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Remote-Only Research Experience Improves STEMM Self-Efficacy in Secondary School Students

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ABSTRACT: During the COVID-19 pandemic, the existing Student Inquiry and Research program at Illinois Mathematics and Science Academy transitioned to a remote-only format. This paper describes the mentoring of 12 high school juniors and seniors in yearlong remote research projects involving plant biology and protein engineering. Working in groups of two or three, students read scientific articles and proposed experiments. An experienced researcher then carried out the experiments and gave the students the data. Students analyzed data, drew conclusions, and shared their results in an oral presentation and in a written paper. Despite the online-only format, all anonymously surveyed students agreed that the experience improved their confidence in both conducting and communicating scientific research, and 90% agreed that because of the experience, they are more likely to pursue a career in STEMM. These results are similar to those seen from in-person research experiences. Given the positive outcomes from this program, further development and use of remote research experiences may be beneficial, particularly for students who would not otherwise have access to any research opportunities. Remote learning technology thus enables existing resources of time and funding to be allocated differently to provide more students with authentic research experiences.

INTRODUCTION

High school and undergraduate students who have research opportunities experience a host of benefits including improved science self-efficacy, a community of scientific peers and mentors, and improved retention in science, technology, engineering, mathematics and medicine (STEMM) careers (Boyce et al., 2019; Linn et al., 2015; Sams et al., 2015; Tai et al., 2017). The COVID-19 pandemic forced students and teachers at all levels to transition to emergency remote instruction in 2020 and eliminated in-person research opportunities for high school and undergraduate students. There was widespread concern that a lack of research opportunities during the COVID-19 pandemic could cause lasting damage to the careers of students interested in STEMM (Johnson et al., 2020; Scott Price et al., 2020). Throughout the pandemic, mentors and administrators around the globe innovated to provide remote programming to replace traditional, in-person research experiences.

Remote or virtual mentorship has been examined previously for a variety of applications including supplementing classroom instruction (Arora and Goel, 2018), professional development (Owen, 2015) and to support and retain students with disabilities (Gregg et al., 2017). However, at the outset of the 2020 academic year, clearly described methods or benefits of entirely remote research mentorship were difficult to find. It is known that poor research experiences or lack of mentorship are harmful to students' scientific self-efficacy and retention in STEMM (Lopatto, 2007). In fact, STEM students' favorable attitude toward science decreased dramatically during the first semester of remote-only learning (Wester et al., 2021). It cannot be assumed that a remote-only experience will be positive and beneficial to students. Therefore, the goal of this paper was to determine whether a carefully designed remote research experience might provide at least some of the benefits of a traditional, in-person experience. Several studies have recently been published describing remote research mentorship of undergraduate students. As these novel mentorship methods have been evaluated and published, several themes have emerged which support the research reported in the current study:

- ***Remote research was generally a positive experience for students***, improving their research skills (Jensen-Ryan et al., 2021), building of community and networking (Johnson et al., 2020; Scott Price et al., 2020), and reinforcing their desire for a career in STEMM (Speer et al., 2021). However, studies have not directly compared long-term or short-term student outcomes of remote research with in-person research.
- Despite the previous rarity of remote research experiences (Speer et al., 2021), ***the capacity and willingness to mentor students remotely is present and widespread*** (Johnson et al., 2020). However, lack of experience with remote research mentorship and lack of examples to draw from present a large barrier to entry for both mentors and administrators (Scott Price et al., 2020).
- The availability of remote or virtual research mentors ***increased access to research experiences***, particularly for underserved or underrepresented groups (Johnson et al., 2020).
- Students and their mentors both describe ***benefits when students collaborate in research groups of their peers rather than working independently*** (Jensen-Ryan et al., 2021; Scott Price et al., 2020)
- Most remote research has primarily ***emphasized analysis of existing data and on reading and writing skills*** rather than on collection of new data (Scott Price et al., 2020). Programs that provided experimental setups to students had some success but also experienced difficulties (Jensen-Ryan et al., 2021).
- ***Students value the structure of a set schedule***, but remote research experiences have generally lacked the structure of traditional in-person experiences (Jeffery and Bauer, 2020; Jensen-Ryan et al., 2021).

In the fall of 2020, the Illinois Mathematics and Science Academy (IMSA) transitioned its existing Student Inquiry and Research (SIR) program to a fully remote format. The SIR program is described in more detail below, but of published studies on high school research experiences, SIR is most similar to the program described in Boyce et al. (2019). Twelve students were mentored during this study. A combination of personal observations and anonymous student pre/post surveys were used to assess how students' skills, scientific self-efficacy and STEMM aspirations were influenced by the yearlong remote research experience. This work expands upon previous studies in two important ways: first, by providing quantitative analysis of changes in students' skills and self-efficacy before and after a virtual research experience; and second, by focusing on high school students in a yearlong program rather than summer undergraduate research experiences. It is hoped that the following data and anecdotes will encourage further development of intentional remote research experiences for high school students.

