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ORIGINAL PAPER

Experimenta con PREM: Outcomes and best practices from a two-decade materials research summer program for underrepresented high school students

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Abstract
Experimenta con PREM (meaning "Let's Experiment with PREM" in Spanish) is a dynamic summer research program at the University of Puerto Rico for high school students. The initiative encourages students to pursue STEM degrees, engage in research as undergraduates, and explore careers in materials science and scientific research. Since its inception in 2005, nearly 400 students—66% of whom are women—have participated in a 2-week research immersion at the Humacao and Cayey campuses. *Experimenta con PREM* showcases materials science as an inclusive discipline that covers diverse interests and competencies, including materials characterization, device fabrication, soft matter, crystallography, and both experimental and theoretical-computational approaches. Faculty mentors tailor laboratory experiences to mirror their research and guide students through the entire research process, from literature review to presenting findings. Notably, 84% of alumni have continued STEM studies, with 79% earning STEM bachelor's degrees.

Introduction

Studies indicate that the shift in students' mindsets from merely being interested in science and engineering to visualizing themselves in a science, technology, engineering, and mathematics (STEM) career can happen as early as kindergarten [1] However, robust statistical evidence shows that high school students' career aspirations remain flexible. Generally, participation in summer STEM programs enhances their propensity toward a STEM career [2]. Among the various summer STEM programs for high school students, those based on direct research experiences have proven to be highly effective. These early career research experiences in STEM offer students the chance to engage in genuine scientific research, thereby exposing them to the work and viewpoints of STEM researchers [3]. For many years, these activities have been successfully targeted at undergraduate students, as seen in NSF-sponsored Research Experiences for Undergraduates (REU) programs [4]. However, in recent decades, the scope of such programs has been expanded by numerous institutions to include secondary and elementary school students [5]. Indeed, by participating in early career research experiences, both undergraduate and high school (HS) students can gain a more profound understanding of scientific concepts and methodologies. They also develop essential skills such as critical thinking, problem-solving, and communication, which are crucial for success in STEM disciplines [5, 6].

Materials Science provides an ideal setting for HS research experiences due to its highly interdisciplinary and collaborative nature. It welcomes researchers with a wide range of skills, from theoretical and computational to

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experimental, engineering, synthesis, and characterization [7]. The creation and analysis of new materials, the immediate visibility of applications, and the experience of teamwork are some of the discipline's key features that are utilized to steer high school students toward materials science specifically, and STEM disciplines in general.

Participation in HS research can enhance self-efficacy, which in turn can positively influence academic performance and leadership skills. This is particularly beneficial for historically underrepresented students, including minorities, women, and students from low-income families in rural areas and small towns, who often do not have access to these opportunities [8–10]. Expanding access to research opportunities has been recognized as a crucial strategy for diversifying the STEM pipeline [11, 12]. Therefore, initiatives to offer STEM research experiences to these students are vital for fostering a more inclusive STEM community.

This paper describes a summer research program for HS students, called "Experimenta con PREM" (ECP), initiated in 2005 at the University of Puerto Rico at Humacao (UPRH) and the University of Puerto Rico at Cayey (UPRC). It discusses the program's progression, current structure, offerings, and best practices. Finally, it presents findings from a longitudinal study of the program's alumni from 2005 to 2023. While the influence of a specific program on the career choices of high school students will be the subject of a more in-depth study, the question we aim to answer in this paper is: Did participants of ECP persist and graduate from STEM programs?

Program history and description

The *Experimenta con PREM* summer research program for HS students is a highlight of the UPR-PENN Partnership for Research and Education in Materials (PREM) program [13], sponsored by the National Science Foundation (NSF). This collaboration between the University of Puerto Rico at Humacao (UPRH), the University of Puerto Rico at Cayey (UPRC), and the University of Pennsylvania's (PENN) Laboratory for Research on the Structure of Matter was initiated in 1998 under the NSF CIRE (Collaborative to Integrate Research and Education in Materials) program and then sustained through PREM support since 2004.

