Roads, Rails and Race Cars: a STEM Educational Program for 4th-12th Grade Students

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Abstract

Many U.S. public school systems have experienced declining standardized test scores in math and science. Of particular concern is an increasing disparity in the scores of underprivileged and underserved students compared to other peer groups. This trend poses a distressing problem for the engineering field, and has been identified as a major issue by the US Department of Transportation, being viewed as a threat to the sustainability of the nation's infrastructure and economic growth. This issue is compounded by a growing demand in the transportation industry for skilled workers.

Recognizing these concerns, a number of entities, including the University of Nebraska's Mid-America and Nebraska Transportation Centers (MATC/NTC), the Nebraska Center for Research on Children, Youth, Families and Schools (CYFS), the Nebraska Department of Education and Lincoln Public Schools, of Lincoln, Nebraska, formed a consortium to address this issue. In 2010, the consortium created and implemented an after school program intended to foster learning and engagement in science, technology, engineering and mathematics (STEM) among our nation's students. The result was the Roads, Rails and Race Cars (RRRC) program.

RRRC utilizes a science-as-inquiry approach in a club-based format. Club lessons and activities highlight real world applications of STEM concepts, emphasizing transportation issues that students encounter in their daily lives through the use of a curriculum developed collaboratively by partners from the fields of engineering, education and educational psychology. RRRC clubs are guided by teams comprising of STEM teachers and college engineering student mentors, who mirror the rich diversity of the primary and secondary school systems. This positive role modeling and one-on-one attention are a key focus wherein the program encourages students to explore STEM careers and discover paths to achievement. Further, clubs frequently feature career presentations by community professionals from the private sector to encourage this career exploration.

While establishing itself as a sustainable program model that positively impacts students, RRRC has also been beneficial to its multiple partners. K-12 teachers have received additional training in STEM education that they can implement in their core classrooms; student mentors have gained opportunities to improve their interpersonal and public speaking skills; and community partners, like the Nebraska Trucking Association, have gained opportunities to reach out to their future workforce.

Following a highly successful middle school pilot program, RRRC expanded to include the elementary and high school levels, providing evidence of the program's successful transferability across age groups and locations. To date, club attendance has reached over 5,200 in combined attendance by approximately 900 different students across 12 separate program sites. Moreover, the program continues to be evaluated through qualitative and quantitative metrics in order to

ensure that the goals of the program are being met and to identify potential areas for improvement.

This paper provides an overview of the development of the RRRC program and its goals, briefly summarizes current and future pre- and post-measures of effectiveness and presents concluding remarks regarding future program applications.

Introduction

Decreasing interest and a growing lag in the skill development necessary to promote the transportation industry is clearly visible within our nation's primary and secondary school systems. Standardized science and math testing scores have fallen significantly among K-12 students within recent years, especially among underrepresented populations within science, technology, engineering and mathematics (STEM) subjects[3]. In addition, the transportation industry has witnessed a decline in interest and professional involvement, causing concern among leaders in the field[2,7]. Though students are falling behind their international peers in some academic areas[3], most are equipped with the capacity and potential to succeed if and when their talents are nurtured, and when they are taught the skills that will help them become the innovative leaders of the future—leaders of whom the transportation industry is in dire need.

Recognizing this decline among our nation's future workforce in interest and skill pertaining to STEM areas, a consortium of public and private partners based in Lincoln, Nebraska created an after school program intended to enhance student knowledge and interest in transportation and STEM subject matter and careers. The resulting after school program, "Roads, Rails and Race Cars" (RRRC), provides transportation-based lesson plans and activities within primary and secondary school classrooms across the Midwest. Further, RRRC is designed to reach out to students who are historically underserved and/or underrepresented in STEM degree-granting programs and careers.

RRRC's unique transportation-based curriculum was developed by engineers and educators from the state of Nebraska. Club activities highlight real world applications of science- and math-based concepts in a manner that intends to engage student interest and learning. RRRC clubs are led and facilitated by engineering graduate and undergraduate student mentors from local universities, under the supervision and with the participation of STEM classroom teachers. These student mentors and teachers are selected to represent the rich diversity of the primary and secondary school systems in which the clubs are held. They also contribute an important element of positive role modeling and one-on-one attention that students may not experience in their daily lives.

