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Pre-College Summer Program in Entrepreneurial and Design Thinking Influences STEM Success for African American Students

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ABSTRACT: Sustained innovation and economic strength of the U.S depends on a greater participation of underrepresented minorities in science, technology, engineering, and mathematics (STEM). University-based outreach programs that serve African American and other minority populations should do more to infuse invention education in activities that engage pre-college students from these groups to motivate them to pursue STEM degrees. The Research, Discovery, and Innovation (RDI) Summer Institute is a design and science entrepreneurship program that is offered at North Carolina Central University to high school seniors who have been accepted for admission to a STEM degree program at the university. This study found the RDI Summer Institute program to be effective based on proximal outcomes of gains in composite entrepreneurial thinking skills (entrepreneurial, managerial, engineering design, and technical skills) as perceived by the participants and measured by pre- and post-surveys. Eighty-seven percent of the pre-college participants were African Americans, showed high levels of creativity and innovativeness, and presented product ideas that were conscientious in meeting their community needs. Program impact was assessed based on near-term and distal academic outcomes in college through a rigorously designed quasi-experiment which compared 31 case-control matched pairs of students who had been RDI participants and non-RDI participants. A conditional logistic regression showed first-year retention in STEM degree programs for students who had been RDI participants was five times that of students who had been non-RDI participants. Additionally, first-year STEM retention in differential comparisons favored female students, students from very low/low SES households, and students from single parent households. Also, students who had been RDI participants performed higher in STEM gatekeeper courses, and a strong positive impact of the RDI Summer Institute program was associated with higher STEM persistence even two and three years after pre-college students participated.

INTRODUCTION

Innovation is one of the most important drivers of economic growth in the United States. Over 90% of innovators and entrepreneurs hold undergraduate degrees in engineering, physical and life sciences, and mathematics, and many have advanced degrees and work experience in major technology companies (Gompers and Wang, 2017; Nager et al., 2016). However, the science, technology, engineering, and mathematics (STEM) workforce continues to fall short in gender and ethnic diversity when compared to the overall population of the United States (U.S.). Although women make up 48 percent of the U.S. workforce and earn half of the bachelor's degrees in STEM, they represent only 27 percent of STEM workers. Whereas African Americans comprise 14 percent of the U.S. population, they represent 11 percent of the overall U.S. workforce, but only 9 percent of STEM workers. People who identify as Hispanic make up 16 percent of the workforce, but only 7 percent of all STEM workers (Gladstone Institutes, 2021). Disparities in the innovation space parallel these disparities in the STEM workforce. Only 12% women, 2% Hispanics, and less than 0.05% African Americans are represented in the pool of U.S.-born innovators (Bell et al., 2019; Gompers and Wang, 2017; Fechner and Shapanka, 2018; McEwen et al., 2022; Nager et al., 2016). The persistent challenge of producing and retaining enough STEM talent in the U.S., not only threatens a shortage in the science and engineering workforce (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007, 2010, 2011; National Science Board, 2022a), but also a decline in innovation progress, where innovation output in the U.S. is already trending downward (Fechner and Shapanka, 2018; National Science Board, 2022c). At present, the percentage of science and engineering bachelor's degrees awarded averages only 24.6% to underrepresented minorities (15.7% to Hispanics, 8.5% to African Americans, 0.4% to Native Americans), and the science and engineering workforce is only 8% of Hispanics and 7% of African Americans who have bachelor's degrees or higher (National Science Board, 2022a, 2022b). With the demographics of the U.S. population moving towards "majority minority", with minorities already comprising 40% of the college-age population (Frey, 2018; Vespa et al., 2018), the innovation and economic strength of the U.S. will depend on a greater production and participation of underrepresented minorities with STEM degrees (Fechner and Shapanka, 2018; Gompers and Wang, 2017; Nager et al., 2016).

Whereas the attrition rate of college entrants who initially begin STEM degree programs is 48%, the departure rate is even higher for underrepresented minority students (Chen 2013; Chen and Ho, 2012; Reason et al., 2006). Factors identified in the literature to be associated with lower rates of persistence and degree attainment of students in STEM, include background characteristics such as first-generation college student status, low socio-economic family status, and pre-college academic under-preparedness, and these factors are reflected in underrepresented minority student populations at high incidence (Chang et al., 2014; Crisp et al., 2009; DeAngelo et al., 2011; McCarron and Inkelas, 2006; Nunez and Cuccaro-Alamin, 1998; Smyth and McArdle, 2004; Terenzini et al., 2001). Race, gender, and socioeconomic status are also influencing factors in development of skills needed for innovation success and exposure to inventor role models (Bell et al., 2016, 2019; Fechner and Shapanka, 2018; Gompers and Wang, 2017; Hosler, 2019; Wilson et al., 2004). Fortunately, there are STEM educational support programs in-college, which have been shown to work in helping overcome disadvantages that some students' background characteristics might present to their academic success and persistence in STEM degree programs (Barlow and Villarejo, 2004; Carter, 2006; Chang et al., 2014). And importantly, there are university-based outreach programs that reach students, pre-college, aimed at promoting, recruiting, preparing, and enrolling them for STEM degree programs (Ashley et al., 2017; Bachman et al., 2008; Cappelli et al., 2019; Chávez et al., 2019; Constan and Spicer, 2015; Elam et al., 2012; Findley-Van Nostrand and Pollenz, 2017; Martinez et al., 2012; Murphy et al., 2010; Zhou, 2020; Zhou et al., 2017). These university-based academic outreach programs range from one-week summer camps to bridge programs that may stretch an entire summer. Their purposes often range from promoting interest and learning in STEM to intensive pre-college academic preparation.

Invention education outreach programs are new options and can offer promising strategies that also engage and empower pre-college students in STEM learning and sustain their interest in STEM and can prepare them to become future inventors and innovators (Boice et al., 2020; Couch et al., 2019; Ghazzawi, 2010; Hosler, 2019; Wilson et al., 2004; Zhang et al., 2019). It is beneficial to provide students with early exposure to design so that they can see and do what scientists and engineers do as they engage in basic elements of the design process with authentic projects (Terenzini et al., 1999). Cultivating innovation through design experiences and opportunities to practice being inventive may have near and long-term impacts on student outcomes such as science and inventor identity development, innovation and entrepreneurial aspirations, college-going, and STEM career intentions. Including activities that encourage students to generate novel and useful ideas that have market value, where they design, build, and test prototypes, and communicate technical information are important elements of experiences that can motivate students to be innovators and entrepreneurs (Dumas and Ero-Tolliver, 2021; Dym et al., 2005; Hosler, 2019; Shartrand et al., 2008).

It is worthwhile encouraging students who are already interested and motivated to realize their ambitions of pursuing a STEM career (Constan and Spicer, 2015), while giving significant attention to efforts of reducing disparities in achievement, and other breakdowns in the STEM pipeline for traditionally underrepresented minority students (Murphy et al., 2010). Graduating high school seniors who are underrepresented minorities, who have applied to college with intent to major in STEM, and who have received acceptance notice from the university should benefit greatly from an innovation and entrepreneurial enrichment experience prior to their college enrollment as much as from an academic enrichment experience (Constan and Spicer, 2015; Findley-Van Nostrand and Pollenz, 2017; Murphy et al., 2010). Therefore, a university-based summer program that offers engineering design skills training, coupled with entrepreneurship content and practice, should have a positive impact on academic performance, retention, and other outcomes for students as they move into STEM degree programs (Dabbagh and Menascé, 2006; Duval-Couetil et al., 2012; Ohland et al., 2004).

Entrepreneurship education in science departments at historically black colleges and universities (HBCUs) typically has not existed (Addae et al., 2015), consequently, little is known about the impact of science entrepreneurship enrichment programs on academic outcomes in STEM for African American students. Therefore, designing quality studies of STEM summer programs is crucial for successfully determining program effectiveness and impact (Constan and Spicer, 2015; Wilkerson and Haden, 2014), yet few studies are rigorously designed to measure specific program outcomes (Ashley et al., 2017) and to accurately capture any knowledge or skill acquisition that reflects outreach participants' experiences in the program (Cappelli et al., 2019; Constan and Spicer, 2015). Although there is literature that reports on the benefits of university-based STEM outreach programs, more research is needed to make generalizable decisions concerning factors that differentiate the success of the programs (Young et al., 2017).

In this paper, we present a novel, pre-college summer program in design and science entrepreneurship, and we conduct rigorous analyses of program effectiveness associated with the proximal outcomes and program impact associated with the near-term and more distal outcomes. We examine whether the program improves design and entrepreneurial thinking competencies, and we investigate whether program participation influences future academic success. We hypothesized that this pre-college summer program in design and science entrepreneurship would be effective and would have significant positive association on near-term first-year student retention in a STEM degree program in college. Further, we hypothesized that a pre-college student's initial success in a STEM degree program in college would positively affect their persistence in subsequent years, however with a small sample size in this study, we may not have sufficient power to observe statistically significant association between the pre-college summer program in design and science entrepreneurship and STEM persistence 2 and 3 years out.

