Promoting the STEM Pipeline and Enhancing STEM Career Awareness Through Participation in Authentic Research Activities (RTP, Diversity)

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Abstract

To promote the STEM (Science, Technology, Engineering and Mathematics) pipeline and enhance the participation of students who have been historically underrepresented in STEM fields in the U.S, a team of faculty investigators with diverse expertise in STEM, education, public health and medicine have been working collaboratively on a National Institutes of Health (NIH)-funded STEM education project entitled the MENTORS (Model Education Networks To Optimize Rural Science) Project. In this paper, we describe the project activities and present the findings of a study aimed at exploring the responses of high school students to research experiences conducted on the university campus during the summer of 2017. Using a qualitative case study design, the study explored the impact of authentic, hands-on, hypothesis-driven, summer research experiences on career aspiration of nine students. Participants were selected from applicants at two high schools located in the southwestern region of the U.S., in counties where the residents have among the lowest socioeconomic status and educational attainment in the U.S. The majority of participants were Hispanic and female. Laboratory assignments were based on the specified interests expressed by the students, who worked with individual faculty and laboratory personnel on original research projects. Data were collected using pre- and post-experience surveys and student reflections. Findings indicate that students enjoyed working in the laboratory settings with the researchers and participating in authentic research activities. Their career goals in STEM and health-related professions were reinforced and strengthened as a result of their participation.

Introduction

Interest in Science, Technology, Engineering and Mathematics (STEM) fields has been declining among students in the U.S., while the number of available positions in STEM fields is steadily increasing [1]. Research shows that student interest in STEM field decreases as their grade levels increase [2]. It is expected that in the next five years, there will be a shortage of talented and skilled employees in STEM fields [1], [2].

Among the reasons that U.S. students lack interest in STEM fields is their perception that formal K-12 STEM education is not directly relevant to their daily life experiences [3], [4]. The mathematical and scientific content presented in formal settings does not appear to be directly useful in their day-to-day experiences and their interactions with others in their community. Content knowledge is often presented in a way that seems compartmentalized and impractical [3] – [7]. Especially in their social interactions with peers, family members, and others in their community, K-12 students do not use or refer to the STEM knowledge they have recently learned in school [5], [6].

This disconnectedness has a negative impact on the career aspirations of K-12 students. Unless they are intrinsically motivated, or their parents or peers have convinced them to pursue careers in a STEM field, K-12 students find these pursuits uninteresting and irrelevant to their daily life experiences [7]. While student interest is declining, the demand for a trained and talented STEM

workforce continues to grow in the U.S. To meet this need, K-12 students will need to perceive that the material they learn in schools is directly relevant to their daily life experiences and social interactions. Engineering is one of the STEM professions that has immediate and recognizable practical implications in daily life, and could be utilized to build the missing connections. However, engineering content knowledge has not been well incorporated into the K-12 curriculum.

Our multi-disciplinary project team has worked collaboratively to address the missing connections between daily life experiences and STEM educational content. Health-related educational programs focusing on biomedicine, health disparities, kinesiology, public health, and biomedical engineering have the potential to illustrate the missing connections between the STEM fields and day-to-day experiences [8]. Students at the 6^{th}-12^{th} grade levels can easily engage in conversations about health-related subjects. For example, chronic illnesses, especially those that disproportionately affect underserved or low SES communities, including symptoms, treatments, and preventive strategies, are relevant to their daily life experiences, especially when their family members, peers, or others in their community are affected. When students learn important facts about prevention and causes of chronic illnesses that are prevalent in their communities, they can easily communicate and share relevant information. Communicating this new information with others in their community, in formal or informal academic settings, can be a powerful motivation for pursuit of careers requiring STEM knowledge. Students who find their learning informative and beneficial to the wellbeing of their families and communities will be more likely to develop positive attitudes towards learning. Students will also be more likely to set career goals in STEM and health sciences when they witness the impact of this knowledge on community members. The social interaction can play a powerful role in students' career aspirations. The impact may be even more influential when the students are from family-oriented cultural groups. Thus, the capacity to directly assist family members and communities may motivate some students to choose STEM careers.