RRRC clubs meet weekly for one hour, during which RRRC teams provide brief lessons illustrating STEM concepts, pairing these lessons with hands-on activities that are conceptually linked to transportation issues students may encounter on a regular basis (e.g., sustainable energy, the dangers of texting and driving, engineering approaches to enhancing passenger safety). During each club session, RRRC mentors work closely with students to break down STEM subject matter into more digestible concepts, with the hope of facilitating a greater

understanding and deeper awareness of the daily life applications of STEM concepts. Further, the program functions as a career-building opportunity that encourages students to connect their classroom content to real-world professional applications, thereby facilitating an awareness of various potential transportation- and STEM-related careers and the steps students may need to take to achieve them.

Following a well-received pilot program at a Lincoln, Nebraska middle school in 2010, RRRC has reached over 5,200 in combined student attendance at 12 separate RRRC academic and summer program sites in three Midwestern states. Since its inception, over 900 individual elementary, middle and high school students have participated in the program at least once, many of whom attend multiple club sessions.

Program Development

Conceptual Framework

RRRC's developers recognized that middle school was a critical transition period for students from high-need, underserved populations faced with unique obstacles in the way of continuing education. It was felt that preemptive action should be taken in order to supplement classroom learning and encourage student academic success and career readiness. With this reasoning in mind, RRRC's developers chose to first implement the program in middle schools. Following its initial success, the program was later adapted for and implemented within elementary and high schools. RRRC's unique transportation-based curriculum provides students valuable assistance in connecting the math and science concepts they learn in the classroom to meaningful, real-life applications. This approach provides a natural connection between abstract concepts and visual, concrete applications. Developers also recognized that students could be aided through the additional support of positive role models; consequently, graduate and undergraduate engineering university students were recruited as mentors. It was believed that the mentors could motivate RRRC's participating students to pursue and attain their individual academic and career-related goals.

Furthermore, the developers believed that improving students' hope and readiness for future careers in transportation could be facilitated through demonstrating that rewarding careers would be available to those students who attained the necessary skills and education. Therefore, RRRC was designed to offer participants specific career information that might correspond to their unique interests. This is accomplished by inviting program partners from different transportation career fields to speak at club events. These partnerships provide an opportunity to expose students to the diverse variety of career possibilities found in the transportation field, and encourage students to stay focused on their long-term educational and career goals. The consortium currently includes Faubel Financial Services, Flatbed Express, Lincoln Community Learning Centers, the Mid-America Transportation Center, the Nebraska Children and Families Foundation, the Nebraska Department of Education, the Nebraska Department of Roads, the Nebraska Transportation Center and the Nebraska Trucking Association. This public industry and private sector involvement was intended to demonstrate to students that, 1) profitable jobs for individuals from a variety of backgrounds are available in the transportation industry, and 2) people from the community are invested in the education and future of public school students.

Overall, members of the transportation workforce must be prepared with the skills and knowledge required to design, maintain, build and implement the nation's transportation infrastructure—tasks that will be increasingly challenging as the existing transportation infrastructure ages and the current demand on the system increases. Therefore, RRRC's developers designed the after school clubs with these necessary skill and knowledge components in mind. The developers also ensured that graduate and undergraduate assistants and program partners represented diverse groups in order to reinforce the notion that educational and career success is attainable to every individual with adequate preparation and self-motivation.

Existing Engineering Education Outreach Literature

Transportation engineering outreach is not a new entity. Many outreach programs exist that focus on building stronger science, math and engineering skillsets and interest amongst our nations students[5]. From the development of classroom and web-based materials to transportation fellowships and service learning programs, engineering outreach programs are taking multiple measures to ensure that the new group of transportation professionals is equipped with the knowledge and skills necessary to address the unique needs of an every growing, changing and aging transportation field[5]. Consistent with much K-12 engineering education outreach literature is the call for outreach programs that:

1) Utilize a team approach of faulty, college mentors and professional engineers to deliver engineering educational information to students.
2) Assist K-12 educators in building their proficiency in STEM subjects.
3) Develop curriculum materials and instructional strategies.
4) Build partnerships between schools of engineering, facilities of education and science, teacher populations and other stakeholders (including parents).
5) Engage family support with assisting students on determining their future education and career.
6) Evaluate efforts of both the implementation and effectiveness of materials and strategies[1, 4, 5, 6].

