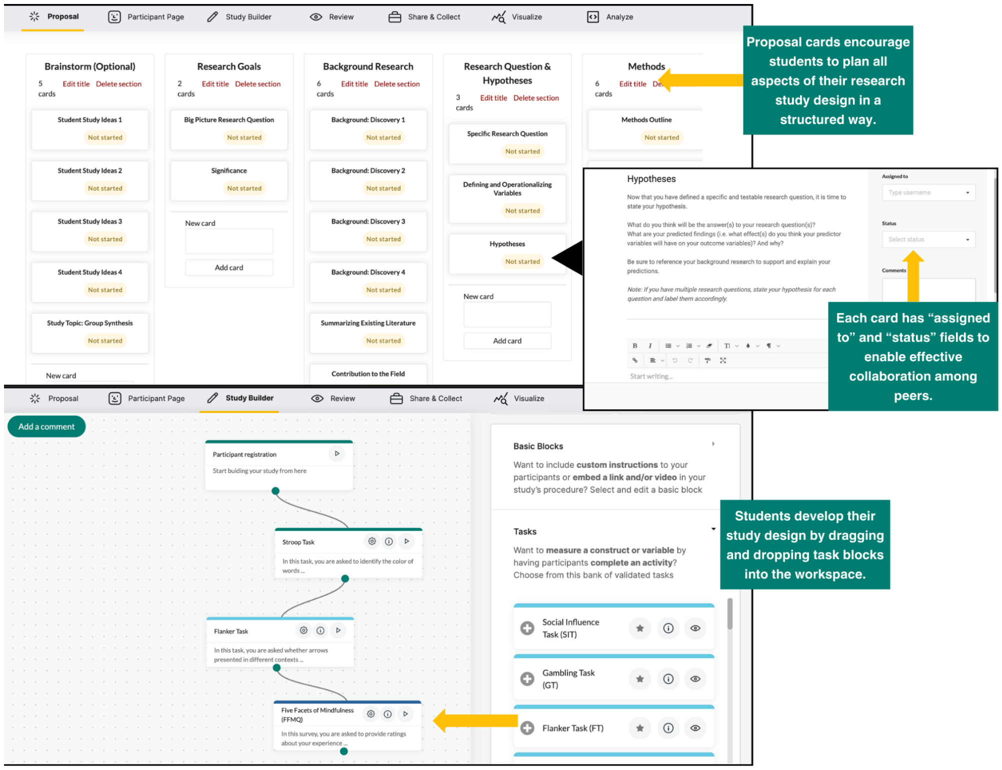


**Figure 1: Screenshots of the Proposal Board (top) and Study Builder (bottom) on the MindHive platform.**

## 3 RESULTS

### 3.1 Overview of MindHive's components

MindHive consists of [8]: (1) a Discover area, in which users can explore and participate in studies created by others; (2) a Repository of public tasks and surveys that users can incorporate into their studies; and a Develop area, which includes a Proposal Board, Study Builder, Peer Review, and Data Analysis tools. The Proposal Board uses digital cards that users can specify and organize to structure their study designs (e.g., "research question," "participants," "procedure"); assign tasks to team members; update task statuses ("in progress," "needs feedback") and exchange comments among peers and teachers [8]. Teachers can create class networks and track and provide feedback on students' activities. In the Study Builder users drag and drop study components, including tasks, surveys, instructions, and weblinks, creating their own content, or tweaking validated tasks and surveys from MindHive's Repository [27]. For example, users might use a Stroop Task and audio excerpts to test the impacts of music tempo on selective attention (Figure 1). Below, we describe how these components supported the CSI dimensions of exploration, expressiveness, enjoyment, and collaboration.

### 3.2 Exploration

Exploration is critical to the early stages of research, allowing one to encounter new ideas, and to imagine potential outcomes. The Discover area supported students' exploration by offering an interface for finding and participating in existing studies. This served as a means of inspiration, a way to empathize with participants, and to learn firsthand the importance of best practices and limitations of research. As Student 16 shared: "we were able to see how other people did their work and (. . .) if we liked it we could (. . .) do something that they did or if they didn't like it, we would make sure not to do it how they did theirs." Moreover, the drag-and-drop card interface of the Survey Builder allowed students to further explore possible designs, and to discover areas for improvement. As Teacher 1 described: "Having the students make something concrete and seeing it on the platform, previewing it and interacting with it, was very cool." Thus, the platform's existing studies offered models of how to use MindHive's resources, and tools for visualizing designs facilitated students in identifying and refining their own ideas.