METHODS

Design.

Setting. North Carolina Central University (NCCU), a historically black college/university (HBCU) received a grant from the Historically Black Colleges and Universities Undergraduate Program (HBCU-UP) of the National Science Foundation (NSF), for a project entitled "DREAM STEM—Driving Research, Entrepreneurship, and Academics through Mastering STEM." The NSF established the HBCU-UP to enhance the quality of undergraduate STEM education and research at HBCUs to help in broadening the participation of underrepresented minorities in the nation's STEM workforce (Clewell et al., 2010). The DREAM STEM Project offers the Research, Discovery, and Innovation (RDI) Summer Institute to pre-college students who have been accepted for admission to a STEM degree program at NCCU. The RDI Summer Institute provides experiential learning in the research-design-build part of the entrepreneurship cycle to enhance science competence through creative design and discovery of new technologies and products (Barker and Hall, 2004; Carlson and Sullivan, 2002; Kim and Fish, 2010), and to develop entrepreneurial thinking skills to enable students to recognize and act on opportunities (Krueger, 2005; Shane et al., 2003). Initial funding from NSF for the DREAM STEM Project began in 2012, and subsequent NSF funding in 2017 and 2018 supported continuation of project activities, especially the RDI Summer Institute.

Entrepreneurial Thinking. Central to the definition of entrepreneurship are perceiving, seeking, and acting upon opportunities (Kruger, 2005). Entrepreneurial thinking has been defined by Mitchell and colleagues (2002) as the mental models that people use to make assessments, judgments, or decisions involving opportunity evaluation, venture creation, and growth (Mitchell et al., 2002). Key competencies that reflect entrepreneurial thinking fall in three broad categories of skills (Lichtenstein and Lyons, 1996, 2006; Lucas et al., 2009; Mitchelmore and Rowley, 2010):

- Entrepreneurial Skills—ability to recognize and take advantage of opportunities, generate ideas, and create solutions that capture those opportunities.
- Managerial Skills—ability to organize, coordinate, and manage business operations.
- Technical Skills—ability to conceptualize, analyze, and perform the key functions required in the specialized field.

A fourth category of entrepreneurial thinking competencies (Chegini and Khoshtinat, 2011; Lichtenstein and Lyons, 1996, 2001, 2006; Smith et al., 2007) comprise personal characteristics of the individual:

- Personal Traits—decision-making ability, ability and willingness to accept responsibility, self-awareness, and emotional intelligence.

Mitchelmore and Rowley (2010) and Lichtenstein and Lyons (1996, 2006) presented frameworks for entrepreneurial competencies; however, they did not present a corresponding measurement instrument. The DREAM STEM Project team, along with the external evaluator, constructed a survey to measure entrepreneurial competencies based on a preponderance of literature (Chen et al., 1998; Chang and Rieple, 2013; Lichtenstein and Lyons, 2006; Lucas, et al., 2009; Mitchelmore and Rowley, 2010; Smith et al., 2007; Schelfhout et al., 2016). The survey addressed four categories of competencies to measure participants' perceptions of their entrepreneurial knowledge and skills. The survey also addressed two categories of competencies to measure participants' perceptions of their Design Skills and Technical Communication.

Engineering Design. Informed design is a pedagogical approach for design training which enables inexperienced students to enhance their own related knowledge and skills base before attempting to explore design solutions (Burghardt and Hacker, 2004). This is done through a just-in-time manner of performing short, focused activities known as "Knowledge and Skill Builders", or "KSBs", which provide structured inquiry learning about key technology, science and mathematics process skills, and concepts that underpin the design problem (Burghardt and Hacker, 2004; Forsberg, 2007). The RDI Summer Institute applies informed design to guide engineering design learning and skills development.

Measures. Assessing the effectiveness and impact of an intervention requires making inferences about the outcomes observed for participants due to the program, compared to outcomes had the program not existed. Through the administration of pre- and post-surveys, we collect data on participants' self-report perceptions of their design skills and entrepreneurial competencies before and after the program. We then generate results on program impacts by a quasi-experimental analysis comparing near-term and distal academic outcomes for statistically equivalent matched pairs of program participants and non-participants (Marks, 2003). Table 1 presents the operational definitions of the variables used in the current study.

Table 1. *Operational Definition of Variables.*

Variable	Description
Independent Variables	
Group Affiliation (RDI Summer Institute)	A categorical variable was coded: 1 = Participant in RDI program; 0 = Non-Participant in RDI program.
Program Outcome Variables	
Entrepreneurial Skills	7 items; 5-point Likert scale.
Managerial Skills	11 items; 5-point Likert scale.
Technical Skills	7 items; 5-point Likert scale.
Personal Traits	8 items; 5-point Likert scale.
Engineering Design Skills	5 items; 5-point Likert scale.
Technical Communication	5 items; 5-point Likert scale.
Near-Term and Distal Outcome Variables	
GPA	The Grade Point Average (GPA) of the student computed on earned credits for completed courses.
Retention Rate	The percentage of first-time, full-time freshman students who re-enrolled the next fall semester after their first fall semester enrollment at the institution.
Persistence Rate	The percentage of first-time, full-time freshman students who re-enrolled in their major continuously in subsequent years after the year of their first enrollment in that major at the institution.

Procedure. The Research, Discovery, and Innovation (RDI) Summer Institute is a 5-week, residential STEM pre-college outreach program on the campus of North Carolina Central University. Participants for RDI Summer Institute have been recruited each year from the admission accepted students list provided by NCCU Admissions Office. The minimum requirement for admission to NCCU is a 2.5 high school GPA. The opportunity to participate in the RDI Summer Institute is used as an incentive to help boost enrollment in the undergraduate degree programs of Chemistry, Environmental Science, Mathematics, and Physics. Each year approximately 150 names on the admission accepted list are pre-college students who have been accepted into these undergraduate degree programs. Because of program costs, however, only residents of the State of North Carolina are considered for the RDI Summer Institute with priority consideration for those who are from underrepresented minority groups. This reduces the list of admission accepted pre-college students to approximately 40 names which are selected for recruitment to RDI Summer Institute. Recruitment efforts begin with invitation letters about the opportunity being sent and cold calls being made to identify the pre-college students who have committed to attending NCCU in the following fall semester. Those pre-college students who express interest in participating in the RDI Summer Institute are sent applications, and all who complete the application process are accepted. There have been as few as four to as many as nine pre-college students per year participating in the RDI Summer Institute.

The RDI Summer Institute starts at the end of June when high school students have graduated and lasts until the end of July, before the start of their first semester in college. There are no academic prerequisites or specific background requirements for participants. RDI participants complete a pre-survey on the first day and a post-survey on the last day of the program. Participants earn a $1100 stipend and a certificate of participation when they complete the program.

The RDI Summer Institute staff is composed of two professors, a laboratory manager, a graduate student, and an administrative assistant. Guest trainers or lecturers include entrepreneurs-in-residence, Service Corps of Retired Executives (SCORE) mentors, and business owners. The RDI Summer Institute consists of a laboratory and a classroom lecture. Figure 1 shows a sample RDI Summer Institute schedule of activities.

The Engineering Design and Engineering Lab sessions were led by an engineering physics professor, who is one of the co-authors. In the instructional part of the Engineering Design and Engineering Lab, participants engage in the creative design process, acquiring conceptual knowledge with just-in-time learning from Knowledge Skill Builders (KSBs). They then apply this knowledge through experimenting and testing in a hands-on laboratory context. After acquiring basic design skills, RDI participants are to identify a technological problem or need in their everyday lives and to think of a solution to address that problem or need. They

RDI Summer: June 27th – July 29th (excluding holidays)