To realize the potential benefits of integrating the health-related activities into STEM learning, and making it more relevant to daily tasks and social interactions of middle and high school students, our team has initiated the MENTORS (Model Education Networks to Enhance Rural Science) Project. The Project employs evidence-based pedagogies and engages students in authentic research and career development experiences. MENTORS is funded by the Science Education Award Program (SEPA) of the National Institute of Health (NIH). Recent funding from the National Science Foundation (NSF) for the PATHS-UP (Precise Advanced Technologies and Health Systems for Underserved Populations) Engineering Research Center (ERC) will allow the team to increase the focus on biomedical engineering, and the development of technological advances to address challenges of medically underserved and rural communities.

Evidence-based Pedagogies

Evidence-based pedagogies are often student-centered and learner-oriented [3], [9], [10]. Bransford, Brown, and Cocking (2000) reported that an effective learning environment includes the following four characteristics: (a) knowledge-centeredness, (b) learner-centeredness, (c) assessment-centeredness, and (d) community-centeredness [3]. A knowledge-centered instruction develops conceptual understanding and organization of the knowledge in the field. In a learner-centered environment, students' pre-conceptions and alternative conceptions are explored prior to teaching, and the instruction focuses on what students know, what they want to know, and how they will use the knowledge. Assessment centeredness provides frequent opportunities for formative feedback over the course of the learning, and the pace and format of the instruction are adjusted based on the feedback. For a learning environment to be truly community centered, learners interact and engage in dialogue with their peers, family members, and others in their community. In this approach, students witness the value and benefit of their new knowledge. The community-centered characteristics allow the designed learning environment to positively impact developing interest in and career aspirations for STEM fields. When students use the new knowledge in their social interactions with others, the ideal learning environment achieves its objective.

There are several other instructional strategies that are among the evidence-based pedagogies. Active learning, cooperative learning, peer-led team learning, peer instruction, problem-based learning, project-based learning, inquiry-based learning, and challenge-based learning are among the evidence-based strategies that are student- and learner-oriented [10] – [21]. Systematic integration of the evidence-based pedagogies has the potential to retain students in STEM fields.

It has been proposed that the traditional instructional strategies that are knowledge oriented and teacher centered contribute to the lack of interest in STEM fields and careers by many students, including women and those from underrepresented groups. The role of social interactions in learning and development are often not addressed in the traditional STEM education in K-12 levels. The lack of social interaction and awareness of how and why the STEM knowledge relates to their daily life experiences results in inadequate academic preparation and career aspirations.

The MENTORS Project

Our team received funding from the NIH to develop culturally relevant programs for K-12 students in Rio Grande Valley of Texas to stimulate awareness of, interest in and preparation for STEM careers. The ultimate goals of the MENTORS Project are to support the STEM pipeline and to promote diversity of the health and engineering workforce. The majority of students in the targeted schools are members of racial or ethnic groups that have been historically underrepresented in STEM fields in the U.S. Some of the schools are in close proximity to the southern border, have a predominantly Hispanic student population, and are in communities that are medically underserved. Reaching out to these students not only promotes the STEM pipeline, but also addresses social injustice and health inequity in the U.S.

Study Purpose

The purpose of this study was to explore the experiences of the students who participated in the "Lab Rats" program that provided opportunities to conduct authentic, hands-on, hypothesis driven research on a university campus during the summer of 2017.

Study Design

In this qualitative research, we employed a case study design [21], [22]. The experiences of the students who participated in the Lab Rats summer research program were the unit of analysis [21].

Participants and their Selection

The study participants were high school students in the "Lab Rats" research program during the summer of 2017. The majority of the participants were selected from two pre-identified public schools in south Texas, located in communities near the Mexican border. The intent of this selection was to specifically reach out to historically underrepresented minority students (URMS) in STEM fields in U.S. Students were invited to apply online through the MENTORS website that featured a list of the research faculty willing to host students in their labs, along with a description of their research.

A total of 30 students applied, 17 from School 1 and 13 from School 2. Using carefully designed rubrics, and with input from the project liaisons and administrators at both schools, our project team selected 16 applicants, 8 students from each school, for interviews. Ultimately eight students, four from each school, were selected to participate in the program. In addition, a student from a local school joined the Lab Rats program, for a total of 9 participants, ranging in age from 16-18. The 2017 summer research cohort included seven females and two males. Seven of 9 students (78%) reported their ethnicity as Hispanic, and 2 as Asian (22%); two of the students reported their race as white (22%), and 0 reported as Black/African American. We did not include the names of the schools or students, and demographic data are presented only in aggregate. We report student responses only in a de-identified fashion. Portions of comments that could be identifying were redacted for this report.