RRRC attends to each of these deemed components of successful outreach programs. As aforementioned, RRRC utilizes a team approach with pairing professionals, educators and engineering college mentors together to facilitate the clubs. Further, RRRC attends to the importance of diversity in providing role models for students, a point argued by Ivey, Golias, Palazolo, Edwards and Thomas as essential for outreach programs. Based on their efforts to attract students to transportation engineering, it was concluded that a needed key component necessary for outreach success is that of having diverse faculty, college mentors and profession engineers as the primary facilitators of outreach efforts:

> "Faculty and college mentors, along with professional engineers who speak to participants about their careers, are critical for influencing students to consider engineering majors. Therefore, it is important to make sure that a wide variety of mentors and speakers in the transportation workforce of diverse gender, race, and

> ethnicity are involved in outreach programs so that students are able to identify with someone and recognize the importance of diversity." (pg. 95)

Further embedded in the RRRC program is that of utilizing STEM teachers and providing assistance to them in further professional development – for example offering a Summer Institute training seminar for incorporating STEM and transportation engineering materials into one's existing curriculum. Further, the RRRC team also works together to develop curriculum and instructional strategies that attend to the current trends of the transportation engineering field, utilizes community professionals and stakeholders to assist with career information dissemination as well as utilizes social media and newsletters to inform parents of club lessons and activities. Of current focus is that of developing evaluation measures to accurately assess the implementation and effectiveness of materials and strategies utilized for club.

Roads, Rails, and Race Cars Club Development

Pedagogy and lessons

What sets RRRC apart from many other outreach efforts is the attendance to each of the critical components listed above, paired with a weekly program rather than the predominant utilization of summer programs. Thus the RRRC club format and curriculum is based on weekly transportation applications and hands-on activities, and simultaneously emphasizes proficiency in meeting state math and science testing standards – which attends to the initial argument of desiring to supplement further STEM understanding and interest opportunities for our students. The extensive involvement of program partners educates students on the many ways in which STEM concepts are utilized by real-world transportation professionals. Many of the curriculum's transportation-based engineering lessons were previously developed and tested for classroom use as a result of the "Professional Development for Math and Science Summer Institute Program" for secondary school teachers, that was sponsored by MATC, CYFS, and the Nebraska Coordinating Commission for Postsecondary Education (CCPE) during the summers of 2007-2012. A lesson bank, located at http://tse.unl.edu/trc/lesson_plans.php, was established to provide easy access to the lessons and activity plans developed by Summer Institute teachers. These lesson plans cover topics ranging from basic science to advanced physics, and were designed around the principle of turning transportation engineering research concepts into lesson plans for the classroom. Utilizing state-of-the-art technology and hands-on activities, the lessons apply otherwise complex mathematical and scientific concepts in ways that students can relate to and understand. For example, during the "Speed" curriculum, teachers and mentors implement a "Motion and You" PowerPoint and interactive lesson that provides instruction based on Newton's laws of motion. Teachers and mentors pair the abstract knowledge learned from the lesson with an activity in which students measure the motion of different types, sizes, shapes and weights of mobile objects as they race down a car track. Additionally, new lessons and activities are continuously being developed by teachers and mentors based on noted student interest, advisory board feedback, teacher/mentor areas of expertise and evolving transportation issues (e.g., "Green Transportation").

Site teams and attendance

The RRRC club pilot project was first implemented at a Lincoln, Nebraska middle school during the fall of 2010 and spring of 2011. Club planning and lesson/activity development occurred during the second quarter of the 2010 school year, while club implementation began in January and ran until May of 2011. The club was facilitated by one teacher in collaboration with two MATC/NTC transportation engineering graduate students. The club was well received, with 18-20 students attending each club session, and was deemed very successful as judged by qualitative student feedback, thereby providing a foundation for expansion.

It was quickly acknowledged following the RRRC pilot year that many of the club lessons and activities could be conveyed across different age groups. Thus, following the pilot project at the Lincoln, Nebraska middle school, and utilizing external funding received by the Garrett A. Morgan Technology and Transportation Education Program, clubs were implemented at multiple grade levels (i.e., elementary, middle and high school) in the second cycle of implementation. Materials used for the prior year's middle school level were given to the elementary and high school teachers to adjust lessons for applicability and cognitive development appropriateness of their students' age groups.