The PREM's research and education focus encompass two interdisciplinary research groups (IRG's): IRG-1: Charge dynamics in transition metal and carbon-based materials, and IRG-2: Surface-functionalized nanomaterials for sensing applications. The educational focus aims at diversifying the materials research community by identifying and guiding students through a pathway from K-12 to STEM undergraduate programs, and then onto graduate school. To reach underrepresented students within a 99% Hispanic student population, the program targets women and students from disadvantaged backgrounds, such as low-income families, first-generation college students, and those living in geographically isolated areas in Puerto Rico.

Initiated in 2005, ECP was designed to provide early, hands-on research experiences to high school students from the Eastern region of Puerto Rico, with the goal of igniting a passion for STEM education and careers. Now, 19 years later, the program continues to evolve, offering students comprehensive training in materials research.

To effectively reach our intended demographic of students from disadvantaged backgrounds, participation in ECP has been restricted to those enrolled in public high schools from the initiation of the program. The program's immediate success was evident through the surge in applications and the notable number of participants who went on to pursue college-level STEM studies. These encouraging outcomes at earlier stages propelled us to expand ECP to UPR-Cayey in 2016.

As the program evolved, we (1) integrated partners from PENN into the training efforts; (2) enhanced the scope and depth of our professional development workshops; and (3) continued reforming the hands-on laboratory experiences to reflect the evolution of the participant faculty's research areas. Moreover, we integrated the students' families into the activities by organizing laboratory tours and inviting them to the final presentations, empowering them to become active supporters of their children's STEM educational journey.

During the COVID-19 period in 2020 and 2021, the program continued. Laboratory kits were prepared and delivered to students' homes for them to conduct the experiments while connected with faculty via the Zoom™ virtual platform [14]. Despite the challenges of communicating with students virtually during these hands-on workshops, ECP proved to impact more than just the student participants. For example, we learned that many family members performed the laboratory practices after the Zoom session was over. Also, the virtual offering of ECP allowed communication/networking between the Humacao and Cayey cohorts in a way that had not happened before. After returning to the in-person programs in 2022, the format was modified to include joint events with the two campuses connected via Zoom.

ECP is structured to mirror the comprehensive experience students encounter in a Research Experience for Undergraduates (REU) Summer Program, spanning from the initial application to the culmination of presenting their research findings. The maximum number of participants is 20 for each campus. The duration of the program is set at two weeks, a period thoughtfully chosen to align with the availability of faculty mentors from undergraduate institutions. This ensures that their commitment to guiding students through this program is balanced with their ongoing research and other academic duties.

Application and participant selection process

ECP is actively promoted within public schools, specifically through STEM teachers, as well as through various media channels including social media, local radio broadcasts, and newspapers. These latter methods aim to reach parents and other family members of potential student participants who will encourage them to apply. Former participants also play an important role in disseminating the information in their schools and communities.

Prospective applicants are required to submit a comprehensive application package that includes *Personal Information*, to establish a basic profile of the applicant; *Essay of Interest,* allowing students to express their motivation and expectation for joining ECP; *Letter of Recommendation* provided by a STEM teacher endorsing the student's capabilities and fit for the program; and *Academic Transcripts*. The application package aims to prepare students for what they can expect when applying to similar programs as high school students or future undergraduates. For the essay, students are asked to answer 3 guiding questions: (1) What experiences have motivated your interest in scientific research? (2) What are your academic and professional goals? and (3) How will participating in ECP help you reach those goals?

The rubric used for the selection of students is included as a supplemental document.

The main criteria for admission are the Essay of Interest and Recommendation from a STEM teacher. The GPA is not the most important criterion, although we pay attention to grades in math courses as they may be better predictors of success in our target population.

In our commitment to inclusivity, particularly for students from underprivileged backgrounds, we request additional information such as *Residential Address*, to help determine the geographical diversity of our applicants, and *Parents' or Guardians' Education level and Occupation*, to assist in identifying candidates who may have limited access to educational resources. Teachers are encouraged to inform us of any special circumstances that may not be apparent from the application. The considerations are included under the diversity criteria in the rubric. Additionally, the student's academic level (sophomore or junior) is taken into account, as juniors have had more time for courses and other academic experiences.

Program organization

A recent ECP schedule is shown in Table 1. It begins with a research mini-symposium that acquaints students with materials science and PREM research. This is followed by a sequence of workshops designed to impart essential scientific research skills. Moreover, students interact with PREM undergraduates who freely exchange insights and address inquiries in an environment without faculty presence.