### 3.3 Expressiveness

Expressiveness in research is the ability to address questions that are personally meaningful, and in ways that are valid and reliable. Students used MindHive's Proposal Board to collaboratively generate ideas that they and their peers deemed important. As explained by Student 8, who designed a study on the impacts of social connectedness on peer influence: "When we were brainstorming (...) we thought a lot about how social media influences kids (...). If their best friend posts something on Instagram, are they more likely to follow up and repost it versus someone that they don't know? (...) It seemed relevant to me and my generation."

In building their studies, MindHive's Repository ensured access to validated and customizable tasks and surveys. As Student 9 described: "MindHive gave us (. . .) a lot of different tools (...) to create our project from start to finish, and we were able to (...) take parts from other tasks and surveys and (. . .) integrate into our own project." Students and teachers also commented on the ease with which these elements could be customized. As Teacher 1 noted: One group exploring 'filtered photo preference' is using HTML tags to embed images into their survey and it's taken off." Teacher 3 moreover shared how one student used the tools to construct a novel "learning task with blocks. He is assessing how well participants can stack blocks based on set parameters (e.g., similar colors cannot touch). He designed a practice demonstration, and three levels of testing with increasing difficulty."

## 3.4 Collaboration

Collaboration occurs throughout the research process, and is likewise a feature integrated across MindHive's components. For example, students' ability to work collaboratively on generating ideas in the Proposal Board became a form of team bonding, as Teacher 2 described: "We spent a lot more time on the brainstorming column of the Proposal Board so that they feel more connected to each other." Students could also coordinate their efforts by tagging teammates on cards to assign tasks, and updating the card statuses (e.g., "in progress," "needs feedback," "done."). Student 11 expressed appreciation that: "we could put our names on the different cards, so that we knew who had done what. It helped us distribute the work so that not one person was doing everything." As well, the ability for teachers, students, and mentors to write comments on cards enabled peer review on all aspects of the research process—within and across schools—and promoted students' appreciation for the open science process. As Student 2 explained: "I think it's more impactful to have peer review (...) at all stages of an experiment so that you can perfect before collecting data and before data analysis (...) to measure the right things that you're looking for."

## 3.5 Enjoyment

Enjoyment in an activity is related to feelings of competence and autonomy, and can determine interest in, and motivation to pursue it [9]. Students expressed enjoyment in, for example, the ease with which study designs could be visualized and modified, as Student 10 shared: "It was super straightforward (...) to connect things (. . .) just drag and drop a line, and you kind of lay them out in order (...) it was really just (...) satisfying (...) made you feel like you [had] (...) full control over how everything was laid out." Teacher 1 further observed that students "were eager to try their hand at developing surveys (. . .) given the opportunity to apply what we learned about survey design and relate it to their study was motivating to many." Enjoyment also came from how the platform promoted social interactions. For example, Student 16 noted that "actually doing other experiments (. . .) it was fun (. . .) Look[ing] at people's different ideas, I think that was one of my favorite parts." Student 9 likewise commented on liking to complete experiments together: "I felt like with that interactivity that we really worked as a class."

## 3.6 Results worth effort

Results worth effort refers to the perception of the value of a task, and expectations for success, as related to choice, performance, and engagement in that task [21]. The ease of use of MindHive's tools contributed to students' perceptions that otherwise complex tasks were achievable, and worth the effort to achieve the outcome. Student 7 shared that "figuring out how to customize my own studies was (. . .) complicated, but [with] (. . .) the pre-existing studies, (. . .) once I figured out how (. . .) customize those, it wasn't too hard." Student 14, commenting the StudyBuilder, said that: "even though [the surveys and tasks are] already pre-built things, you can make one from scratch (...) and take an already built block and then just build off of that."

## 3.7 Shortcomings in supporting creativity

Platform limitations also limited students' creative experiences. One group, studying the effects of music on attention, realized that the Study Builder did not support media integration. Instead, they used their phones to play music in between participants' completion of online tasks. Such shortcomings required them to compromise on their ideas, introduced potential for error; and reduced the capacity for expressiveness, and the feeling that the results are worth their efforts.

# 4 DISCUSSION AND CONCLUSION

This paper explored students' experiences of creativity when using a participatory science platform. Students noted the utility of model studies and pre-made tasks as customizable templates, facilitating exploration of ideas, expressiveness as researchers, and the feeling that their efforts were worthwhile. Yet, platform limitations also limited students' creative experiences. Our ongoing work aims to increase the platform's usability to enable users to focus more wholly on their research. Features such as autosave, real-time collaboration (locking a text field while it is being edited by a collaborator), broader media integration support, and data visualization tools, may contribute to users' exploration, expressiveness, enjoyment, and ultimately, immersion in research [19] (not addressed in this study). Future research might explore quantitative methods for understanding users' creative experiences [5]; and examine how the platform works in conjunction with the curriculum, teachers, and mentors, to nurture students' views of themselves as creative researchers [19].

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