Chancellor's Award for Excellence in STEM Education

Developing skills to persist and succeed in STEM: Comparing self-directedness, learning, curiosity, and persistence in more- and less-structured Science Discovery Camps

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Introduction and Project Overview

The proposed research tests the effectiveness of an intervention designed to increase self-directedness in children in informal STEM learning environments. We have conducted an initial study at CU, which shows that the more time children spend in less-structured activities in their daily lives, the better their ability to set goals for themselves and reach them. Conversely, the more time children spend in adult-structured activities, the *worse* these self-directed abilities[1]. These findings are promising, and they may have broad implications given that such abilities in childhood predict a range of important life outcomes, including performance in STEM education. However, an experimental study is needed to address causal questions, potential for intervention, and implications for informal STEM learning environments. Funds are requested to allow us to conduct this work, in which we will manipulate the time that children spend in more- and less-structured activities in the context of CU Science Discovery summer camps. We will test effects on self-directedness to build on our initial findings, and extend our investigation in important ways to assess effects on learning, curiosity, and persistence. This study will forge interdisciplinary collaborations and provide data that will support a dissertation grant focusing on the effects of experiences in informal STEM learning environments, and extend CU's research on STEM education to foundations in early development.

Background and Theoretical Framework

Students who spend time in informal STEM learning environments, which provide more opportunities for self-directed behavior[2], show increased interest in STEM education and careers, and increased beliefs about personal self-efficacy[3–5]. Exploring the self-directed nature of these learning opportunities may provide insights into how informal STEM experiences benefit STEM-related outcomes and advancement. Underscoring the importance of such efforts, modern students spend much *less* time in unsupervised activities, including outdoor play and independent travel[6,7], and much *more* time in structured, adult-led activities, such as practice and lessons [8–10]. The implications of such changes in society are unclear[11,12 13,14] given limited research on this topic, but they could impact characteristics and processes in young learners of relevance to success in STEM education[3–5], laying a foundation in early development that predicts later outcomes. If it is found that less-structured learning environments foster greater interest in STEM activities and occupations, then this could inform STEM teaching practices.

Executive functions (EFs) represent a promising target for investigating such issues, because they are important for success across many aspects of life[15–20], including performance in STEM education[18,21,22], and they develop gradually across childhood[23,24] and are malleable through experience[25,26]. EFs are a set of goal-directed cognitive processes, including manipulation of information in working memory, inhibition of unwanted thoughts, feelings, and actions, and flexible shifting from one task to another. EFs are important for behavior in the short- and long-term. EFs in the first years of life predict school readiness in preschoolers[15], later academic performance[16–19], and health, wealth, and social outcomes in adulthood[20]. EFs also support emerging scientific and analogical reasoning skills[22,27,28].To build new explanatory frameworks for understanding scientific phenomena, children must detect how new information conflicts with previously useful explanatory frameworks, and inhibit old ways of thinking. EFs can be improved through intervention. For example, preschool classroom curricula that target support for self-regulatory skills have improved children's ability to flexibly shift from one cognitive task to another[25,26].

Such investigations have focused on *externally-driven* EF, where adults provide instructions about what children should do, and when. Much less is known about the development of *self-directed* EF, where children must decide for themselves what goal-directed actions to carry out, and when – for example, when choosing interests to pursue on their own, without being directed by parents and teachers. Developing such self-directed EF is a fundamental aspect of growing up. Moreover, it may be particularly vulnerable to recent societal changes in how children are raised. For example, as children spend less time in unsupervised activities and more time in adult-led activities, they may have fewer opportunities to practice setting goals for themselves and determining how to reach them, which may alter their developmental trajectories.

We have recently taken an important first step in testing this possibility. We collected detailed information about how 6-7 year-old children spent their time; we then systematically coded and classified this information and tested its relationship to children's self-directed EF[1]. We found that children who spent more time in less-structured activities, such as free play, unguided practice, social activities, and enrichment events, showed better self-directed EF in a task where they had to generate autonomous, internal cues about what should be done, and when. By contrast, children who spent more time in adult-structured activities, such as lessons, practices, organizational meetings, homework and chores, showed *worse* self-directed EF.