Teams of 3–5 students are formed, ensuring diversity across gender, schools, academic level, town of residence, and scientific interests. After the initial symposium and workshops, these teams spend four days rotating through various laboratories, where they conduct experiments, analyze data, and compile their findings into scientific reports with constant guidance from faculty, staff, and undergraduate assistants. After the lab rotations, each team is assigned a workshop and a laboratory experience for a final oral presentation that is aimed at an audience consisting of faculty members and families of the students. The integration of families adds the additional challenge of preparing a final presentation to an audience composed of scientists and the general public.

Training workshops

The workshops are crafted to foster the development of soft skills crucial for scientific inquiry. These skills encompass *Diversity Awareness* to cultivate an inclusive environment that values different perspectives, and *Laboratory Safety* to ensure a secure and compliant research setting. Beyond these foundational skills, the workshops provide exposure to current *Research Trends* to keep students informed about the latest scientific developments and to provide practical skills that will be useful for the laboratory experiences.

Our recent sessions have included interactive, hands-on workshops focusing on *Scientific Writing*, *Programming*, *3D*

Table 1 Typical *Experimenta con PREM* program

	Day 1	Day 2	Day 3	Day 4–7	Day 8	Day 9
AM	Opening/research mini-symposium	Workshop: scientific writing	Workshop: data visualization	Laboratory practices	Final presentation preparation	Practice presentations
PM	Workshop: Diversity/lab security Panel with PREM UG researchers	Workshop: coding or 3D printing	Workshop: microfluidics (PENN)	Laboratory experiences (cont.)/data analysis/report preparation		Final presentations/evaluation/lab tours for families

Printing, *Data Visualization*, and *Microfluidics*. Our PENN partners have an active role in this training, especially by introducing new research topics. Each summer, the program is enriched by the involvement of PENN partners, who travel to Puerto Rico and bring a wealth of knowledge and experience to the workshops.

Research experiences

Nine UPR faculty mentors, 5 at Humacao and 4 in Cayey, create laboratory experiences that are closely aligned with their own research and that expose students, within the time constraints, to one day in the life of a researcher in each laboratory.

Over the course of the program, our projects have evolved significantly, reflecting the dynamic nature of scientific research. Figure 1 summarizes recent work conducted by ECP students in our laboratories. The experimental projects have included the following:

1. *Polymer Nanofibers*: Using electrospinning to fabricate ultrafine fibers with potential applications in medicine, filtration, and electronics [15].
2. *Cellulose Membranes*: Developing biodegradable structures for biomedical uses. Functionalizing cellulose membranes with para-aminobenzamidine for the detection of aldehydes [16].
3. *Cellulose Microwell Plates*: Fabrication of biodegradable cellulose microwell plates for colorimetric estimation of enzymatic activities [17, 18].
4. *Reduced Graphene Oxide/Cellulose Composite Membranes*: Developing flexible electronic devices. Fabricating membranes that combine the strength and electrical conductivity of graphene with the versatility of cellulose [19].
5. *Gold Nanoparticles*: Synthesizing particles and performing quantitative analysis of protein/nanoparticle interactions for biological sensors [20–22].
6. *Dye-Sensitized Solar Cells*: Creating cost-effective alternatives to traditional photovoltaic cells [23, 24].
7. *Multiferroic Thin Films*: Exploring materials with multiple ferroic properties, particularly ferroelectric and magnetic properties, and fabricating thin films via the RF sputtering technique, which are useful in memory devices [25–27].

Characterization of materials is performed using techniques such as *Scanning Electron Microscopy*, *Fluorescence- and UV/Vis-spectrophotometry and microarray image analysis app*, and *Current–voltage measurements*.