METHODS

Students from IMSA, a public residential high school for grades 10, 11 and 12, were mentored in this study. Admission to IMSA is determined by a highly competitive process. All students at IMSA are encouraged to participate in the SIR program, which is designed to allow students to "conduct original investigations on compelling questions of interest, collaborate with other students and professional researchers, and to share their investigation results through public presentations and publications." During a typical (non-pandemic) year, students spend one full day each week on site with a laboratory scientist research mentor and produce several written documents throughout the year. Although IMSA was remote-only for the entire 2020-2021 academic year, the schedule still included one full day each week for SIR to be conducted virtually. For more information on the SIR program, see https://imsa.edu/academics/student-inquiry-and-research-sir/.

Because the SIR program was already established prior to the pandemic, an existing framework of assignments guided student research (Table 1). Assignments included an annotated bibliography, paper introduction, research proposal, midterm update, poster abstract, oral presentation and final paper, each of which had clear expectations. Within the constraints of these expectations, research mentors can choose their own format and approach to mentoring the students.

It is helpful to divide research mentorship into two roles: the mentor, who is the primary contact for the students, and the researcher, whose focus is to perform the experiments. The mentor's role is to teach scientific skills, such as reading scientific literature, writing technical documents and performing statistical analysis. The mentor also guides students in the scientific thinking required to understand the field and ask useful questions. The researcher's input is necessary to develop feasible experimental plans and to help students understand the research process and interpret their data. In this case, the author performed both the roles of mentor and researcher, but the roles could feasibly be divided between a high school science teacher (the mentor) and a laboratory technician (the researcher) or another similar arrangement. The roles of the mentor and researcher are detailed in Table 1.

Twelve students requested to work with the author based on a short, written description of the ongoing work and divided themselves into groups of 2-3 students each based on their choice from five broad questions that fell within the existing experimental plans. Weekly hour-long lab meetings were mandatory for all students and were used to introduce

Table 1. *Schedule of SIR assignments with the corresponding activities of the students, mentor and researcher.*

	Student	Mentor	Researcher
Phase 1			
9/16/2020 SIR starts	Complete Guided Learning exercises Read and present papers	Produce Guided Learning materials Prepare and deliver introductory lectures Teach students to read and present papers *Administer SI*	Prepare GoPro videos of protocols
Phase 2			
11/13/2020 Research proposals due	Design experiments Draft a research proposal Provide feedback on peers' proposals	Teach students experimental design Teach students specific experimental methods Facilitate lab meeting Provide feedback on experiments Provide feedback on proposals	Provide feedback on experiments
Phase 3			
12/1/2020 Annotated bibliography due	Continue to read and present papers	Facilitate lab meeting	Carry out experiments
12/15/2020 Progress report due	Prepare progress report	Provide feedback on progress report	Carry out experiments
12/9/20 - 1/27/21 Winter break			Carry out experiments
Phase 4			
3/15/2021 Abstract due	Analyze data as it becomes available Engage in troubleshooting Give progress updates at lab meeting Draft and edit an abstract	Facilitate lab meeting Help students analyze data Provide feedback on abstracts	Carry out experiments Help students analyze data Help students troubleshoot experiments
Phase 5			
4/14/2021 Presentation due	Analyze data as it becomes available Engage in troubleshooting Give progress updates at lab meeting Prepare a presentation Give feedback on peers' presentations	Facilitate lab meeting Help students analyze data Provide feedback on presentations	Carry out experiments Help students analyze data Help students troubleshoot experiments
4/21/2021 Presentation given	Practice and deliver presentation	Attend presentation	Attend presentation
5/15/2021 Final paper due	Prepare and submit final paper	Respond to students' inquiries *Administer SI, SES and free-response questions*	Respond to students' inquiries

students to aspects of the field and to teach skills such as reading primary literature, designing experiments and scientific writing. To help students learn the concepts at their own pace, "guided learning" homework was designed which included video lectures and additional links. GoPro videos of laboratory procedures were also created to provide students with a first-hand perspective on the research being performed. Students presented their progress at the weekly lab meeting, with presentations ranging from a brief paper summary to experimental designs to analyzed data. Students were encouraged to engage with each other by asking questions and providing feedback on the work presented.