During the 2011-2012 academic year, the RRRC clubs were implemented in five schools throughout the Lincoln Public Schools district, including our pilot middle school (Quarters 1, 2, 3 and 4), one elementary school (Quarter 3), two additional middle schools (Quarters 2, 3 and 4) and one high school (Quarters 2, 3 and 4). Eight teachers and 14 graduate and undergraduate engineering student mentors participated in facilitating clubs during year two. Topics of the program year fell under four unit categories: Defining Transportation, Transportation and Speed, Transportation Design and Transportation Technology. Total attendance over the 2011-2012 academic year for all sites was 1,366, with the total number of individual student participants who attended the clubs at least once over the course of the grant period being 235.

Drawing on the momentum from previous implementation years, and observing consistent interest and high attendance by students during the second iteration of RRRC, club organizers desired to yet again expand the clubs, this time focusing specifically on geographic transferability. During the 2012-2013 academic year, RRRC expanded to 12 total sites in Iowa (one site), Nebraska (10 sites) and Wisconsin (one site). All five Lincoln, Nebraska sites from the previous academic year returned for the third cycle of RRRC: our pilot middle school (Quarters 1, 2, 3 and 4), one elementary school (Quarter 3 and 4), two additional middle schools (Quarters 2, 3 and 4) and one high school (Quarters 2, 3 and 4). Quarter 3 saw the Lincoln, Nebraska additions of two elementary schools, one middle school and one high school; one additional Nebraska middle school; one middle school in Iowa; and one middle school in Wisconsin (all added sites participated in implementation in Quarters 3 and 4). Seventeen teachers and 30 graduate and undergraduate engineering student mentors participated in the facilitation of clubs during year three. Topics of the program year fell under three unit categories: Introduction to Transportation, Green Transportation and Transportation Technology. Total attendance over the 2012-2013 academic year for all sites was 2,945, with 466 individual students attending the clubs at least once over the course of the grant period.

Club structure

RRRC clubs meet once per week for approximately one hour. During this time, the following format and structure is implemented:

1) Club meetings begin with an introduction to the main concept underlying the day's lesson and activity. This introduction includes probing questions designed to gauge student comprehension and promote lesson engagement.
2) A multimedia presentation follows, delivered by engineering graduate and undergraduate student mentors. The presentation further elaborates on concepts from the STEM lesson and the relationship of these concepts to transportation.
3) Next, students engage in hands-on activities, utilizing and applying the main concepts of the day's lesson.
4) Typically, transportation professionals are invited to club sessions, where they provide a multimedia presentation pertaining to their respective field, a project going on in the community and/or a specific sector of the workforce (e.g., salary information and educational requirements). This presentation tends to take place toward the end of the club period.
5) The program day ends with a "wrap-up" activity to summarize main themes or ideas and record reflections on the day's activities.
6) At the end of each quarter and/or semester, students hold a celebration in recognition of their accomplishments during the course of the club period. The students work in teams to prepare short presentations to be delivered to their peers, families and the school community.

Club members

Multiple RRRC project participants have helped to make the after school club a success, including students, mentors, teachers, community members and "behind the scenes" assistants.

The role of students

During the after school program, students are the focus of attention. The goal is to introduce students to engineering and transportation, while building upon their STEM-related skill and knowledge base. The role of the student is straightforward: attend, learn and have fun. An additional central tenet to RRRC is that when students have a say in the curriculum, they tend to display extra motivation when participating in club lessons and activities. As such, students are encouraged to provide feedback; their opinions are valuable for the refinement of club lessons and activities, aiding in the effort to continually reach out to a wider audience. Further, students assist, through informal and formal evaluation methods, in generating ideas and setting goals that make for richer club activities. Student feedback is regularly requested through informal, anecdotal approaches, such as by asking students at the end of each quarter which were their favorite/least favorite activities and why. Students also complete pre- and post-RRRC assessment measures to gauge attitudes, perceptions, interest and engagement in STEM and transportation.