	Time	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1	9:00 – 10:00	**Orientation** Pre-Assessments	Engineering Design Session	Engineering Design Session	Math Session	Entrepreneurship Session
	10:00 – 11:00					
	11:00 – 12:00					
	12:00 – 1:00	Lunch	Lunch	Lunch	Lunch	
	1:00 – 2:00	Professional Development (PD) Session	SolidWorks Training	Engineering Lab Session	SolidWorks Training	
	2:00 – 3:00					
	3:00 – 4:00					
		Monday	Tuesday	Wednesday	Thursday	Friday
Week 2	9:00 – 10:00	Engineering Design Session	SolidWorks Training	Engineering Design Session	Math Session	Entrepreneurship Session
	10:00 – 11:00					
	11:00 – 12:00					
	12:00 – 1:00	Lunch	Lunch	Lunch	Lunch	
	1:00 – 2:00	Engineering Lab Session	Engineering Lab Session	Engineering Lab Session	SolidWorks Training	
	2:00 – 3:00					
	3:00 – 4:00					
		Monday	Tuesday	Wednesday	Thursday	Friday
Week 3	9:00 – 10:00	Engineering Design Session	SolidWorks Training	Engineering Design Session	Math Session	Entrepreneurship Session
	10:00 – 11:00					
	11:00 – 12:00					
	12:00 – 1:00	Lunch	Lunch	Lunch	Lunch	
	1:00 – 2:00	Engineering Lab Session	Engineering Lab Session	Engineering Lab Session	SolidWorks Training	
	2:00 – 3:00					
	3:00 – 4:00					
		Monday	Tuesday	Wednesday	Thursday	Friday
Week 4	9:00 – 10:00	Engineering Design Session	SolidWorks Training	Professional Development	Math Session	Entrepreneurship Session
	10:00 – 11:00					
	11:00 – 12:00					
	12:00 – 1:00	Lunch	Lunch	Lunch	Lunch	
	1:00 – 2:00	Engineering Lab Session	Engineering Lab Session	Engineering Lab Session	SolidWorks Training	
	2:00 – 3:00					
	3:00 – 4:00					
		Monday	Tuesday	Wednesday	Thursday	Friday
Week 5	9:00 – 10:00	Engineering Design Session	SolidWorks Training	Professional Development	Math Session	**Closing Ceremony** Post-Assessments
	10:00 – 11:00					
	11:00 – 12:00					
	12:00 – 1:00	Lunch	Lunch	Lunch	Lunch	
	1:00 – 2:00	Engineering Lab Session	Engineering Lab Session	Engineering Lab Session	Engineering Lab Session	
	2:00 – 3:00					
	3:00 – 4:00					

Figure 1. Sample RDI Summer Institute Schedule of Activities.

then proceed to design, build, and develop a prototype and evaluate their idea or solution. Specific KSBs supporting engineering design have included: electrical circuits theory, calculations, and measurements; reading and interpreting electrical schematics, breadboarding, and mini-CPU programming; electrical circuit design, build, and testing; lab safety. A laboratory manager maintains the individual design lab workbench stations and a graduate student assists with lab setup. Each RDI participant has a workbench which is supplied with electronics lab equipment for circuit assembly and testing. In laboratory sessions, RDI participants are provided Arduino kits with Proteus Circuit simulator software to develop hands-on design and build skills in microprocessor programming and control, and skills in system design and data analysis. RDI participants also learn 3D modeling with SolidWorks and rapid prototyping with 3D printers. RDI participants then work individually on their project, developing and constructing models of their ideas, fabricating prototypes, and evaluating and refining their product design.

The Entrepreneurial Thinking sessions were led by Entrepreneurs-in-residence at NCCU through Summer 2019. Later sessions were led by a physics professor, also one of the co-authors, who was trained in the National Science Foundation's Innovation Corps (I-Corps™) program. The NSF I-Corps was created to help scientists and engineers explore the commercial potential of technologies developed in university laboratories to help move products out of the lab and into the marketplace. The entrepreneurial thinking sessions were held in a classroom setting. In these sessions, RDI participants engaged in entrepreneurial opportunity identification and product feasibility analysis, learned about customer discovery and how to develop a business model, identified financing sources for their venture, and prepared a business pitch of their product. The problem that RDI participants identified in the engineering design/lab sessions was the subject of discussion and activities in the entrepreneurial thinking sessions. RDI participants worked on the development of their value proposition and were introduced to the Business Model Canvas and the Customer Discovery process. They learned and specifically used the Lean Canvas to help them (1) define the problem or unmet need they were addressing, (2) investigate existing alternatives, (3) describe their solution, (4) describe their product features, and (5) describe the competitive advantages of their product. Invited guest speakers from SCORE and from NCCU School of Law Intellectual Property (IP) Clinic helped participants explore how new products are commercialized and how intellectual property is protected. RDI participants receive a business presentation outline to help them prepare their business pitch presentation. RDI participants make a presentation of their product and demonstration of their prototype in a closing ceremony at the end of the program, and each participant receives a certificate of participation.

Data Analysis.

Data Sources. In the current study, the primary program data were from pre- and post-surveys administered to participants at the beginning and at the end of the RDI Summer Institute. The pre-survey was designed to gather basic descriptive data on student participants, including name, intended major, prior experience with research and/or entrepreneurship programs, and expectations for participating in the RDI Summer Institute. Prior to starting the program, participants also rated their career interests, confidence in STEM knowledge, participation in co-curricular activities, and level of confidence in their skills in areas such as entrepreneurship, management, design, scientific literacy, communication, and data analysis. A post-survey that included many of the items from the pre-survey, especially those focused on levels of confidence, was administered on the last day of the program to measure participants' growth. Both surveys were administered through SurveyMonkey and analyzed by the external evaluator, who is one of the co-authors. While the pre- and post-surveys were primarily composed of closed-ended items, several open-ended items were also included to gather qualitative data that could potentially support quantitative findings and suggest program improvement. These open-ended items included participants explaining why they planned to pursue their career choice, explaining program aspects and activities that were most/least valuable in preparing them for their academics and future, and identifying areas that were most strengthened because of participating in the program. (See Supplementary Materials for full copies of both surveys.)

Data on student records for program participants and for the general population of first-time, full-time (FTFT) freshman STEM students enrolled at the university were provided by the NCCU Office of Institutional Research and Analysis (IRA) and Information Technology Services (ITS). These data include information on demographics and family background, pre-college academic record, college admit term and initial major, as well as graduation records for the students. To assess program impacts, we conducted a retrospective quasi-experiment to test for differences in first-year retention between STEM students who had been RDI participants, and a comparison group (non-RDI participants) drawn from the general population of STEM students at NCCU. As assignment to conditions in quasi-experiments is not by random act, selection bias is a threat to internal validity of causal inference, therefore we performed case-control matching and analysis to adjust for confounding and other threats to validity in the impact study. The approach enables us to attribute any differences between outcomes of participants and the matched group, to the program with higher confidence (Caliendo and Kopeinig, 2008; Cook, et al., 2002; De Graaf, et al., 2011).

Case-Control Matching. The simplest example of a matched design in case-control studies is one case matched to a single control and a single binary outcome. Then a variable is defined to represent the treatment condition for each subject in the sample. A case is then matched to a control. The matching variables could be gender, age, race, or other stable and reliable covariates (Breslow and Day, 1980; Hosmer et al., 2013).

The general population of FTFT freshman STEM students and the RDI participants both self-identify with science by virtue of having applied to and been accepted into a STEM degree program, which should reduce selection bias effects. Drawing a sample from this general population of FTFT freshman STEM students and matching to RDI participants can further reduce the effects of selection bias. In case-control study, better matching results can be achieved when the matching variables are stable and reliable (Cook et al., 2002). Five variables known to affect academic outcomes were identified for case-control matching: gender, race/ethnicity, HS GPA, Total SAT, and admitted academic major. Based on these covariates, we conducted a one-to-one case-control matching analysis using IBM SPSS 27 (IBM SPSS 27, 2021). The parameters for the case-control matching were set such that gender, race, and STEM major were to match exactly. The parameters for HS GPA and SAT were set for a maximum delta of 0.95 for HS GPA and maximum delta of 325 for Total SAT. The period of the retention and persistence in STEM study was from Fall 2013 to Fall 2021. Case-control matching analysis was run with 34 RDI participants and 1734 FTFT freshman STEM majors who were not RDI participants. After analysis, there were 31 case-control matched pairs.

Conditional Logistic Regression. In case-control studies, a case subject is assigned a treatment variable value equal to 1 and a control subject is assigned a treatment variable value equal to 0. There are then two subjects in each stratum (group), or one case-control pair. The total number of strata (groups) equals the total number of case control matched pairs. The values of relevant other covariates are then measured for each subject in a stratum. Therefore, the effect of a given covariate on the binary response variable is measured relative to the covariate values within the matched group—a conditional likelihood, rather than relative to all values of the covariates in the dataset as is the case in regular logistic regression. (Hosmer et al., 2013, p. 246).

Conditional logistic regression is the standard for analyzing matched case-control data. With a binary response value equal to 1 for an event and equal to 0 for a non-event, the possible outcomes for a single case-control pair can be represented by four 2×2 tables (Breslow and Day, 1980, p. 164). When dichotomous covariates present identical data for the case and the control, called concordant pairs, two of the four table configurations of outcomes show both the case and the control for an event, or both the case and the control for a non-event. These concordant pairs contribute no information for estimation of the covariates’ coefficient and therefore contribute no information about the odds ratio. The remaining two of four table configurations of outcomes show either the case alone or the control alone for an event, which result from discordant pairs. Discordant pairs do contribute information for estimation of the covariates’ coefficient and hence do contribute information about the odds ratio. The practical significance of this is that the maximum likelihood estimator of the covariate’s coefficient may be based on a fraction of the total number of possible case-control pairs to determine the result (Breslow and Day, 1980, Hosmer et al., 2013), and the odds ratio is more accurately determined.