In addition to the weekly large-group lab meeting, each of the five student groups also participated in a smaller meeting in which the details of their project were discussed. These group meetings occurred on an as-needed basis during a reserved hour of time on the same day as the lab meeting. Group meetings were often used to ask specific questions about a protocol, troubleshoot failed experiments, or discuss analysis of a dataset. Finally, virtual office hours were held the evening before each lab meeting to assist students as they prepared for lab meeting the next day.

The assignments set by the SIR program served to break the academic year into five phases:

In Phase 1, students learned the field through lectures and by reading primary literature. The weekly meeting was spent introducing high-level concepts and broad questions on which the mentor's research program is built. Students were given a folder containing roughly 60 papers which included important results, key techniques, and literature reviews. The students each read a few of the papers, added them to a collaborative annotated bibliography, and summarized them for their peers during the weekly meeting. This phase culminated in each student producing an annotated bibliography of at least five sources, while each group produced a short introduction to their research proposal. Each group also produced a short list of research questions that represent "the edge of what is known in the field."

In Phase 2, students learned about specific techniques that can be used to answer the questions formulated in Phase 1. The emphasis in this phase was on understanding how each technique works at a theoretical level, and which techniques are useful to answer which questions. Student groups were instructed to propose an experiment to answer each research question from Phase 1. Phase 2 culminates in each group producing a detailed experimental plan for the researcher to follow, along with a written research proposal.

In Phase 3, the researcher performed all the students' experiments. Students had finalized their experimental plans right before an extended winter break, giving the researcher roughly two months to conduct experiments before the student researchers returned. While students awaited their data, they were provided with a variety of instructional videos on how to analyze data in its raw format (e.g. from a plate-reader or LI-6400 instrument), as well as GoPro videos of the researcher performing the experiments (link to videos provided in Associated Content at the end of this manuscript).

In Phase 4, the students analyzed the data, drew conclusions and identified future directions of follow-up research. They presented their progress and conclusions at lab meetings to receive feedback from their mentor and peers. For some groups, the experiments proposed were straightforward and the data was easily collected. For other groups, one or more experimental steps failed. In these cases, students were given the data up to the point of failure and engaged in weekly group meetings to troubleshoot the experiments.

In Phase 5, students communicated their final results both in writing and in an oral symposium presentation. They submitted an abstract for the oral symposium, prepared a 10-minute presentation, and virtually presented their data to family and friends in a live video-conferenced event. Following the event, students prepared a research paper describing their results and proposing future directions for research. Group meetings in Phase 5 focused on communication skills such as concise writing and how to structure a presentation.

Student impacts were measured in multiple ways. During the first meeting of the year, students were asked to fill out a "Skills Inventory" (SI) ranking their competence in 18 research-related skills (see Table 2 and Supplement) on a scale from 1 ("I don't even know what this is") to 5 ("I'm so good at this I could teach it.") Students were presented with the same SI at the end of the year. Students' perceived changes in competence were tracked across the academic year. A survey was also conducted at the end of the year. This included a Likert-based science self-efficacy scale (SES, Sams et al., 2015), a Likert-based questionnaire about intent to pursue a career in STEMM, and anonymous free response questions assessing the research experience (see Supplement). The SES scale was an end-point measurement that asked students, "For the following statements, please indicate the level to which you believe each factor increased as a direct result of your mentorship experience." Thus, although the SES represents a single timepoint, it measures perceived improvement in skill since the beginning of the mentorship experience.

RESULTS

Survey Outcomes. A pre/post SI measured students' self-reported competence in the areas listed in Table 2. Of the 12

Table 2. *Skills Inventory results. Significant results are indicated in red.*

Skill	Mean Pre	Standard Deviation Pre	Mean Post	Standard Deviation Post	Change	Heteroscedastic t-test	Paired t-test
Number of students	n=12	n=12	n=10	n=10	n=10	n=12	n=10
Statistical analysis	3.42	0.90	3.30	0.82	-0.10	0.75	0.80
Using Excel to analyze data and make graphs	3.67	0.65	4.20	0.63	0.70	0.07	0.02
Drawing conclusions from data	4.08	0.51	3.80	0.79	-0.20	0.34	0.51
Reading and summarizing scientific literature	3.42	0.51	4.00	0.94	0.60	0.10	0.05
Proposing and justifying ideas in writing	3.67	0.78	3.50	0.85	0.00	0.64	1.00
Describing results and conclusions in writing	4.00	0.43	4.00	0.67	0.00	1.00	1.00
Making conceptual figures	3.25	0.97	3.50	0.97	0.20	0.55	0.51
Making/presenting a scientific poster	3.67	0.98	3.70	0.95	0.00	0.94	1.00
Giving a scientific talk	3.33	0.98	3.50	0.71	0.10	0.65	0.80
Giving helpful feedback to others	3.83	0.94	3.50	1.35	-0.20	0.52	0.68
Accepting feedback from others	4.42	0.51	4.60	0.52	0.30	0.42	0.08
Active listening to others	4.58	0.51	4.20	0.79	-0.30	0.21	0.39
Contributing productively in a group	4.42	0.90	4.40	0.52	0.00	0.96	1.00
Resolving conflict	4.08	0.67	4.60	0.52	0.50	0.05	0.10
Time management	3.42	0.67	3.20	1.14	-0.10	0.60	0.76
Organization	4.25	0.62	3.70	0.82	-0.50	0.10	0.05
Motivation	4.25	0.75	4.00	0.94	-0.20	0.51	0.59
Asking for help	4.00	0.74	4.00	0.82	0.20	1.00	0.51
Total	**69.75**	**6.97**	**69.70**	**9.24**	**1.00**	**0.99**	**0.72**