Complementing the hands-on research, ECP computational experiences immerse students in

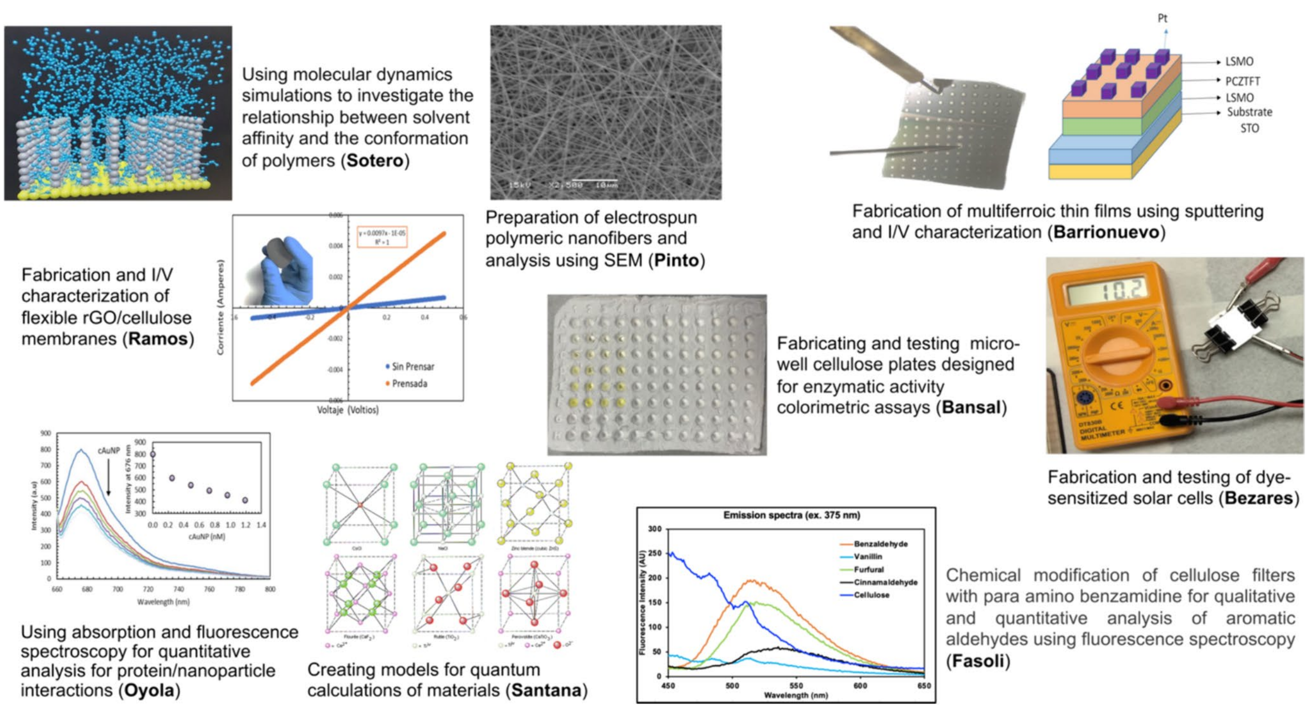

Fig. 1 Examples of ECP students' research activities with each UPR faculty mentor (Ramos, Sotero, Bansal, Barrionuevo, Bezares, Fasoli, Oyola, Pinto, and Santana)

1. *Coarse-Grain Molecular Simulations* to model polymer behavior in various solvents [28, 29].
2. *Quantum Level Molecular Simulations* for the theoretical calculations of crystal structures.

This comprehensive approach not only equips students with practical laboratory skills but also with computational expertise, preparing them for the interdisciplinary nature of modern scientific endeavors. Figure 2 shows a selection of images of ECP students during in-person and online laboratory experiences.

Program evaluation

The evaluation includes pre- and post-program surveys to assess changes in participants' knowledge about materials science. An exit survey is conducted to assess satisfaction of the participants and their recommendations to gauge the program's effectiveness. Additionally, interviews and focus groups are conducted by external evaluators at the end of the program. All the students are interviewed and participate in the group discussions. Guideline questions for the focal group were included as a supplementary document at https://osf.io/yf2x4/.

Persistence in STEM

A longitudinal study was conducted by the program to analyze the persistence of ECP participants in STEM fields. The data are organized in three categories: the field of interest at the time of application to ECP, the field of admission to college, and the field of graduation from college. Retention rates after admission to a college STEM program are compared with those of the general population of UPRH students during the same periods. The data collection methods for this analysis are described below.

As part of the application process, students complete a survey providing demographic information and outlining their career plans. This information is used as the baseline to follow their career trajectories. Upon their expected high school graduation, students are contacted via email, phone calls, and social media to complete a short survey. The questions include: "Did you continue your studies in college?" and "What is the university and program?".