The Study Context: The Summer Research Camp

Each student was paired with a faculty member, based on research interests and preferences of the student. The nine student participants spent six weeks conducting research in various labs on campus. The MENTORS Project provided accommodations and breakfast, lunch, and dinner daily for the residential students and a $1,200 stipend for all students. Since the participating students were minors, they were accompanied by project staff continuously while on campus.

On the first day of the summer program, and before beginning their research, students attended a full day of orientation that included a campus orientation and required training on general and laboratory-specific biosafety and blood borne pathogens. After the training, the participants began working in their assigned laboratories. Over the course of the 6- week, summer program,

students also attended didactic sessions and participated in discussions of research ethics, scientific misconduct, and the appropriate use of animals in research. In addition, the students participated in regular lab meetings with their research teams, and attended a workshop on preparation and delivery of a 10-minute scientific talk.

Throughout the program, the group also participated in enjoyable social and educational events on weekends and evenings. These events included movie nights, a visit to a local museum, pizza and burger nights at local restaurants, a visit to a research barn to observe an ongoing equine study and a Tae Kwon Do class taught by one of the post-doctoral fellows.

Students participated in the Summer Research Symposium on the last day of the program. Each student worked with his/her laboratory team to develop a 10-minute oral "platform" presentation, which included an introduction, statement of hypothesis, methods, results and conclusion. The students delivered their PowerPoint presentations to an audience of their research mentors and other personnel from the participating laboratories (technicians, post-doctoral fellow and graduate students), MENTORS project program staff, fellow Lab Rats and some family members of the participants. Following their presentation, the students answered questions for about 5 minutes.

Research Instruments

Two research instruments were designed to collect data from the students. Some of the questions in the two surveys were different.

- *A pre-experience survey:* This survey included questions to explore the participants' expectations, concerns, and goals for the program, prior to initiating the project activities.

- *A post-experience survey*: This survey included questions to explore the participants' experiences with the project. The extent to which the experiences met their expectations, affected their career goals, and impacted their self-esteem and confidence in achieving educational and career goals were explored. The post experience survey included both open-ended and Likert-scale questions. As part of the post experience survey, we also asked students to write down their experiences as an open-ended self-reflection. Each student provided detailed reflections.

Data Collection

Participants completed the pre-experience survey before they began their research activities on campus. Participants completed the online survey at a time of their convenience. We set aside time for the students to complete the pre-experience surveys.

On the last day of the program, students were asked to complete the post-experience survey. Surveys included a self-reflection portion, where students provided their insights about the experiences they had and the research they conducted.

Data Management and Analyses

Survey responses were collected and compiled. In our analyses of the responses to open-ended questions, we employed a constant comparative method [24]. employing open coding, selective coding, and axial coding strategies [22]. In the first reading of the students' responses, open-ended codes were generated, and these codes were categorized and grouped in the second reading. In the third reading, codes were organized around main categories to generate the main themes. Codes that did not contribute to any one of the main categories or the themes were deleted in this final stage of the analyses. We report the findings under the main themes and illustrate them using the excerpts from the students' written responses. For the Likert-scale type questions, we report the frequencies of the responses.

Findings

Pre-experience responses - The analyses of the pre-experience survey responses revealed that: (1) the students applied to the program because they wanted to learn more about STEM research and laboratory work, and (2) the students were very excited to learn that they had been selected for the project participation.

To learn more about research: The participants were aware that a major goal of the program was to provide authentic, scientific research experiences. One of the major themes that emerged from our analyses was that the primary reason that all nine participants applied to the program was to learn more about research. This is illustrated by the following typical responses to the question***:*** ***"****I applied to the Summer Research Internship program because…"*

- "*I wanted to gain deeper than the surface-level understanding provided by the basic chemistry, physics, and biology coursework*."
- "*I applied to the summer research program to get a better understanding of the research part of medicine, rather than the typical diagnosing. I also applied to the internship program to also get the necessary lab experience I would need to do research in my undergrad years.*"

Students also indicated their desire to explore STEM career opportunities.