This allows organizers to gain information regarding the club effectiveness and for refinement of the clubs. Another student role is that of club advertiser. Student advertising occurs during the school day throughout most of the year, as well as during end of quarter and semester celebrations, when students advertise through student activity displays what they have accomplished over the course of the program.

The role of mentors

Engineering graduate and undergraduate mentors are selected to participate in the after school program based on various factors including GPA, extracurricular activities and displayed interest. Further, it is a tenet of RRRC that operating with a diverse group of mentors will help participants to better visualize themselves following various STEM career paths. Therefore, effort has been made to ensure that RRRC mentors embody the rich diversity of the program sites. Additionally, mentorship for the RRRC after school program requires a wide range of skills and abilities. Throughout the school year, a mentor might be asked to create and lead a lesson or hands-on activity, or simply to provide support for the person instructing. As such, mentors are an integral component of the program. Their presence allows for greater one-on-one student instruction than might otherwise be possible in a normal classroom environment. Importantly, mentors also act as role models, and it is crucial that they actively attempt to relate to and provide a positive influence for participating students. Ultimately, mentors have the power to give hope. They can uniquely convey to students the idea that, with effort and willpower, every person has the capacity to accomplish what may at first seem difficult or out of reach.

Additionally, mentors rotate the leading of lessons throughout the quarter, giving brief show-and-tell presentations about specific actions they took during middle and/or high school that assisted them in preparing for college. For example, mentors explain why or how they chose their particular field of study, discuss the challenges and opportunities involved in achieving a college education or elaborate upon the potential for monetary assistance that is achievable through college scholarships. Introductions are followed by anecdotes about interesting experiences or opportunities gained from college, and explanations are provided as to how those opportunities and experiences helped to shape the mentors' lives and educational or career paths.

The role of teachers

Teachers are vital to RRRC's operation. Among other diverse roles, teachers recruit students, make arrangements for space and technology needs, collaborate with mentors to prepare weekly lessons, facilitate clubs and provide classroom management; simultaneously, they incorporate their own educational expertise to facilitate student learning and involvement. Rather than acting as the primary source of information, teachers provide access to information, so to foster self-efficacy and a sense of fascination as students strive to develop their own knowledge and skill-sets related to club topics. Moreover, teachers assist in determining a curriculum based on student interest, so to foster intrinsic motivation and stimulate the passion to learn. Adopting the role of the student, teachers gain new knowledge alongside their students, actively participating in activities and lessons while encouraging students to put forth their own best efforts.

Community involvement

A team of community leaders with diverse yet complementary experiences was also assembled for the purpose of providing career and professional exposure to the students, thereby establishing a program with long-term sustainability and creating a broad network of public and private support. These partners are committed to the goals of improving student STEM skills and knowledge, cultivating interest in transportation fields as well as implementing a program that will both have a widespread impact and expand far beyond its initial schools and district. Further, these community partners are able to provide tangible information regarding transportation careers, including salary ranges, working environments and educational and skill requirements, as well as provide testimony as to their own chosen career path. Such information is indispensable to support students' growing interests and academic and vocational development.

Behind the scenes assistant

Club success also relies on the dedicated assistants whose work supports club teachers and mentors. Specifically, the program coordinator and media relations specialists each have a unique role in facilitating club operations and promoting RRRC clubs around the nation. The program coordinator trains mentors and teachers in their club roles and duties, develops and determines club curriculum, organizes all necessary supplies for each club day, facilitates communication between all involved parties and offers general support and guidance. The media relations specialist documents clubs through pictures and videos that are published on an image sharing portal accessible to families and posted on the Lincoln Community Learning Centers and Lincoln Public Schools websites. An electronic newsletter elaborates upon club activities for family and peers in the community, with the goal of fostering the community involvement that is essential to providing students with resources and encouragement.