In addition to relating to self-directed EF, less-structured experiences may benefit children's emerging self-directed scientific exploration and curiosity. For example, children's exploratory behavior can be influenced by teacher pedagogical practice, such that direct instruction may inhibit children's tendency to engage in independent exploration. When playing with a novel toy, young children who have been exposed to direct instruction informing them of the toy's function (via either instructions to them, or overheard instructions to another child) will restrict their exploration of the toy, and fail to discover new functions, relative to children who have not been exposed to direct instruction[29]. Promoting student curiosity is important, as desire for knowledge predicts important outcomes, including academic goal-setting and learning[30], positive subjective well-being, the belief that goals are attainable, and enjoyment of effortful cognitive tasks[31], and job motivation and performance[32].

The proposed research builds on these promising findings to test the causal role of less- and more-structured time in developmental outcomes of relevance to STEM education, in the context of an informal STEM learning environment, CU Science Discovery. We predict that children who attend less-structured camp sessions (where children, rather than adults, play a larger role in structuring activities and goals) will show improvements on post-test measures of self-directedness, learning of scientific concepts, scientific curiosity, and persistence, relative to children attending more-structured camp sessions, controlling pre-test scores on each outcome measure. Other work provides a foundation for this innovative approach, showing that interventions of a week or less yield benefits to children in children's externally-driven EF, willingness to try challenging problems, and ability to deal with personal challenges[33–38], potentially because they trigger an adaptive cycle of behavior. We predict that the benefits of our manipulation will be specific, and will not extend to a comparison measure of child vocabulary.

Study Design and Methods

We will test the impact of manipulating the amount of time children spend in more- and less-structured activities, in an ecologically-valid, rich setting that nonetheless affords excellent experimental control: the CU Science Discovery summer camps, which bridge STEM disciplines to connect K-12 students and teachers to hands-on science experiences, impacting more than 20,000 individuals each year. We will collaborate with Science Discovery to develop, teach, and assess intervention fidelity in four sessions of week-long camps. Children who enroll will be randomly assigned to a structured or less-structured version of one of two camps: a "Science of Toys" camp for 6-8 year olds (N = 32; 16 per condition), or a "Toy Engineering" camp for 8-10 year olds (N = 32; 16 per condition). In the more-structured camps, an adult will instruct and guide children on what and how to build, while in the less-structured camps, children will decide what and how to build. We will compare self-directedness, scientific learning, curiosity, and persistence between the two groups.

Parents will be informed when signing up for the camp that CU Science Discovery is collaborating with Psychology and Neuroscience to explore effects of types of environments on children's learning. After signing up, parents will be provided with details and asked for informed consent for their children's participation. (Children > 7 years will be asked for their assent.) Testing time will be conducted during one 20-minute session on the first day of camp, and one 25-minute session on the last day of camp.

To manipulate the degree of structure within less-structured and more-structured camps, we will implement curricular changes that vary in whether the instructor or students take primary responsibility for structuring the learning environment, choosing activities, and setting goals (Table 1). Although the two camp versions will differ in the degree of overall structure, both will still meet the goals of Science Discovery by providing students with a materials-rich, hands-on STEM experience that introduces fundamental scientific concepts and the engineering design cycle through fun and engaging projects. The two camp versions will include the same key projects (e.g., hula hoops, cars, rockets, boats) but the level of facilitation provided throughout each camp will differ.

Structured camp curriculum

Structured-condition camp settings will follow a 'traditional' curriculum, in which the instructor will determine daily goals, activities, and projects, with little input from students. Each day, the instructor will introduce children to specific scientific concepts, then guide them through a predetermined project related to those concepts (e.g., children might explore concepts of potential and kinetic energy by making a rubber band-powered toy car). Children will maintain notebooks where they will write down instructor-given project steps, directions, and goals. For group work, children will be assigned to a specific role within a specific group. Additionally, free time and recess periods will be structured around adult-organized games and activities.