- "*I want to expand my knowledge to other career options.*"
- "*It is going to be a great opportunity to learn new things, and it will also help me take a [deeper] look into the science branch."*

The students also indicated their anticipation of specific benefits of participating, when responding to the question*: "I expect this research experience to benefit me by…"*

- *"Laboratory skills, giving me the opportunity to expand my knowledge in a field of science in a focused area."*
- *"Giving me a lot more knowledge, so that when I return….. I can share with my teachers and friends what I learned."*
- *"Giving me the laboratory experience that can help me advance in a medical career."*

Excited to be selected for the program: Another major theme that emerged from our analyses was that the participants were very excited and some reported being surprised to learn that they had been selected to participate. When asked about their "*first reaction to learning they had been selected*," some of the student responses were:

- *"I was extremely excited about the opportunity to conduct hands-on laboratory research and work with professionals."*
- "*I was really happy, because I really wanted to come. I was also surprised because the other students that applied are really smart so I had a little bit of competition."*
- "*I was ecstatic and I still am, but I wish that some of the other highly-qualified applicants had been selected*."
- *"I really couldn't believe it."*

Despite this, when asked about their *"level of confidence" that they "could successfully complete the program,"* 56% responded that they were "very confident," and 44% that they were "pretty confident."

Post-experience responses

The analyses of the post-experience survey responses revealed that participants liked (1) working in the laboratory, and (2) the research presentations.

Working in the laboratory: When asked: "*Which activities did you liked the most?," the* participants reported that working in the lab was among the things that they enjoyed most about the program.

- *"I liked to work in my lab, because everyday, I was learning something new, and I love learning each and every day."*
- "*I enjoyed everything I did from lab work, [to] activities with the lab rats team."*

Enjoying the research presentations: The students attended a variety of research presentations during the 6 weeks of laboratory activities, often as part of regular laboratory meetings held in the host laboratories. Students also made individual presentations about their research at the Summer Research Symposium on the last day of the program. Students reported:

- *"I enjoyed listening to the research projects that the graduate students were doing in the lab because it gave me the opportunity to learn a little bit of everything*."
- *"Presenting [is what I liked the most] because it gave a view of everyone together."*

Social activities: Over half of the students also commented on their enjoyment of group social activities:

- *"I enjoyed eating out with the lab rats and the coordinators. Spending time with the coordinators really allowed me to bond with them and visiting downtown with them and the lab rats was an awesome experience."*
- *"Going to the movies and definitely going to the George Bush museum."*
- *"The movie nights were also a blast."*

When students were asked about their career plans "a*s a result of participating in the Lab Rats program,"* seven out of nine (78%) participants reported that they are "definitely more likely" to pursue a STEM career, one participant (11%) responded "probably more likely," and only one participant responded "neutral" (Figure 1).

