A Multi-Site Study of the Role of Informal Science Education Programs in Developing STEM Identity

Abstract

This project measured the STEM Identity and STEM Self-Efficacy[1] of youth before and after their participation in a SciGirls informal science education program (both summer camps and afterschool programs) at eleven sites across the United States. Using data gathered from youths' pre- and post-surveys, the results indicate that participating youth experienced growth in their STEM identity from pre- to post-program, and this change was largely driven by youths' changes in perceptions about the extent to which other people see them as a science person.

Objectives and Purpose

Women represent less than one-third of STEM jobs (NSF, 2017). The decline in interest and identification with STEM begins as early as elementary school (Archer et al., 2012; Poirier et al., 2009; Tai et al., 2006). Research has highlighted the benefits of informal STEM education programs as venues that can strengthen girls' interest and sense of belonging in STEM (Adams et al., 2014; Hughes & Roberts, 2019; Cakir et al., 2017; National Research Council, 2009; Riedinger & Taylor, 2016). Unfortunately, most research studies have focused on one program or have compared disparate programs making comparisons of identity development difficult to fully assess.

This study addresses this concern by studying the impact of specific programming – SciGirls – on participating girls' STEM identity for eleven different programs. The overarching goal for this research study was to determine the role of the SciGirls gender-equitable strategies (Billington et al., 2014) on participating youths' STEM identity changes in participating SciGirls

[1] The authors use capital letters when referring to the constructs measured in this study compared to general STEM identity and self-efficacy referenced in other literature.

programs across the nation. By including multiple programs which all utilized the same informal educational strategies, we can begin to parse out the overall impacts of these programs without being context-bound to individual sites and programs. The research question guiding this project is: What effect does participation in SciGirls programs have on participants' STEM identity?

Theoretical framework

We chose to define STEM identity using Calabrese Barton and colleagues' (2013) as well as Carlone and Johnson's (2007) research. According to these researchers, to develop a stronger STEM identity, individuals must have opportunities to perform their competence in STEM and be recognized for that competence by perceived experts. Calabrese Barton and her colleagues' highlight the tension that exists between an individual's identity work and how it is accepted or rejected by others. STEM identity development is both a reflection of how one perceives and positions oneself within STEM, and how one is perceived and recognized by meaningful others (Carlone & Johnson, 2007).

Research highlights that other aspects are important to individuals' STEM identity development. These include: interest in STEM concepts (Eccles, 2007; Gilmartin et al., 2007; Hazari et al., 2010); confidence in one's competence in STEM – self-efficacy in STEM (Eccles, 2007; Hazari et al., 2010; Rittmayer & Beier, 2009; Usher & Pajares, 2006); and resources and support related to STEM – STEM Capital (Archer et al., 2015). These combined influences on STEM identity drove our selection of survey instruments which included metrics for STEM Capital, Self-Efficacy (which includes interest and competence) and STEM Identity (which includes perception of oneself as a STEM person and beliefs that others see one as a STEM person), with the goal to determine what changes occurred in these categories from pre to post program.

The SciGirls programs are all designed around the SciGirls Gender-Equitable Strategies which include providing opportunities for girls: to collaborate; work on projects that are personally relevant, hands-on and open-ended; receive feedback that focuses on effort as opposed to innate ability; to think critically; and to form relationships with diverse women role models (Billington et al., 2014). These strategies are taught to SciGirls educators in trainings. Each program is also encouraged to create a learning environment where all participants feel valued and safe (Simpkins et al., 2017). Consequently, each of these programs is created based on a shared structure and creates a community of practice wherein youth have opportunities to perform and be recognized for STEM competence (Lave and Wenger, 1991).

Data Sources

In this project we studied the impact of SciGirls programs at eleven sites over two years (2017 and 2018). Of the eleven sites, six were summer camps and five were after-school programs. All programs were required to utilize the SciGirls gender-equitable strategies, but the individual lessons, activities, and role models were at the discretion of each site. Sites were not required to host single-sex programs, although many elected to do so. Each site administered a pre- and post-program survey, which could be done as a hard-copy or electronically. All hard copy surveys were entered by the research team. Both electronic and hard copy surveys were matched to appropriate consent forms before being included in the final analytic sample. The final analytic sample included 148 youth across the eleven sites.