Table 1. Comparison of Structured and Less-Structured Camp Curricula

Program Element	**Structured Curriculum**	**Less-structured Curriculum**
Setting classroom rules (Day 1)	Decided by instructor	Developed by class
Planning activities/projects for each day	Decided by instructor	Chosen by children (from possible set of activities)
Child scientific notebook	Instructor tells children what to write	Instructor provides general guidelines for content
Break time organization	Instructor organizes games and activities	Children determine how to use time
Group formation	Instructor assigns children to groups	Children select groups
Role assignment within groups	Instructor assigns roles	Children determine roles

Less-structured camp curriculum

In less-structured camp sessions, children, rather than the instructor, will make choices about daily goals, activities, and projects. After the class collectively chooses a topic for the day from a possible set of topics, the instructor will expose children to general scientific concepts, then give them the freedom to choose and structure activities to explore those ideas (e.g., children might explore potential and kinetic energy by using a variety of materials to develop a toy car). As in the structured condition, children will maintain notebooks, but they will be given general, rather than specific instructions about how to use those notebooks (e.g., instructors will give general directions, e.g., "Now that you've come up with your project, you should write out a plan for what you are going to do.") Additionally, children, rather than the instructor, will decide on group composition and roles within groups, and free time and recess periods will be structured by children, rather than adults (e.g., adults will supervise children, but will not organize games or activities).

To maximize our ability to detect effects of our manipulation, pre- and post- measures will be administered, and the session instructor (CU graduate students from the College of Engineering & Applied Science and the School of Education who will remain blind to hypotheses) will be held constant across conditions. We will include comparison measures to test the specificity of observed effects.

Child Outcome Measures

- *Self-directed executive functioning*: Children's pre- and post-intervention problem solving ability will be assessed using semantic verbal fluency, a standard laboratory measure of self-directed, goal-oriented behavior[39]. In this task, children are provided with an overall goal, but must generate their own rules for how and when to achieve that goal. Participants are given a category (e.g., foods), and asked to produce as many words falling within that category as possible across a 1-min interval. Children and adults who produce many words on the task tend to cluster responses (by grouping words that fall within the same semantic subcategory) and switch between subcategories when available exemplars are in short supply (by detecting the need to switch, and selecting what to switch to, e.g., desserts, vegetables, or fruits). VF will be assessed using different prompts pre- and post-intervention to minimize practice effects.
- *Retention and understanding of scientific concepts:* As a pre-test measure, we will administer a 5-minute assessment of children's knowledge about general scientific concepts covered during the course (e.g., potential and kinetic energy, buoyancy, circuits and electricity). Post-intervention, we will assess children's learning of scientific concepts taught across the camp session. Items will assess children's memory for specific activities ("What toys did you make during camp?"), as well as their understanding of foundational concepts covered during the session (e.g., "How did winding the rubber band more tightly affect how the toy car moved?")
- *Scientific curiosity*: To investigate differences in children's scientific curiosity, we will administer pre and post-test, age-adapted versions of the Children's Scientific Curiosity Scale (CSCS)[40]. The CSCS is composed of 30 Likert-scaled items which assess domain-general scientific curiosity (e.g., "I want to know what causes wind;" "It is boring to learn new science words").
- *Persistence*: As a secondary post-test measure, we will index children's persistence via a child-adapted version[41] of the Short Grit Scale (Grit-S), which measures trait-level perseverance and passion for long-term goals. Items are Likert-scaled, and include statements such as, "Setbacks don't discourage me" and "I finish whatever I begin".