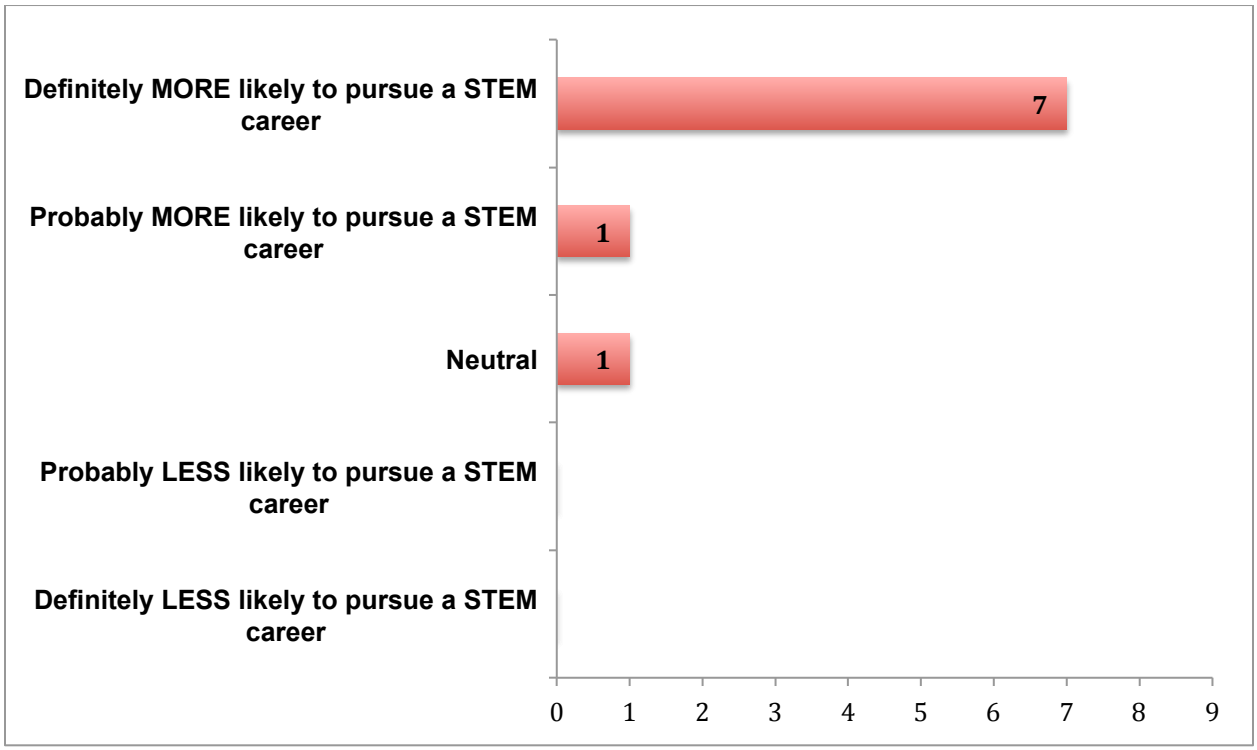

Figure 1. Responses to the question: "As a result of participating in the Lab Rats program I am…"

In response to the question: "*Did the Lab Rats program influence your career goals?*" eight participants (89%) reported a lot or some influence, and one participant (11%) reported "a little" (Figure 2).

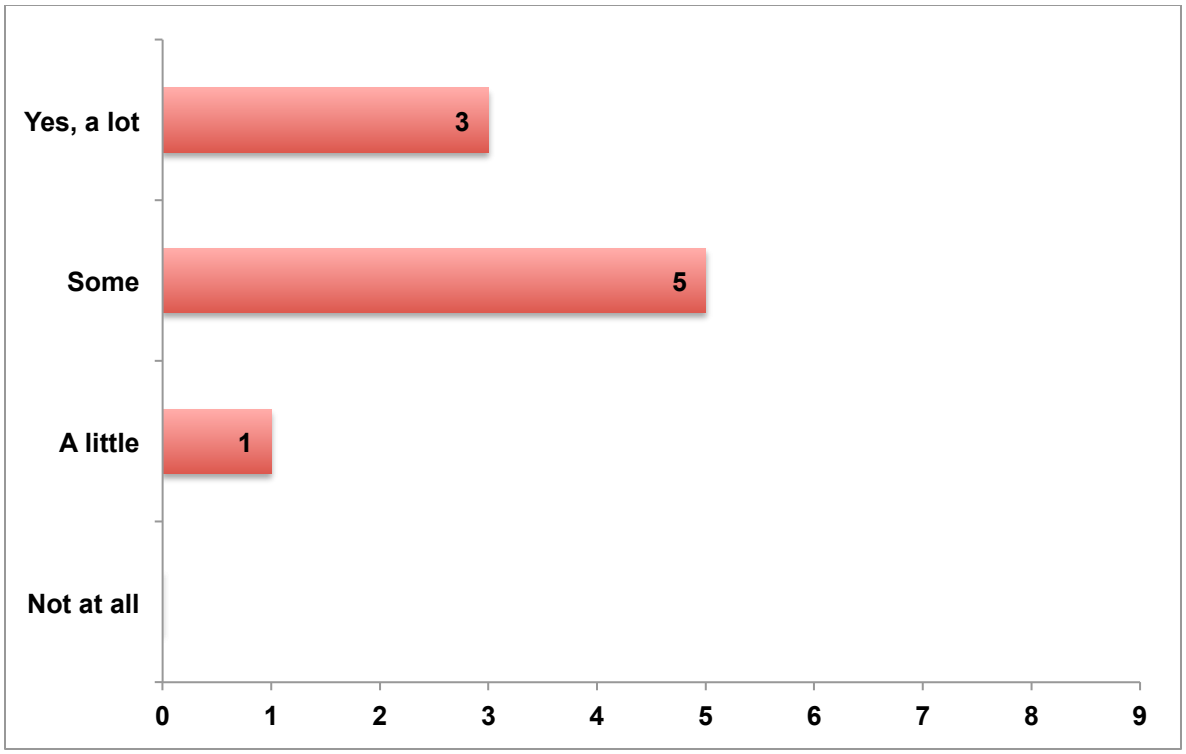

Figure 2. Responses to the question: "Did the Lab Rats program influence your career goals?"