Students are contacted again 5 years into their college education with another brief survey, asking: "Did you graduate from college?", "What was your program and university?", and "What are you doing or what are your plans after graduation?" If students are unreachable, the same questions are directed to parents, guardians, or family members.

Since 2005, ECP has integrated 391 participants, 66% women. The percentage of women is high to the representation of women in the applicant pool of high school sophomores and juniors attending public schools in Puerto Rico (51%) [30] and closer to the percentage of women admitted to STEM program at the University of Puerto Rico at Humacao [31]. The participants came from 34 towns and 59 schools in Puerto Rico. All those who qualified for graduation before May 2024 graduated from high school

Fig. 2 Scenes from Experimenta con PREM

(353) and over 80% of them continued in STEM fields as undergraduates.

The charts in Fig. 3a and b aim to correlate the participants' career aspirations at the time of applying to ECP with their eventual fields of study and graduation. The analysis only includes those who completed their undergraduate studies in 2006–2022 and those who had been enrolled in college programs for at least 6 years and had not reported graduation at the time ($N=232$). Data from a sample of the general population of UPRH students ($N=2258$) are shown in Fig. 3c for comparison [32].

The information in Fig. 3a is organized in three broad categories: "STEM" (based on categories used by NSF [32] and detailed later in this section), "Health" (including medicine, nursing, pharmacy, etc.), and "Other" (non-STEM or Health). The results show that over 99% of the students expressed interests in either STEM (87%) or health careers (12%) before participating in the ECP program. At the time of admission to college, 84% of the HS graduates entered STEM programs, 12% were admitted to "Other," and 4% to "Health" programs. Note that the reduction in the "Health" category could be influenced by ECP or other factors. Additionally, in Puerto Rico direct admission to certain health programs (like pharmacy or medicine) is not possible. When analyzing bachelor's degree graduation data, it is observed that after six years in college, 79% of the students had graduated with STEM degrees, 6% in health fields, and 15% in "Other" areas. Less than 1% are unreported and thus their graduation status is unknown ("NRG6").

To have more in-depth information about ECP students' career paths, Fig. 3b shows their career trajectories by STEM field. The STEM fields are "Chemistry," "Engineering," "Math/CS" for both Mathematical Sciences and Computer and Information Sciences; "Physics" for Physics and Astronomy; and "Life" for Life Sciences. The category "Other-STEM" includes Geosciences, Psychology, Social, Behavioral, Economic Sciences, and STEM Education. In the health sciences, "Medicine" was separated from other health-related disciplines grouped under "Health."

The chart shows that ECP participants applied to the program motivated by their interest in STEM, although many had not selected a specific field of study. For college admission and graduation, the majority of the students went into life sciences programs, followed by engineering, chemistry, and other (non-STEM) disciplines.

In comparison with the performance of ECP participants, the distribution of UPRH students (Fig. 3c) is 71% in "STEM," 20% in "Health," and 8% in "Other." Of these, 37% graduated in "STEM," 20% in "Health," 15% in "Other," and 36% "NGR6." Overall, ECP students performed significantly better than UPRH students in terms of retention and timely graduation in STEM fields.

In the program evaluation, students reported high levels of satisfaction and newfound knowledge. The following are extracts from a typical open-ended discussion at the end of the program:

> Scientific research is simply done by questioning something, and from those questions, everything arises. Through research we can obtain answers and expand our knowledge.
> The importance of scientific research lies in the acquisition of knowledge through a quantitative and qualitative processes of an experiment.