In the current study, RDI participants are the cases and non-RDI participants are the controls, for 31 case-control pairs. We conducted conditional logistic regression analysis using Stata/MP 16 (Stata, 2021) to estimate the impact on first-year retention in STEM as an outcome associated with participation in the RDI Summer Institute. Lastly, we analyzed course performance for RDI participants and non-RDI participants using GraphPad Prism version 9.5.5 for Windows (GraphPad, 2023)

Program Effectiveness. We performed paired t-test analyses on each program variable to assess program effectiveness. We calculated effect sizes using Cohen's d to assess practical significance. We also computed confidence intervals for effect size (Fritz et al., 2012).

Outcome Variables. The primary outcome variable to assess program impact is student retention in STEM after the first year in college. The main independent variable for this analysis is the RDI Summer Institute program: 31 freshman STEM majors were RDI participants, and a case-control matched 31 freshman STEM majors were non-RDI participants.

Participants. Participants in the RDI Summer Institute were recruited in the Spring from a list, provided by the NCCU Admissions Office, of high school students who applied and were accepted to NCCU for the upcoming Fall semester as FTFT freshman STEM majors. Having names on an admission-accepted students list is no guarantee that a given high school student will choose to enroll at NCCU in the Fall. Therefore, inviting admission-accepted pre-college students to participate in the residential RDI Summer Institute, which also pays a stipend, is a recruitment strategy of the DREAM STEM Project that increases the likelihood that an accepted student will commit to enrolling in a STEM degree program at NCCU.

RDI Survey Respondents. The period of study for the RDI Summer Institute is from Summer 2013 through Summer 2022. Data were collected on participants each summer of the program in the form of a pre- and a post-survey. There was a total of 39 RDI participants during the study period. The demographics were 11 Black Females (28%), 1 Asian Male (3%), 23 Black Males (87%), 3 Hispanic Males (8%), 1 White Male (3%). The average age of these participants was 18.85 years old. However, only 24 RDI participants submitted both pre- and post-surveys, therefore only those 24 participants were included in the analysis and results on program effectiveness of the RDI Summer Institute. For this subset of participants, the demographics were 6 Black females, 15 Black males, and 3 Hispanic males.

Matched Pairs. Although there were 39 RDI participants during the study period, five (5) participants in the Summer 2022 cohort had not entered college yet to have generated academic records at NCCU. Consequently, 34 RDI participants with academic records at NCCU were in the case-control matching analysis. This analysis generated 31 case-control matched pairs: 31 RDI participants and 31 non-RDI participants of the RDI Summer Institute. This study had NCCU Institutional Review Board (IRB) approval (#1201408), and we followed appropriate guidelines.

Figure 2. Product Prototypes of RDI Participants.

RESULTS

Design and Science Entrepreneurship Product Prototypes of RDI Participants. At the end of the summer program in a closing ceremony, RDI participants gave oral presentations of their product ideas along with a demonstration of their product prototypes which they designed and built. They submitted a promotional or advertising product flyer that described their product as part of their business pitch presentation and their flyer was printed in the closing ceremony booklet. After their oral presentation, RDI participants gave a demonstration of how their product would work by operating their prototype. Often RDI participants created products that addressed problems or needs in their community from urban agriculture to alternative energy sources. Figure 2 shows three samples of the promotional flyers and a photograph of a sample of demonstration prototypes produced by RDI participants. The product ideas in the flyers shown in the upper half of Figure 2 addressed home security (A), personal safety (B), and clean energy (C). Shown in the lower half of Figure 2 is a photograph of the prototypes designed by RDI students used to demonstrate how their products work. The prototypes typically consisted of a microcontroller, electronic circuits, and electromechanical parts (motors, actuators, propellers, etc.) that came from Arduino design kits.

Descriptive Statistics of Case-Control Matched Pairs. Case-control matching analysis produced a control sample that was statistically equivalent to the sample of participants

Table 2. *Descriptive Statistics for Case-Control Matched RDI Participants and Non-RDI Participants.*

	RDI Group (N=31)		Non-RDI Group (N=31)	
Variables	n	%	n	%
Gender				
Female	7	22.6%	7	22.6%
Male	24	74.4%	24	74.4%
Race/Ethnicity				
Asian	1	3.2%	1	3.2%
Black	27	87.1%	27	87.1%
Hispanic	2	6.5%	2	6.5%
White	1	3.2%	1	3.2%
Pre-College Academic Measures				
SAT Total	1107 ± 146		1088 ± 147[ns]	
High School GPA	3.6 ± 0.7		3.5 ± 0.5[ns]	
HS Rank Percentile	63 ± 27		66 ± 20[ns]	
Admitted Academic Major				
Chemistry	5	16.1%	5	16.1%
Mathematics	6	19.4%	6	19.4%
Physics	20	64.5%	20	64.5%

ns: not statistically significant via chi-square test

in the RDI Summer Institute program. Table 2 shows the descriptive statistics of the resulting 31 case-control matched pairs, RDI participants and non-RDI participants. The results show exact matches for gender, race, and initial major, and there were no significant differences in HS GPA and SAT.

Baseline Conditions. Table 3 provides descriptive statistics for non-controlled covariates, serving as baseline conditions. These include parent marital status, family socioeconomic status, and first-generation college student status. The family

Table 3. *Descriptive Statistics of Parent and Socioeconomic Variables of RDI Participants and Non-RDI Participants.*

	RDI Group (N=31)		Non-RDI Group (N=31)	
Variables	n	%	n	%
Parent Marital Status				
Single Parent Household	17	54.8%	17	54.8%
Two Parent Household	13	41.9%	13	41.9%
Missing	1	3.2%	1	3.2%
Family Socioeconomic Status (SES)[ns]				
Very Low SES	5	16.2%	7	22.6%
Low SES	6	19.4%	10	32.3%
Medium SES	12	38.7%	8	25.8%
High SES	6	19.4%	4	12.9%
Missing	2	6.5%	2	6.5%
Parent Education Level[ns]				
No college educated parents/ First-generation college student	6	19.4%	5	16.1%
High School GPA	24	77.4%	25	80.6%
HS Rank Percentile	1	3.2%	1	3.2%

ns: not statistically significant via chi-square test

Table 4. *Mean Pre- and Post-Entrepreneurial Skills Scores of RDI Participants.*

	Variable	N	Post-Mean	Pre-Mean	t-score	p-value	Effect Size
Entrepreneurial Skills		**24**	**3.9**	**3.5**	**3.73**	**.001**	**.8**
1	Developing a product plan	24	3.9	3.2	4.30	.000	.9
2	Turning ideas into feasible business opportunities	24	3.8	3.2	3.39	.003	.7
3	Use a variety of problem-solving techniques	24	4.1	3.6	2.77	.011	.6
4	Coming up with many ideas for new products or services	24	3.8	3.5	2.23	.036	.5
5	Recognizing opportunities in many situations	24	4.0	3.8	1.66	.110	.3
6	Seeking new opportunities	24	4.1	4.0	1.45	.162	.3
7	Identifying market opportunities	24	3.6	3.4	0.96	.347	

socioeconomic status (SES) variable is based on family size and household income as determined from the low-income guidelines published by the U.S. Department of Health and Human Services in the *Federal Register* (U.S. Department of Health and Human Services, 2017). The federal poverty level (FPL) is defined as a household income of $25,750 annually for a family size of 4. Therefore, approximate SES thresholds are: (i) Very Low SES < FPL, (ii) FPL < Low SES < 2FPL, (iii) 2FPL < Medium SES < 4FPL, (iv) High SES > 4FPL. Although these variables were not case-control matching parameters, the RDI participants and non-RDI participants were closely matched on these variables.

Entrepreneurial Skills. Table 4 shows results of t-test analyses of entrepreneurial skills. The scale average serves as a measure of entrepreneurial skills. The scale average was statistically significantly higher for post-test ($M = 3.92$, $SD = 0.69$) than for pre-test ($M = 3.50$, $SD = 0.58$), $t(23) = 3.73$, $p = .001$. The Cohen's d value indicates a large effect size ($d = .76$; CI[.30, 1.21]). Four of the seven items presented in Table 4 have pre- and post-survey scores that are significantly different ($p \leq .05$). Participants felt more confidence in their ability to develop a product plan, turn ideas into business opportunities, use a variety of problem-solving techniques, and come up with ideas for new products/services. Open-ended responses from participants provided additional evidence of this growth in entrepreneurial skills and additional insights in starting businesses. In the words of one participant, "This particular program allows me to be immersed in a scientific and entrepreneurial environment which allows me to see what I may truly seek as a future for myself." Another participant stated, "The RDI Program is all about the development of innovative and research skills. The development of these skills are pivotal to any aspiring scientist."