Club Results

Student Impact

During the 2012-2013 academic year, RRRC participants completed a survey that focused on assessing attitudes, perceptions, interest and engagement in STEM and transportation. This survey was developed by two University of Nebraska-Lincoln Educational Psychologists as a preliminary metric to assess the above constructs 1) at baseline, and 2) at the conclusion of the club for each student. Standard reliability and comparison analyses were conducted – assessing also for differences between gender, grade level and racial categories; results were inconclusive. It is theorized that many of the measured constructs exhibited no change between pre- and post-survey data collection because interested students self-selected into the clubs. However, it is important to note that 33.7% of the individual student participants of the academic year clubs (157 out of a total of 466) attended at least half of the club dates at their respective sites, with most attending nearly all club dates. The fact that many students voluntarily attended the program is an important metric of success. Thus as a result of the high numbers of attendance across educational levels of elementary, middle and high schools, we have determined our goal

of transferability across age groups has been achieved as well. Additionally, anecdotal evidence based on informal discussions with the student participants also provided evidence that students found the club to be worthwhile. Further, it is believed that the diversity of the club's activities, as well as the incorporation of technology and a constant influx of new presenters, maintains students' consistent club participation and engagement.

Additionally, RRRC met the goal of reaching out to a diverse population of students: 51.5% of total academic year and summer club students identified themselves as being a racial or ethnic minority (293 out of the total 569). Students also revealed that they believed RRRC affected their interest in STEM by the following percentages: 48% stated that RRRC increased their interest in science, 50% stated that RRRC increased their interest in technology, 49% stated that RRRC increased their interest in engineering and 35% stated that RRRC increased their interest in mathematics. A future goal is that of assessing student learning gains as a result of the intervention project; the authors are currently attempting to correlate student learning in STEM classrooms to participation in the after school program.

Impact on Mentors and Teachers

Based on qualitative feedback, mentors report benefitting in multiple ways from RRRC participation, ranging from gaining the satisfaction of giving back to the community, to improved interpersonal and public speaking skills. RRRC teachers also benefit from participation as RRRC team members, in terms of the intrinsic satisfaction gained from working with students. These impacts range from instilling hope to feeling a sense of self-fulfillment.

Other Impact

Over time, it became apparent that the RRRC club curriculum has the potential to reach a much larger audience of students. Teachers hold the power to utilize the club curriculum to exponentially increase the number of students exposed to transportation- and STEM-related concepts and ideas, even among students not involved in the after school program. For example, if each teacher worked with approximately 120 students daily, and if each of the past or current 19 club teachers introduced club concepts during their regular class periods, 2,280 students could potentially be indirectly or directly impacted by the program each year.

Sustainability of RRRC

The RRRC after school program was designed in a manner that lends itself to expansion to other schools, cities and states. Lesson plans have been organized into club presentations, instructions for program implementation as well as handouts used during each lesson and activity. These are located on the RRRC SlideShare account, and are available for public download (https://www.slideshare.net/stemafterschoolprogram). As previously noted, an on-line repository houses the lessons and worksheets created by STEM middle school teachers during the MATC/NTC Summer Institutes. Connections have also been and will continue to be made through various avenues including student organizations, University Transportation Centers (UTCs) and personal contacts at various universities in order to continue to provide up-to-date,

scientifically sound lesson plans and activities that encourage and enable students to achieve a new level of STEM comprehension and creativity.

Conclusions and Recommendations

Over the course of just three years, the RRRC program expanded in size to reach over 900 individual students, 36 mentors and 19 teachers. Through public and private partnerships, the program introduces students to community mentors and transportation professionals, and provides the knowledge and skills necessary to foster hope and construct positive goals and expectations for future achievements among students. The foundation of the program has been laid out, and the program is prepared for further expansion. However, this is only the beginning. The next goal for program developers is to continue to spread the RRRC program to other geographic locations, as well as to extend it to additional summer learning programs. Ideally, the summer school program could include field trips to transportation-related destinations, such as the Nebraska Department of Roads, the City of Lincoln Traffic Management Center, freight distribution centers and lab facilities at the University of Nebraska-Lincoln, as well as job shadow days hosted by the Nebraska Department of Roads, the Nebraska Logistics Council, the Nebraska Trucking Association and University of Nebraska-Lincoln affiliated faculty members. The authors believe this would provide additional motivation and understanding of STEM career opportunities to participants.

It is envisioned that by expanding the current RRRC after school club, program developers will achieve the goals of reaching additional high-needs populations across the United States, equipping students with the STEM skills necessary for their future educational and career aspirations as well as in demonstrating to students that community educators and professionals are interested and invested in their continued success. Through well-planned efforts, programs such as RRRC have the ability to foster a more highly skilled, better-educated and more diverse transportation workforce.

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