Comparison Measures and Fidelity of Intervention Assessment

As a comparison measure, children will complete the EVT (Pearson Assessments, Bloomington, MN), a standardized, nationally normed, expressive vocabulary test. (This measure will also be used to control for individual differences in vocabulary in tests of verbal fluency performance.)
Instructor adherence to the assigned curriculum (either structured or less-structured) will be assessed through observation at 2 time points during each 1-week camp session.

Timeline

STEM Grant Funding Period

Task	May	Jun.	Jul.	Aug.	Sept.	Oct.	Dec.
Complete IRB Protocol	X	X					
Finalize curricula and pilot learning outcome measures	X	X					
First Wave Data Collection		X	X	X			
Analyze First Wave Data				X	X	X	
Report of initial findings to CU Science Discovery							X
Refinement of curricula and learning outcome measures in preparation for							X

2nd Wave Data Collection							

Outcomes/Impacts

Professional Development: The proposed body of work will build upon and forge connections between my graduate training, which has focused on laboratory-based investigations of the mechanisms supporting cognitive development, and my past experiences conducting classroom-based research. Our finding that children's time in less-structured activities relates to their developing self-directed EF has real-world implications for learning and STEM education. However, this proposal represents the first translational project building on these findings. This project would also position me to apply for a NRSA Predoctoral Fellowship, which I plan to apply for to support my dissertation work. Experimental manipulations remain the gold standard for testing questions of causality, so this study will provide essential pilot data isolating causal factors.

Benefits to the Department of Psychology and Neuroscience: One of the major goals of our department and of the field is to test psychological theories and findings from our laboratories in the real world, and to develop applications that will have an impact beyond the walls of our labs and classrooms. This project would forge interdisciplinary collaborations across the Department of Psychology and Neuroscience, CU Science Discovery, and the College of Engineering & Applied Science, and the School of Education (via interactions with doctoral students from those departments who will contribute to this proposed work as CU Science Discovery instructors). This collaboration would support our department's first opportunity to test psychological theories and findings in an informal STEM learning environment, and to inform the development of STEM curricula in a program that impact tens of thousands of individuals each year. This project would lay the foundation for future collaborations, given the highly relevant interests of many faculty members in our department, in psychological processes that impact STEM learning and their developmental foundations.

Support for STEM Education at CU Boulder and Broader Impacts: Findings from this project would also support innovation in STEM-related instruction in informal learning environments, both at CU, and within the wider community, by providing tools that will allow CU Science Discovery to evaluate their existing curricula and instructional strategies. If it is found that less-structured learning environments foster greater interest in STEM activities and occupations, then this could inform STEM teaching practices. Informal STEM learning environments (which are considered more likely to be self-directed and individually-motivated[2]) have been shown to foster greater interest in STEM education and careers, and increase beliefs about self-efficacy, achievement[3–5] . Exploring the self-directed nature of these learning opportunities may provide insights into how informal STEM experiences benefit STEM-related outcomes and advancement, and how these relate to STEM educational experiences more broadly. Such work would represent the first extension of CU's STEM Education research initiative to the foundations of STEM learning, early in development. Additionally, this project would forge an interdisciplinary collaboration between Stacey Forsyth and CU Science Discovery and the Department of Psychology and Neuroscience, along with scholars from Engineering and Education.

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Budget Justification

Personnel

Psychology and Neuroscience GRA, 50% Summer 2015, 25% Fall 2015: This funding will provide support for all phases of the planned work, including development of structured and less-structured camp curricula, piloting of measures, overseeing data collection and coding, analyzing data, and preparing a written report of findings CU Science Discovery. Full stipend funding will allow me to devote the research time required to achieve the aims of this collaborative project within the project period; I would otherwise need to take on a half-time teaching positions that would require a substantial time commitment.

Budget

PROPOSED BUDGET DETAILS

Salary, Wages, and Fringe Benefits
(Base salary = 47,759)

Graduate Research Assistant (pre-comps)			
50%	2.75	months (Summer 2015)	5,472
25%	4.50	months (Fall 2015)	4,477
Total GRA Salary (no fringe)			**$9,949**