Managerial Skills. Table 5 shows results of t-test analyses of managerial skills. The scale average serves as a measure

Table 5. *Mean Pre- and Post-Managerial Skills Scores of RDI Participants.*

	Variable	N	Post-Mean	Pre-Mean	t-score	p-value	Effect Size
Managerial Skills		**24**	**3.6**	**3.1**	**2.69**	**.013**	**.5**
1	Performing a Gap Analysis	24	3.0	2.0	3.71	.001	.8
2	Developing Sales Strategies	24	3.7	3.1	3.25	.004	.7
3	Appraising and learning from competitors in the market	24	4.0	3.3	3.21	.004	.7
4	Conducting a Market Analysis	24	3.5	2.7	2.70	.013	.6
5	Developing a business plan	24	3.7	3.0	2.23	.036	.5
6	Identifying Customers	24	4.1	3.7	1.99	.059	.4
7	Making decisions intuitively	24	3.8	3.5	1.50	.148	.3
8	Developing financial and accounting plans	24	3.2	2.9	1.07	.295	.2
9	Completing the legal process of setting up a new business	24	3.1	2.8	1.05	.303	.2
10	Approaching Customers	24	3.9	3.9	.19	.852	
11	Setting standards and performance criteria for success	24	3.4	3.4	.16	.873	

of managerial skills. The scale average was statistically significantly higher for post-test (M = 3.58, SD = 0.81) than for pre-test (M = 3.11, SD = 0.71), t(23) = 2.69, p = .013. The Cohen's d value indicates a medium effect size (d = .55; CI[.11, .97]). Five of the eleven items presented in Table 5 have pre- and post-survey scores that are significantly different (p ≤ .05). Participants felt more confidence in their ability to perform gap analysis, develop sales strategies, appraise and learn from competitors, conduct market analysis, and develop a business plan.

Technical Skills. Table 6 shows results of t-test analyses of technical skills. The scale average serves as a measure of technical skills. The scale average was statistically significantly higher for post-test (M = 4.00, SD = 0.63) than for pre-test (M = 3.68, SD = 0.59), t(23) = 2.42, p = .024. The Cohen's d value indicates a medium effect size (d = .50; CI[.07, .92]). Three of the seven items presented in Table 6 have pre- and post-survey scores that are significantly different (p ≤ .05). Participants felt more confidence in their ability to apply their science knowledge, select the most promising concept, and generate alternative concepts to satisfy design requirements. Participants offered several open-ended comments on their post-survey that provide additional evidence that the RDI program helped them gain greater technical skills. Many of these comments focused on the program's hands-on approach. For example, one participant stated, "I like that I got to learn things about electronics and learning how to build things", while another stated "This program will help with real world and hands-on experience, so that I'm not lost when something similar is going on."

Table 6. *Mean Pre- and Post-Technical Skills Scores of RDI Participants.*

	Variable	N	Post-Mean	Pre-Mean	t-score	p-value	Effect Size
Technical Skills		**24**	**4.0**	**3.7**	**2.42**	**.024**	**.5**
1	Ability to apply your science knowledge to develop processes and components	24	4.0	3.3	3.24	.004	.7
2	Select the most promising concept	23	4.0	3.4	2.52	.020	.6
3	Generate alternative concepts to satisfy design requirements	23	3.8	3.4	2.11	.047	.5
4	Define the problem	23	4.1	3.8	1.78	.090	.4
5	Manage the project	23	4.0	3.9	0.94	.357	.4
6	Recognize need	23	4.0	3.9	0.90	.377	
7	Gather information	23	4.1	4.1	-0.20	.847	

Personal Traits. Table 7 shows results of t-test analyses of personal traits. The scale average serves as a measure of personal traits. The scale average was borderline statistically significantly higher for post-test (M= 4.35, SD = 0.57) than for pre-test (M = 4.14, SD = 0.55), t(23) = 2.06, p = .051). The Cohen's d value indicates a medium effect size (d = .42; CI[.00, .84]). Only one of the eight items in Table 7 has pre- and post-survey scores that are significantly different (p ≤ .05). Participants had a higher sense of belief in self, particularly in believing they had gained valuable insights into a career path that was suitable and achievable for them. In the words of one participant, "Participating in this program strengthened my career plans by giving me multiple experiences and skills."

Engineering Design Skills. Table 8 shows results of t-test analyses of engineering design skills. The scale average serves as a measure of engineering design skills. The scale

Table 7. *Mean Pre- and Post-Personal Traits Scores of RDI Participants.*

	Variable	N	Post-Mean	Pre-Mean	t-score	p-value	Effect Size
Personal Traits		**24**	**4.4**	**4.1**	**2.06**	**.051**	**.4**
1	High self-belief	24	4.4	4.1	2.14	.043	.4
2	Highly motivated and driven	23	4.4	4.1	1.67	.110	.3
3	High risk-taker	23	4.1	3.9	1.45	.162	.3
4	High control over emotions high ability to manage them	23	4.4	4.2	1.42	.171	.3
5	High ability to persevere through difficult circumstances	24	4.4	4.2	1.31	.203	.3
6	High ability to take initiative and see things through	23	4.3	4.1	1.16	.260	.2
7	Highly action-oriented	24	4.2	4.0	0.77	.450	
8	High-belief that rewards come with own effort/ hard-work	24	4.4	4.5	-0.44	.664	

Table 8. *Mean Pre- and Post-Engineering Design Skills Scores of RDI Participants*

Variable		N	Post-Mean	Pre-Mean	t-score	p-value	Effect Size
Engineering Design Skills		**23**	**3.7**	**3.3**	**2.82**	**.010**	**.6**
1	Calculating electrical characteristics	23	3.6	2.7	3.94	.001	.8
2	Measuring electrical characteristics	23	3.6	2.9	3.54	.002	.7
3	Troubleshooting a circuit	23	3.6	3.0	2.51	.020	.5
4	Implement the design	23	3.9	3.7	1.31	.203	.3
5	Communicate the design	23	3.9	4.0	-0.40	.692	

average was statistically significantly higher for post-test (M= 3.70, SD = 0.85) than for pre-test (M = 3.2.6, SD = 0.87), t(22) = 2.82, p = .01) . The Cohen's d value indicates a medium effect size (d = .59; CI[.14, 1.03]). Three of the five items in Table 8 have pre- and post-survey scores that are significantly different ($p \leq .05$). Participants felt more confidence in their ability to calculate electrical characteristics, measure electrical characteristics, and troubleshoot a circuit. Open-ended comments from participants corroborated these findings. For example, one participant stated, "In the RDI Program I strengthened my skills in Physics and electrical engineering by constantly having hands on experience with different circuits." Another participant stated at the close of the program, "My ability to understand and measure electrical characteristics of circuits was strengthened."

Technical Communication. Table 9 shows results of t-test analysis of technical communication. Neither the scale average nor any of the five items in this category have pre- and post-survey scores that are significantly different.

First-Year Retention in STEM by Program Participation. A near-term program outcome observed for RDI participants was first-year retention in STEM degree programs when they were students at NCCU. We compared first-year retention between RDI participants and matched non-RDI participants. A dichotomous group identification variable was the predictor, and the binary response variable was retention in STEM. There were 31 case-control matched pairs, with two subjects per stratum. Applying conditional logistic regression, we tested associations between group participation and retention relative to values within a stratum. Since discordant pair data contribute to the estimate of the variable coefficient and the odds ratio, only a fraction of the case-control pairs determines the result. Table 10 shows the conditional logistic regression coefficients (B), the Wald test statistic (z), odds ratio [Exp(B)], and the 95% confidence intervals (CI) for the odds ratio for the predictor. FTFT STEM freshman students who were RDI participants were 5 (CI [1.10, 22.82]) times more likely to be retained in STEM the year following their participation in the RDI program than the non-participating case-control matched comparison group.