The youth survey instrument included questions from pre-existing instruments, namely Aschbacher and colleagues' (2010) survey, the Assessing Women in Engineering (AWE, 2008) survey, and Archer and colleagues' (2015) survey. Factor analysis of the combined Aschbacher and colleagues' work and the AWE resulted in two scales: STEM Identity and STEM Self-

Efficacy. For more information on this process, please see the authors previous work (Roberts & Hughes, 2019).The STEM Identity scale was comprised of two subscales: Self-Perception – seeing oneself as a STEM person or someone who is competent in STEM; and External Perception – believing that others see one as a STEM person or someone who is competent in STEM. The STEM Self-Efficacy scale was divided into three subscales: Self-Confidence – confidence in one's competence in STEM; Openness to Challenge – one's confidence in working through difficult concepts and teaching STEM concepts to others; and Willingness to Learn – one's enjoyment of learning in school. A list of individual items in each scale and reliability statistics are presented in Table 1.

Table 1. Scales and Items

Scale	Subscale	Items
STEM Identity (α=0.922)	Self-Perception (α=0.832)	• Science is something I rarely even think about. (Reverse Coded) • I would feel a loss if I were forced to give up doing science. • I really don't have any clear feelings about science. (Reverse Coded) • Science is an important part of who I am. • Being a scientist is an important part of my identity. • No one would really be surprised if I just stopped doing science. (Reverse Coded)
	External Perception (α=0.91)	• I am likely to choose a career in science. • I spend much of my time doing science related activities. • Many people think of me in terms of being a scientist. • Other people think doing science is important to me. • It is important to my friends and relatives that I continue as a scientist. • Many of the people that I know expect me to continue as a scientist.
STEM Self-Efficacy (α=0.90)	Self Confidence (α=0.84)	• I can understand difficult ideas in school. • I can explain science to my friends to help them understand. • I can get good grades in science. • I can effectively lead a team to design and build a hands-on project.

		• In lab activities, I can use what I have learned to design a solution. • I can teach myself to use new technologies. • I can use what I know to design and build something mechanical that works.
	Openness to Challenge (α=0.77)	• I look forward to math class in school. • I am capable of getting straight A's. • I like classes that are easy for me more than classes that challenge me. (Reverse Coded) • When an assignment turns out to be harder than I expected, I usually don't complete it. (Reverse Coded) • I can get good grades in math. • I can explain math to my friends to help them understand. • When I see a new math problem, I can use what I have learned to solve the problem.
	Willingness to Learn (α=0.79)	• I look forward to science classes in school. • I like learning how things work. • I can learn new ideas quickly in school. • I am good at learning new things in school. • School is easy for me. • I can get good grades in science.

Analytic Methods

Three overarching research questions drove the analyses for this project:

1. Do students report significant growth in STEM Identity or STEM Self-Efficacy after participating in one of the programs in the study?
2. Are there differences in STEM Identity and STEM Self-Efficacy growth for different demographic groups?
3. Are there differences in STEM Identity and STEM Self-Efficacy growth between summer camps and after school programs?

To test for overall changes from pre- to post-program (research question 1), paired samples t-tests were conducted for each scale and subscale. Subsequently, changes in each scale were analyzed using linear regression to test for impacts of demographic characteristics on these changes (research question 2). Covariates for each linear regression analysis included gender, race, ethnicity, enrollment in honors classes, grade in school, and STEM Capital. All of these demographic characteristics were self-reported on the pre-program survey, and STEM Capital was calculated based on students' responses to the items from Archer and colleagues' (2015) instrument. The STEM Capital survey questions can be found in Table 2.

Table 2. Items included in STEM Capital Score

STEM Capital Items
One or both of my parents sign me up to activities outside of school time (e.g. dance, music, clubs)
One or both of my parents expect me to go to college
One or both of my parents think science is very interesting
One or both of my parents think it is important for me to learn science
One or both of my parents has explained to me that science is useful for my future
One or both of my parents knows a lot about science
How often do you do the following things outside of school? - Read books or magazines about science
How often do you do the following things outside of school? - Go online to find out more about science (e.g. YouTube, science websites, science games)
How often do you do the following thing when you are NOT in school? - Go to a science center, science museum, planetarium
How often do you do the following thing when you are NOT in school? - Visit a zoo or aquarium
How often do you do the following thing when you are NOT in school? - Do experiments or use science kits
How often do you do the following thing when you are NOT in school? - Fix or build things
How often do you do the following thing when you are NOT in school? - Program computers
How often do you do the following things when you are IN school? - Go to an after-school science, technology, engineering, or math club
How often do you do the following things when you are IN school? - Attend a science presentation or talk
How often do you do the following things when you are IN school? - Take a STEM-related school trip
How often do you do the following things when you are IN school? - Take a school trip to a museum
I have learned a lot about science from museums

The outcome variables for the regression analyses were students' changes in scores for both STEM Identity and STEM Self-Efficacy. Finally, independent samples t-tests were conducted to test for differences in STEM Identity and STEM Self Efficacy changes between summer camps and after school programs (research question 3).