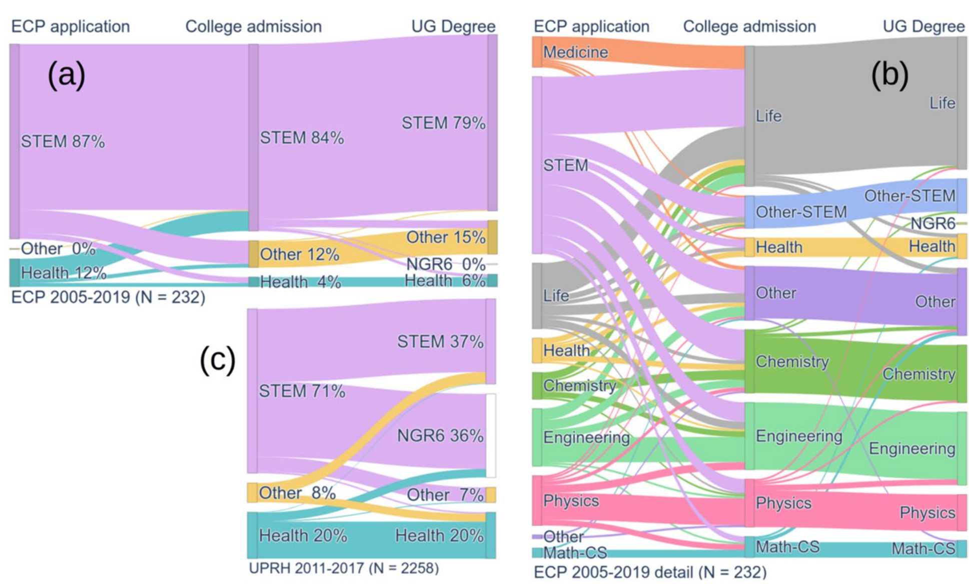

Fig. 3 Post-High School career trajectories among ECP students and comparable cohort of UPRH students. **a** Fields of study identified in ECP application, college admission, and bachelor's degree graduation for ECP students who graduated or have been enrolled in a bachelor's program ($N=232$) for 6 years or more. **b** Same data from (**a**), organized by specific fields of study. **c** Fields of admission and graduation for UPRH students from freshman classes 2011–2017, enrolled in STEM or Health programs at some point during their studies ($N=2258$)

Anyone can do scientific research, because science is not limited to a specific group.

I felt like a real scientist in my house. The dining room table became a laboratory. (Participant of ECP during the COVID period)

In my opinion, PREM is a program that helps us acquire new knowledge and see the future in a different way.

If was an experience that I would be happy to repeat.

Lessons from two decades of Experimenta con PREM

Experimenta con PREM has provided valuable insights and lessons over the years. Here are some takeaways:

1. Diverse Population. The program successfully attracts a diverse group of students, including Hispanics, women, and those from low-income backgrounds, promoting inclusivity in STEM fields.
2. Hands-On Experience. Students gain practical experience in materials science research, using actual research instrumentation and techniques, which enhances their understanding and interest in scientific careers.
3. Skill Development. Participants develop critical skills such as scientific inquire, teamwork, and communication through workshops and collaborative projects.
4. Mentorship and Networking. The program offers opportunities for students to interact with undergraduate students and faculty members, providing valuable mentorship and networking opportunities.
5. Family Support: The program integrates the student's family to gain their support in the student's career planning.
6. Increased STEM Pursuit. A significant number of participants go on to pursue higher education and careers in STEM fields, demonstrating the program's effectiveness in inspiring future scientists.
7. Adaptability. The program has shown resilience and adaptability by continuing to operate remotely during the COVID-19 pandemic and returning to in-person sessions when possible.

These lessons highlight the program's impact on fostering scientific literacy and encouraging students to pursue STEM careers. A long-term program like ECP has been possible thanks to the support of the National Science Foundation, University of Puerto Rico and other contributors. The program can be adapted into any STEM-focused research initiative with a commitment to diversifying the STEM workforce.

Conclusions

For two decades, the summer program *Experimenta con PREM* has offered early materials research experiences to 391 Hispanic high school students (258 of whom are women) from public schools in Puerto Rico. The program recruits Hispanic students, especially women and those from low-income families or living in rural areas or small towns. A longitudinal study spanning from 2005 to 2022 reveals that 84% of ECP students continued their undergraduate studies in STEM fields, with 79% earning bachelor's degrees. *Experimenta con PREM* effectively attracts and prepares students for undergraduate STEM studies. Compared to the general population of students admitted to STEM programs at UPRH, ECP participants demonstrate significantly higher graduation rates. The program's success underscores the importance of providing a holistic experience that integrates exposure to cutting-edge research topics, hands-on activities using actual research instrumentation and techniques, close interactions with mentors and undergraduate students, development of strong communication skills, networking opportunities, and family integration to gain support in career planning.

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Data availability Data used for the longitudinal study (Fig. 3), rubric for participant selection, and guideline questions for focal group discussion at https://osf.io/yf2x4/.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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