Table 9. *Mean Pre- and Post- Technical Communication Scores of RDI Participants.*

Variable		N	Post-Mean	Pre-Mean	t-score	p-value	Effect Size
Technical Communication		**22**	**3.8**	**3.6**	**1.07**	**.298**	**.2**
1	Communicating your design project/research finding in writing to professionals in the science community	22	4.0	3.6	1.86	.076	.4
2	Critiquing the work of student peers	21	3.8	3.3	1.81	.086	.4
3	Facilitate a Q&A of Design Project/Science Research	22	3.9	3.7	0.72	.478	
4	Conducting an effective literature search	22	3.6	3.6	0.21	.833	
5	Reading and interpreting patent applications/journal articles	21	3.6	3.7	-0.30	.766	

First-Year Retention by Program Participation and Demographic Variables. Further analysis of associations was conducted with respect to participation in the RDI Summer Institute at various levels of dichotomous demographic variables. We investigated bivariate relationships using contingency tables (2x2) configured for group comparisons of first-year STEM retention by level of dichotomous demographic variable, and the Fisher's Exact Test was applied to test for associations. The back-to-back stacked bar plot in Figure 3 is an excellent visualization that shows the relative impact of the RDI Summer Institute. The data are directly from the 2x2 contingency tables of the Fisher's exact test analyzed group comparisons and are presented as the size-ordered STEM persistence rates for the different demographic variables. Three interesting factors contributed to higher retention rates for RDI participants although the statistical significance p-value exceeded the 5 percent level. Female RDI participants were retained in STEM at 100% compared to 57.1% for non-participants (p = .096); RDI participants from very low/low SES households were retained in STEM at 90.9% compared to 58.8% for non-participants (p = .077); Male RDI participants were retained at 91.7% compared to 70.8% for non-participants (p = .068). RDI participants from two parent households were retained in STEM the first year at 100% compared to non-RDI participants 61.5% (p = .02; Fisher's Exact Test).

Table 10. *Conditional Logistic Regression Model Predicting First-Year STEM Retention.*

Observed Variable	*B*	*SE B*	*z*	*P>|z|*	*Exp(B)*	*[95% CI]*
RDI Summer Institute (RDI Participant)	1.61	.77	2.08	.04	5.0	[1.10, 22.82]

LR $\chi^2(1, N_{Pairs}=12)=5.82, p=.016;$ *Pseudo* $R^2 = .35$

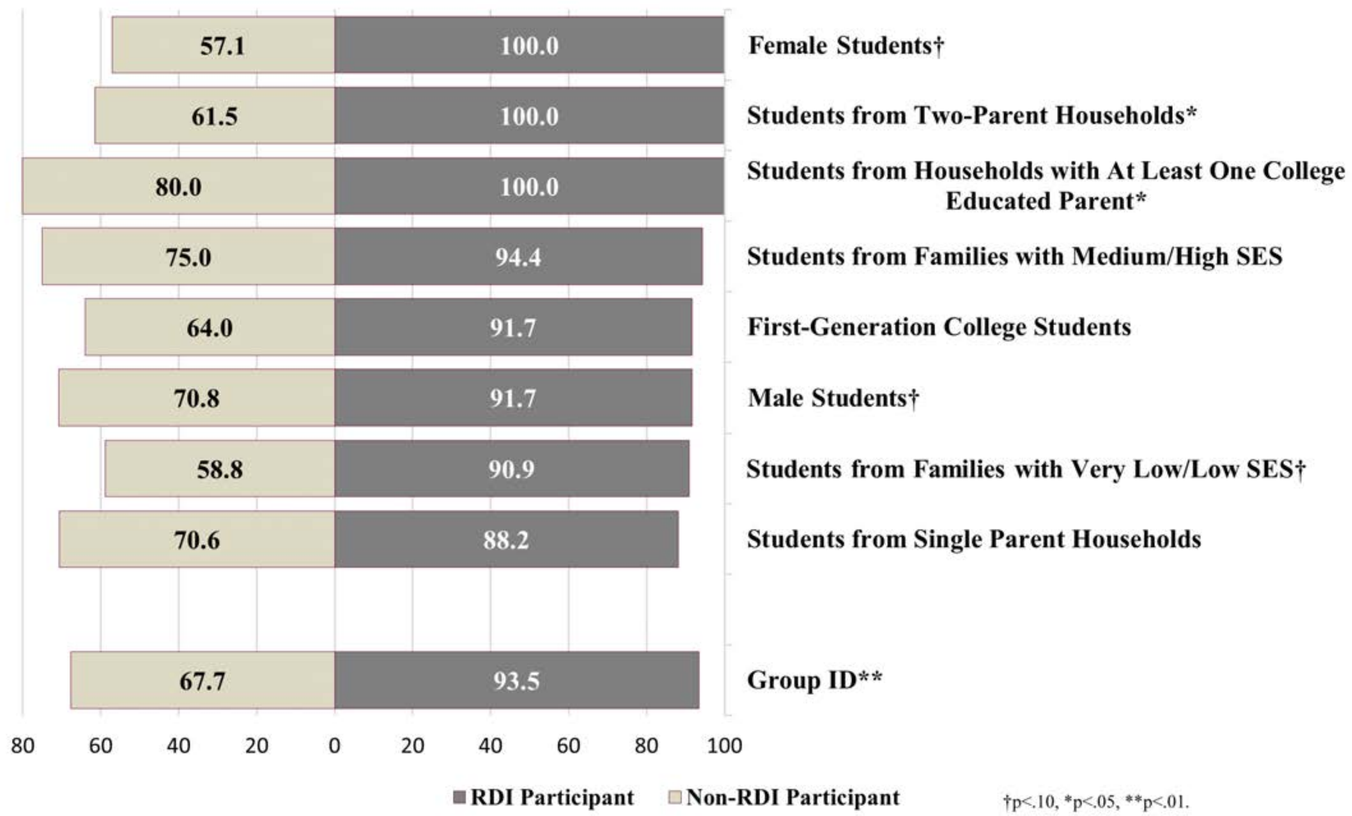

Figure 3. First-Year STEM Retention by demographic factors.

Similarly, RDI participants from households with at least one college-educated parent were retained in STEM the first year at 100% compared to non-RDI participants at 80.0% ($p = .02$). For the remaining levels of dichotomous demographic variables, group differences in STEM retention were not statistically significant.

First-Year Academic Performance by Program Participation. We analyzed near-term program outcomes of course performance for RDI participants and non-RDI participants when they were students in gatekeeper STEM courses—Algebra and Trigonometry, Calculus, Chemistry, and Physics. Figure 4 shows course performance in terms of letter grade outcomes for non-RDI students in comparison to RDI students. Letter grades and corresponding course grade point averages (GPAs) trended higher for RDI students in all four gatekeeper courses analyzed. STEM students must earn a C grade at minimum to pass a STEM course. Not passing these STEM courses means STEM students must repeat the course before they can advance to the next level of courses in their curriculum. Repeating courses, especially multiple times, is associated with student attrition in STEM degree programs. For RDI students, the mean course GPA was near or above 2.0 indicating that most RDI students passed the gatekeeper courses with a C or better. For non-RDI students, the mean course GPA was below 2.0 indicating that most of the non-RDI students did not pass the gatekeeper courses with a C or better. The largest performance difference between RDI and non-RDI students was in the Physics course. An independent-samples t-test indicated that mean course performance was significantly higher for RDI students ($M = 2.3$, $SE = .30$, $N=15$) than for non-RDI students ($M = 1.2$, $SE = .38$, $N=11$), $t(26) = 2.28$, $p < .05$.

Distal Academic Outcomes. Persistence in STEM degree programs in the later 2 or more years is a distal measure of program impact. Figure 5 shows the comparison of STEM persistence for RDI participants and non-RDI participants to the third year in college. After initial enrollment, students who had been RDI participants persisted in STEM each subsequent year at statistically significantly higher rates than the case-control matched sample of students who were non-RDI participants. After the first year, RDI students persisted in their STEM degree program at a rate of 93.5% compared to 67.7% for non- RDI students, $\chi^2(1, N=62) = 6.61$, $p = .022$. RDI students persisted in STEM at a rate of 79.3% after their second year of matriculation compared to 34.7% for the non-RDI students, $\chi^2(1, N = 60) = 10.16$, $p = .002$. After their third year, RDI students persisted in STEM at a rate of 74.1% compared to 22.6% for the non- RDI students, $\chi^2(1, N = 58) = 15.379$, $p < .001$. Because of the small sample size, it was unexpected that these results would be observed. This suggests there is still some associated impact of the RDI Summer Institute on participants several years out.