Participants further elaborated on how the research experiences "*influenced"* their *"career goals:"*

- *"Having research experience made me realize my potential in the field of bioengineering, as opposed to simply biology."*
- *"I realized the importance of taking a statistical approach towards results in an experiment."*
- *"I learned a lot in this program …. [that] would be very helpful in my future career."*
- *"I came into this program not knowing what biomedical engineering really was, and I learned that I want more of a mechanical engineering background."*
- *"It gave me a clear path of what I want to do with my future career."*

Importantly, when asked if participation in Lab Rats influenced *"your belief in your ability to achieve your career goals,"* five of the students (56%) responded that it "increased my belief a lot," and four (44%) reported that it "increased my belief a little." No students reported a neutral or negative effect.

Taken together, these results indicate that participation in the Lab Rats program enhanced knowledge about STEM careers and the required qualifications. Some students reported that their experiences reinforced their STEM career goals, and some changed them, but all of the goals remained within the STEM and health science professions.

Conclusion and Discussions

As part of the MENTORS project, selected students from participating schools conducted hands-on, hypothesis-driven, project-based research in laboratories within multiple colleges on the university campus. Through visits to other research laboratories and educational venues at this Research I university in south Texas, students learned about a variety of health, research, and technology careers. The project focused on schools in small, rural communities along the Texas-Mexico border, which are low SES, medically underserved, and have a high proportion of students that are underrepresented in STEM careers. All of the study participants completed the summer research internships and presented in the Symposium.

Our findings indicate that all nine students were very glad to be selected for the summer research program. They considered this an important opportunity. It is clear to us that most of these students were already at least somewhat interested in STEM, and were good to excellent students. In addition to evaluation of grades and personal statements describing the motivations for applying to the program, the selection process also included assessment of the capacity of the student (maturity, enthusiasm, organizational and time management skills) to participate in this rigorous experience. It is acknowledged that students who were not as successful in school might not have applied to the program. Because our goal is to expand the pipeline of students interested in STEM, we view this potential bias towards selection of students already interested in STEM as a limitation of this study.

The post-survey data indicated that students very much enjoyed working in the laboratories with the researchers on campus, and as a result, became more motivated to continue their studies in STEM fields. Some have decided to switch their career goals to other STEM professions (specifically, physician and scientist/researcher). For some, their participation reinforced their career aspirations in STEM or health-related professions.

We will continue to monitor the academic progress of these students, most of whom are still pursuing their high school education. We will track matriculation into college/university, and their choice of undergraduate degree programs/majors, for the duration of the project. If the students choose STEM or health-related educational programs and careers, the long-term goal of our summer research internships will have been realized.

To replicate similar summer research programs like the Lab Rats, adequate resources and financial support are needed. The MENTORS is an externally and federally funded educational project. The Lab Rats is one of the components of the MENTORS Project, and benefits from the contributions of many research laboratories across the university campus. An advantage of a university campus is the availability of a variety of investigators conducting research in many disciplines. This allows a range of options for students, who were placed in different research laboratories based on their interests. Collaborating faculty members from multiple colleges serve on the Internal Advisory Committee of the Project, and also as research mentors.

Resources for meals, accommodations, and 24-hour supervision (our institution requires that minors be chaperoned at all times while on campus), were provided by the project. In order to replicate this program, an existing research infrastructure and financial support would be needed.

Our institution allows students ≥ 16 years of age to participate in summer research, but a number of requirements must be met. As mentioned above, the students must be chaperoned at all times. In addition, parents (or legal guardians) must sign an extensive permission document, and the project is required to purchase health insurance for the students for the period of their participation. If a similar program is conducted at another Research-I campus or an institution that has multiple operating research laboratories and similar resources, the standard operating procedures (SOPs), evaluation instruments and other documents are fully applicable and transferable.

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