Results

The overall means for each scale and subscale either remained stable from pre- to post-program, or increased. In order to test for overall significance in these changes, we conducted paired samples t-tests. Of the seven scales, three had statistically significant differences: STEM Identity, External Perception, and Self Confidence. Results of these analyses are presented in Table 3.

Table 3. Paired Samples T-Test Results for Scales and Subscales

	Mean Pre	Pre SD	Mean Post	Post SD	*d*
STEM Self-Efficacy	4.1	0.51	4.1	0.56	0.07
Self Confidence	3.9	0.66	4.0	0.66	0.10*
Openness to Challenge	4.0	0.65	4.0	0.65	0.03
Willingness to Learn	4.3	0.52	4.3	0.59	0.00
STEM Identity	3.5	0.87	3.6	0.87	0.14*
Self-Perception	3.8	0.84	3.8	0.86	0.02
External Perception	3.3	0.99	3.5	0.96	0.20**

* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$

For the STEM Self-Efficacy subscales, only the Self-Confidence subscale had significant changes, indicating that participants reported a slight increase in their sense of self-confidence with STEM subjects from pre- to post-program. The overall STEM Identity scale had significant changes from pre- to post-program, indicating that overall participants experienced growth in their STEM identity after participating in the SciGirls program. These changes seem to be driven by the significant changes in the External Perception subscale (Table 3). This indicates that youths' views of themselves as "STEM people" did not necessarily change after participating in a SciGirls program, but their idea of how much other people perceive them as "STEM people" did change. In practical terms, this means that the participants felt recognized by others (e.g.

educators, role models, peers) during their respective SciGirls program which resulted in improved External Perception scores.

Another area of interest for this project was the role of demographic characteristics in shaping STEM Identity and STEM Self-Efficacy. In order to test for significant impacts of gender, race, ethnicity, enrollment/non-enrollment in honors classes, grade in school, and STEM Capital, we ran linear regression analyses with these variables as controls and youths' change in scores for STEM Identity and STEM Self-Efficacy as the outcome variables. Results from these analyses are presented in tables 4 and 5. For STEM Self-Efficacy, none of the demographic characteristics had a significant relationship to changes in youths' scores (Table 4).

Self-Efficacy Table 4. Regression Results for STEM Self-Efficacy

	β	Standard Error
Gender	0.169	0.131
Asian	-0.026	0.091
Black or African American	-0.013	0.073
White or Caucasian	-0.085	0.063
Hispanic or Latino/a	-0.113	0.072
STEM Capital	0.001	0.002
Honors Enrollment	-0.003	0.053
Grade	0.007	0.024

* = p<0.05, ** = p<0.01, *** = p<0.001

Table 5. Regression Results for STEM Identity

	β	Standard Error
Gender	-0.171	0.260
Asian	0.130	0.236
Black or African American	-0.007	0.155
White or Caucasian	-0.023	0.134
Hispanic or Latino/a	0.165	0.147
STEM Capital	-0.002	0.005
Honors Enrollment	-0.021	0.111
Grade	-0.121*	0.049

* = p<0.05, ** = p<0.01, *** = p<0.001

The only significant influence observed was participants' grade in school (Table 5). Results of the regression analyses showed that as youth increased their grade level in school, their STEM Identity score dropped by about 0.12. These results suggest that as individuals progress through school, they begin to lose their sense of belonging and perception of competence in STEM, a finding that is consistent with other research in STEM informal education (Jayaratne et al., 2003; Roberts & Hughes, 2019). None of the other demographic characteristics examined had a significant impact on change scores for STEM Identity.

Since the overall results indicated significant changes from pre- to post-program in STEM Identity, we were curious to see if the type of program in which a youth participated had any impacts on STEM Self-Efficacy or STEM Identity score changes. In order to examine these differences, we conducted an independent sample t-tests on average change scores for summer camps versus afterschool programs. Results of this analysis are presented in Table 6.