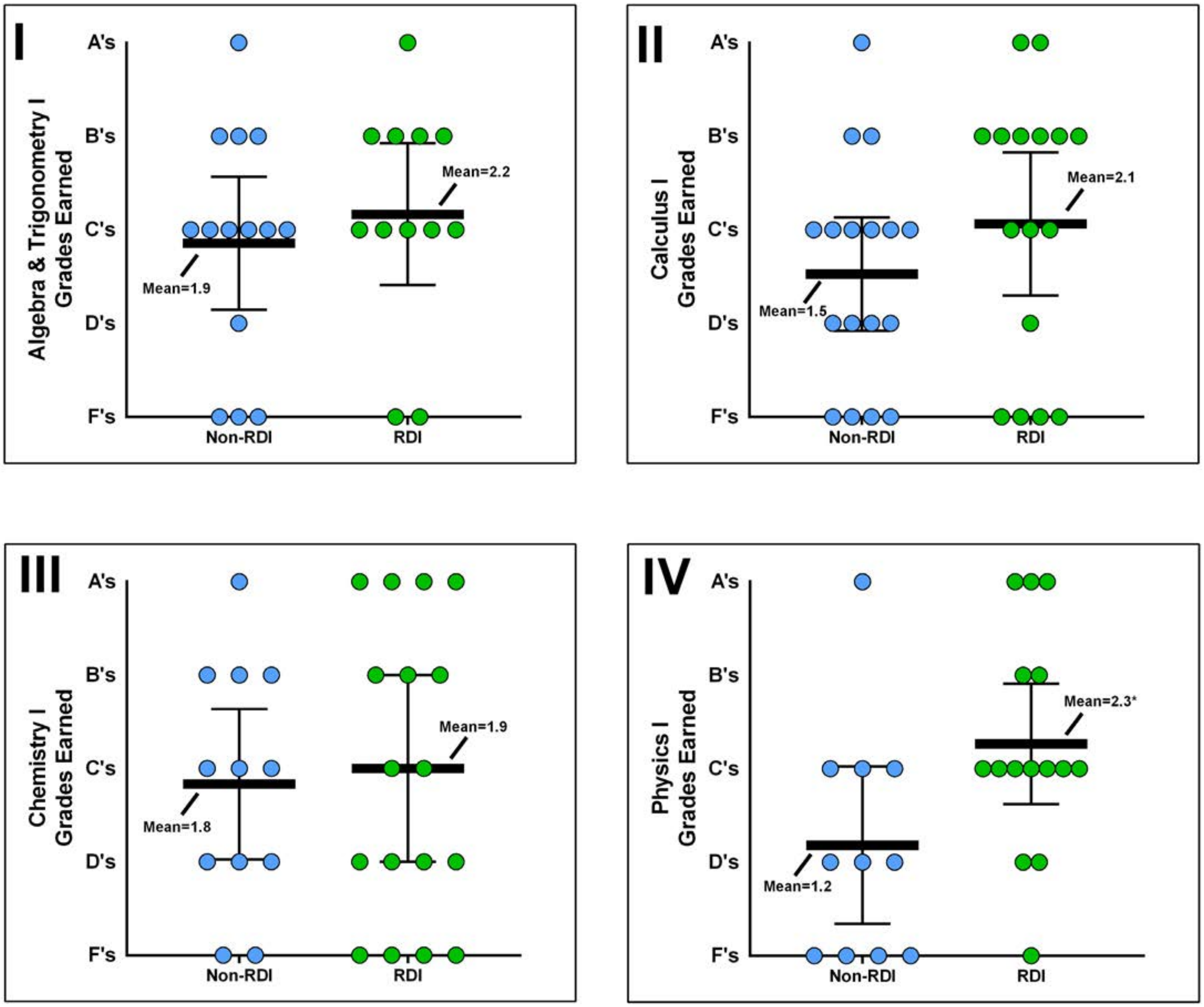

Figure 4. Comparison of course performance in STEM gatekeeper courses.

DISCUSSION

Summary of the Research. In this study, we presented the Research, Discovery, and Innovation (RDI) Summer Institute, a novel innovation education outreach program, which is unlike other university-based outreach programs reported in the literature that reach pre-college students, to promote, recruit, prepare, and enroll them in STEM degree programs. The RDI Summer Institute was offered to graduating high school students who had secured admission acceptance to North Carolina Central University in a STEM degree program. In just five weeks the RDI participants exhibited high levels of creativity and innovation. Their product ideas often revealed how conscientious they were about meeting needs in their community where they presented products that addressed urban agriculture to home and personal safety to clean alternative energy. In addition, the prototypes they produced and used to simulate how their product would work showed their ability to quickly learn essential science and engineering to accomplish their system design.

We examined whether the program improves design and entrepreneurial thinking competencies, and we investigated whether program participation influences future academic success. Pre- and post-survey data for twenty-four RDI participants provided exact measurement of changes in the program-related knowledge and skills, as perceived by participants, and the results showed the RDI Summer Institute was a very effective pre-college summer program. The strongest effects were for competencies gained in entrepreneurial skills, managerial skills, technical skills, and engineering design skills, which are key competencies of entrepreneurial thinking. These entrepreneurial thinking competencies gained by participants may generalize to the pre-college student's ability to assess situations and circumstances, problem solve, be creative, learn and apply science and engineer-

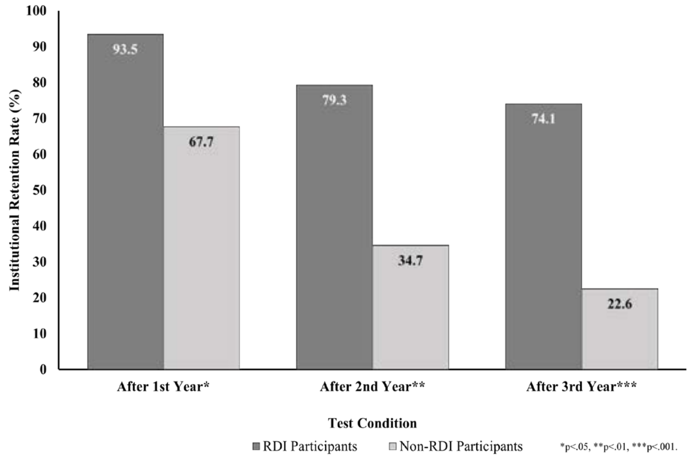

Figure 5. Persistence in STEM Rates by Participation Group.

ing knowledge and skills, plan, and act on a plan, and persist in the face of difficulty. Most likely, these abilities that the RDI participating pre-college students gained contributed to the tremendous success they achieved as they continued into their college STEM degree program.

We expected RDI Summer Institute program success would have significant associations with near-term outcomes, measured within a year, but with the small sample size, we did not expect to detect a significant association with more distal outcomes, measured beyond a year. The RDI Summer Institute program did indeed positively and significantly impact near-term outcomes for participants who went on to STEM degree programs in college. And surprisingly, with small sample size, we found strong indication that the RDI Summer Institute program also had a longer-term positive impact on more distal STEM outcomes for participants.

The near-term outcomes observed were first-year retention in STEM and performance in STEM gatekeeper courses. A quasi-experiment was rigorously designed to compare outcomes for case-control matched pairs of RDI participants and non-RDI participants. A strong association was found. FTFT STEM freshman students who were RDI participants were five times more likely to be retained in STEM than the non-participating case-control matched comparison group. Further investigation made comparisons between groups at the level of students' background characteristics. The demographics and background of the case-control matched sample was: 23% Female; 87% Black and 6.5% Hispanic; 55% from single parent households; nearly 50% from very low/low SES; 65% were majoring in physics. In the literature, some of these demographic and background characteristics of students have been disproportionately linked to students not being retained in STEM. Our results suggest that the RDI Summer Institute program can reduce the effect that a student's background characteristic might have on STEM retention. Female RDI participants were retained in STEM at 100% compared to 57.1% for non-participants. RDI participants from very low/low SES households were retained in STEM at 90.9% compared to 58.8% for non-participants. Male RDI participants were retained at 91.7% compared to 70.8% for non-participants.

To persist in STEM degree programs students must pass so-called gatekeeper courses, which typically are Algebra and Trigonometry, Calculus, Chemistry, and Physics. Not passing and repeating these STEM courses lead to student attrition in STEM degree programs. Our results suggest that a near-term positive effect of the RDI Summer Institute program is enhanced ability of students to pass STEM gatekeeper classes which allows them to progress in their STEM degree program.

The RDI Summer Institute program was found to have an even longer-term impact two and three years after students participated. Specifically, RDI students persisted in STEM degree programs to the third year at a rate 2.3 times that of the case-control matched non-RDI students. While this is a very distal outcome, support for the RDI Summer Institute association of this result can be seen by the trends in previously discussed results, the outcome differences in gate-keeper class performance and the disproportionate first-year retention odds ratio.

Limitations. There are a few limitations to consider regarding the findings of this study. These limitations include the lack of a reliable and valid instrument to document entrepreneurial growth, a small sample size, as well as potential selection or omitted-variable bias (OVB).

While Mitchelmore and Rowley (2010) and Lichtenstein and Lyons (1996, 2006) presented frameworks for entrepreneurial competencies, they did not present a corresponding measurement instrument with valid and reliable items. In addition to lacking a published reliable and valid instrument, our team also discovered that the area of studying entrepreneurial competencies through outreach efforts has very few prior studies resulting in untested theoretical foundations. As a result, the DREAM STEM Project team, along with the external evaluator, set out to develop a new research typology. The team constructed pre- and post- surveys around the key competencies found in literature, including items that have face validity and likely serve as strong proxies for the entrepreneurial competency constructs. However, due to the size of implementation and limited resources, we were not able to validate the instrument used in this study. Also, the measures did not address science and inventor identity development nor innovation and entrepreneurial aspirations. The lack of using a validated instrument may threaten the validity of the entrepreneurial competency findings presented in this study. Although competency, which was measured in the current study, has been linked to self-efficacy and self-efficacy has been linked to identity, the lack of identity and aspiration measures prevents insights on participants' intentions toward becoming inventors, innovators, or entrepreneurs.

Evaluations of summer STEM programs that focus on only one program activity often face challenges related to small sample sizes (Cappelli et al., 2019), and our study is no exception. Our comprehensive outreach program and similar other types of summer enrichment programs that are university-based are very expensive, usually exist because of federal or private funding sources, and can serve a limited number of participants each year. Depending on availability of funding, the program supports from four to nine RDI participants each summer. Consequently, it took several years to accumulate the number of participants included in this study. While the total sample size across cohorts was relatively small, we believe the population we included in the study is representative of our broader population of basic science majors, particularly at other HBCUs and Minority Serving Institutions. Even still, these small n-values likely prevented us from triggering significance in a few key comparisons of RDI and non-RDI participants, particularly in differences across genders and/or socioeconomic statuses. While our small sample size limits some interpretations, the finding of a positive trend toward increasing scores and good effect sizes for all program effectiveness outcomes, except for scientific communication skills, is encouraging.

Additional limitations that are often inherent to this type of research study are self-selection and/or omitted variable bias. We matched gender, race, high school GPA, and SAT, and we did assure that both participant group and matched non-participant group had self-selected as admitted freshman STEM majors. Having left family characteristics as free variables, we were pleased to see how well matched the groups were on parental household makeup and socioeconomic status. Still, it is possible that students choosing to participate in the RDI program differ from non-participants in ways outside of what we studied. For example, after RDI Summer Institute program participation there are many unknowns in a student's collegiate, family, and social experiences that could have had influence on some of our near term and/or distal metrics in ways we did not consider. Since a randomized-controlled trial is not practical and high program cost remains a constraint, to increase the sample size we are restricted to waiting each year of the program offering to collect and add more data.

Lessons Learned. The basic structure of RDI Summer Institute has not changed between the period of Summer 2013 to Summer 2022, but a few adjustments have been made over time. An early change followed the restriction to recruit pre-college students who were residents of North Carolina. We changed the start of the RDI Summer Institute from mid-June to the last week in June to be a week after the last high school graduation in North Carolina. We added an opportunity for RDI participants to assemble and operate a real-world system. During Summer 2018 and Summer 2019, we partnered with nearby North Carolina State University (NCSU) to provide RDI participants a weeklong drone camp experience at NCSU for the first week of RDI Summer Institute. In the drone camp, RDI participants learned how to build, fly, and repair small quadcopter racing drones. At the end of the drone camp, RDI participants returned to NCCU with their drones where drone technology was integrated in the engineering design and entrepreneurial thinking activities of the RDI Summer Institute. The RDI Summer Institute is residential on NCCU campus, however, during Summer 2020, we held a Virtual RDI Summer Institute due to the COVID-19 pandemic. At that time, we shipped design kits and laptop computers to participants' homes, and we delivered the instructional sessions online via WebEx®—a communication and collaboration platform from Cisco®, and BlackBoard® learning management system.

It has been intentional to regularly change the theme of the design component of the RDI Summer Institute. This allowed choice of technology content to be current, engaging, and in contexts that were of interest and appealing to the RDI participants. The themes for the design component have been technology projects that address a community need of safety and security, use drones (unmanned aerial vehicles) to transport products, and use hydropower for renewable energy.

External evaluation of the overall DREAM STEM Project has been conducted across the years of implementation; the lead external evaluator of the DREAM STEM Project is one of the co-authors. Recommendations specific to the RDI Summer Institute have been derived from participants' responses to open-ended questions on post-surveys and interview questions in focus groups conducted by the evaluator. The evaluator also documents recommendations offered by the DREAM STEM external advisory committee at annual project meetings. A sample of recommendations for program improvement from RDI participants and external advisory committee members along with the responsive project action are included in Table 11. RDI participants typically wanted to see more exposure and more assistance on projects, while the external advisory committee wanted to see more outreach and external collaboration. The realization of these recommendations by the project was a value-add to the furtherance of entrepreneurship development of the pre-college students as they entered their STEM degree programs at NCCU. We did not specifically assess the effect of the specific programmatic changes made in response to these recommendations, however, we believe those modifications increased the marketability of the RDI Summer Institute and expanded the innovation and entrepreneurship pathways and opportunities for those who participated.

Conclusion. The innovation and economic strength of the U.S will depend on a greater production of underrepresented

Table 11. *A Sample of Recommendations for Program Improvement of RDI Component and Response Action by Project.*

Participants' Recommendations	Project Design Change Action
"Bring more mentors to help inside the class or if students need assistance"	A previous RDI participant, as an undergraduate, was employed as peer mentor to current participants. The peer mentor assisted the design lab professor in working one-on-one with participants in sessions and met participants in extra sessions to hone their projects.
"Incorporate a entrepreneur showcase"	RDI participants already present and demonstrate their product idea and prototype in the closing ceremony. In 2022, NCCU launched the Center for Entrepreneurship and Economic Development (CEED) with funding from the PNC Foundation and Blackstone Charitable Foundation. CEED and DREAM STEM Project collaborate to provide entrepreneurship professional development to RDI participants after they enter NCCU and encourage participation in the PNC Pitch Competition and Blackstone Launchpad Ideas Competition.
Help students build connections to professionals and companies outside of NCCU	After participants enter their STEM program at NCCU, we invite and assist them in submitting an abstract to present their project at the Emerging Researchers National (ERN) Conference in STEM held annually in Washington, DC. Whether or not RDI participants submit abstracts, they are invited to attend the ERN Conference along with more than 15 other NCCU STEM majors, joining over 1000 student attendees from hundreds of un universities. There they can meet with representatives from academic, government, business, and the non-profit sector with information about graduate school admissions, fellowships, summer research opportunities, professional development activities, and employment opportunities.
External Advisory Committee's Recommendations	**Project Design Change Action**
Look for ways to connect to students' families, churches, and other social/ community organizations.	During FAll 2019 semester, five former RDI participants served on a "Career/College" student panel for the American Association of Blacks in Energy (AABE) Youth Energy Academy. The one day academy hosted 60 youths from area high schools introducing them to STEM careers in the energy industry, and the student panel discussed how the RDI Summer Institute experience and STEM education at NCCU prepares them for their future.
Work to build an internship program with external partners as a way to make this component more attractive.	We established a collaboration with First Flight Venture Center (FFVC) in nearby Research Triangle Park, NC. FFCV is an incubator for science-based startups. We scheduled field trips to FFVC where RDI participants met with owners of the start-ups, visited their laboratories, and talked with them about their innovative products and services. We further collaborated with FFVC to establish Workplace Immersion for New Generation Scientists (WINGS) through which four former RDI participants held paid internships and worked in a start-up company and experienced how research and development is done and commercialized.

minorities with STEM degrees, and university-based outreach programs that serve African American and other minority populations should do more to infuse invention education activities in the programming. Our work gives convincing evidence that a pre-college summer program in design and science entrepreneurship can release the creativity and innovation potential in African American and other minority students when they are able to address the needs of their community as well as themselves. This program also has substantial influence stimulating, motivating, and enhancing the development of pre-college student participants for success in STEM degree programs. The rigorous research design and well-matched case-control pairs of incoming STEM freshmen give confidence in the tremendous impact possible for such a program. It is reasonable too, that the results may generalize to other subgroups of underrepresented minority pre-college students. Notably, first-year STEM retention for female students and students from very low/ low SES households in the RDI group was higher than for comparable students in the non-RDI group. Also, students from single parent households in the RDI group had higher STEM persistence than comparable students in the non-RDI group. In addressing these issues, this study contributes to understanding what works, for whom, and under what conditions in the design of university-based pre-college summer programs.

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ABBREVIATIONS

CI: Confidence Intervals; DREAM STEM: "Driving Research, Entrepreneurship, and Academics through Mastering STEM"; FTFT: First-Time, Full-Time; HBCUs: Historically Black Colleges and Universities; HBCU-UP: Historically Black Colleges and Universities Undergraduate Program; I-Corps: Innovation Corps; IRA: Institutional Research and Analysis; IRB: Institutional Review Board; ITS: Information Technology Services; KSBs: Knowledge and Skill Builders; NCCU: North Carolina Central University; NCSU: North Carolina State University; NSF: National Science Foundation; OVB: Omitted-Variable Bias; RDI: Research, Discovery, and Innovation; SCORE: Service Corps of Retired Executives; SES: Socioeconomic Status; STEM: Science, Technology, Engineering, and Mathematics; US: United States

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