Table 6. Changes in STEM Identity and Self-Efficacy by Program Type

	After School Programs		Summer Camps	
	Mean	SD	Mean	SD
Change in STEM Self-Efficacy	0.02	0.32	0.04	0.24
Change in STEM Identity	0.26	0.75	0.08	0.48

* = p<0.05, ** = p<0.01, *** = p<0.001

The results showed that after school programs on average had greater change scores for STEM Identity, but the difference between these two scores was not statistically significant. The difference in change scores for STEM Self-Efficacy was minimal between the two program types. This non-significant finding could be related to the longer time span for afterschool programs compared to summer programs but a larger sample size would be required to better study this phenomenon.

To further explore the potential differences between sites, we examined pre- and post-program scores for STEM Self-Efficacy and STEM Identity for each site individually, and changes across time for each site. For each individual site, we ran paired-sample t-tests on pre- and post-scores for each metric. Overall, the scores across the sites seem to be relatively stable. While some sites had greater pre- to post-changes than others, only one site had results that stood out from the group – Site 2 and this was only for STEM Self-Efficacy. However, the p-values for these analyses should be interpreted with caution as the sample sizes for the groups were small. Full results for the site-specific analyses can be found in Appendix A.

Conclusions and Significance

The overarching research question driving this study asked whether programmatic use of the SciGirls strategies in informal STEM programs impacted STEM identity. Our results show that these strategies utilized within safe and engaging learning environments positively impacted the STEM Identity of participating youth. These findings are valuable to the field because no previous study has focused on STEM identity changes across programs with similar programmatic structures. Additionally, our results indicated that the impacts of these programs were relatively uniform across demographic subgroups, meaning that the program had consistent impacts for participants, regardless of their demographic characteristics.

Our analyses shed some light on the potential differences between afterschool and summer informal STEM education programs. While we found no statistically significant differences, the average change in youths’ STEM Identity was larger in afterschool programs. This highlights that afterschool programs may play a more valuable role in helping to develop youths’ interest in STEM fields because they engage youth for longer periods of time than summer camps. But more research is needed to determine whether there are significant differences in the impact of afterschool programs versus summer camps.

These findings, when taken together, emphasize the impact that informal STEM education programs have on participating youths' STEM identity, particularly the role of external recognition. Our results showed that participants experienced a positive increase in how much others saw them as STEM people. This supports the value of recognition on youths' STEM identity development. Future research is needed to parse out what types of recognition work for whom and in what contexts.

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Appendix A. Scale Changes by Site

	Site Type	Mean STEM Capital	SD	STEM Self-Efficacy Pre	SD	STEM Self - Efficacy Post	SD	*d*	STEM Identity Pre	SD	STEM Identity Post	SD	*d*
Site 1	After School	2.4	14.65	3.8	0.74	3.8	0.65	0.00	3.3	1.01	3.1	0.95	-0.20
Site 2	Camp	5.2	11.27	4.1	0.56	4.2	0.58	0.18*	3.3	0.89	3.3	0.76	0.00
Site 3	Camp	4.8	7.96	3.8	0.73	3.9	0.57	0.15	3.1	0.73	3.1	0.62	0.00
Site 4	After School	-9.3	20.74	3.6	0.63	3.7	1.24	0.10	2.2	1.25	3.1	1.80	0.58
Site 5	Camp	15.3	8.57	4.3	0.43	4.4	0.49	0.22	4.0	0.67	4.0	0.81	0.00
Site 6	After School	0.0	9.98	3.8	0.58	3.8	0.54	0.00	2.8	0.83	3.2	0.88	0.47
Site 7	Camp	11.1	9.13	4.1	0.43	4.1	0.45	0.00	3.8	0.63	4.1	0.77	0.43
Site 8	After School	8.5	10.92	3.6	0.51	4.2	0.57	1.11	3.5	0.38	3.8	0.65	0.56
Site 9	After School	-5.8	13.46	3.9	0.32	4.2	0.08	1.29	3.0	0.60	3.1	0.89	0.13
Site 10*	Camp	-5.5	14.85	-	-	-	-	-	4.1	0.94	4.0	0.24	-0.15
Site 11	Camp	-9.1	7.75	4.1	0.81	3.6	1.02	-0.54	2.9	1.14	3.4	0.55	0.56

*Only one youth completed the pre-survey at this site, so their scores have been redacted to protect anonymity.