students, only ten responded to the post-survey. Seven of 18 areas showed a decrease in perceived competence, with seven areas improved and four areas unchanged. A heteroscedastic Student's T-test revealed a marginally significant improvement in the "resolving conflict" skill (p=0.05). A paired T-test revealed three areas of marginal significance: the skills of "using Excel to analyze data and make graphs" (improvement, p=0.02), "reading and summarizing scientific literature" (improvement, p=0.05), and "organization" (decline, p=0.05). The students' self-ratings in each category can be summed together to provide a single overall competency score. Competency scores did not significantly change from the beginning to the end of the program (69.8 +/- 7.0 vs 69.7 +/- 9.2, p = 0.98, heteroscedastic Student's T-test). In the SES, students reported that they perceived gains in all 17 categories greater than "some" (coded 3) but less than "extensively" (coded 5) with the strongest gains in making sense of scientific texts, critical thinking and independence (Table 3).

Nine of the ten students who completed the post-survey (90%) agreed or strongly agreed that the online-only experience "improved their understanding of what biological research is like". All students agreed that the experience improved their confidence in both conducting and communicating scientific research. 90% agreed that because of the experience, they are more likely to pursue a career in STEMM, with the remaining 10% responding "neutral".

Unfortunately, this type of evidence had not been previously collected during in-person research experiences at IMSA, so a direct comparison with previous in-person SIR outcomes is not possible.

Gender Differences. As can be expected from beginners in a field, students' proposed experiments were often either too broad or too limited in scope given the time and resources available. Interestingly, there was a clear gender divide among students whose proposals were overly ambitious and those which were not ambitious enough. At the beginning of the year, students spontaneously self-sorted into groups by gender, with three groups of 2-3 male students, one group of two female students and one group containing one female and one nonbinary student. All three groups of male students proposed very ambitious projects and required "reality checks" on the feasibility of their plans. Groups containing female or nonbinary students needed to be encouraged to broaden the scope of their proposal. Female and nonbinary students verbally expressed concerns about not overburdening or imposing upon the researcher. Initial SI results indicated a lower overall self-efficacy for females than males (62 +/- 6.2 vs 71.5 +/- 4.9, p = 0.097), although this effect did not rise to statistical significance. There were no significant differences between males and females in any area examined either in the SES or SI, likely due to small sample size. The nonbinary student was excluded from the gender analysis.

Table 3. *Self-efficacy scale results.*

Category	Mean	Standard Deviation
Problem solving	3.9	0.57
Critical thinking	4.1	0.74
Leadership	3.9	0.88
Independence	4.1	0.74
Self-reliance	3.8	0.79
Reading for meaning	4	0.94
Making sense of scientific texts	4.3	0.82
Innovativeness	3.4	0.84
Strategic thinking	3.7	0.82
Ability to organize thoughts	4	0.67
Creativity	3.6	0.70
Self-motivation	3.7	0.82
Desire for lifelong learning	3.8	1.03
Advocacy	3.6	1.07
Feeling of self-worth	3.6	1.26
Persistence	3.9	1.20
Writing	4	0.94

Student Perceptions. Free-written student responses were categorized according to Jeffery and Bauer (Jeffery and Bauer, 2020). Briefly, *Okay* students are largely unfazed by the transition to online learning; *Keep Calm* students recognize difficulties but are motivated to push on despite them; *Structure Seeking* students struggle with the loss of structure from in-person experiences and express difficulty with time management and self-motivation; *Loss* students lament and despair over "missing out" on the typical experience; and *Lemons* students are angry and frustrated. Free responses provided by students were divided equally among *Okay*, *Keep Calm*, and *Structure Seeking* with no responses in the *Loss* or *Lemons* categories.

Several students commented on the loss of the structure of an in-person research experience. During in-person SIR experiences, students travel by bus to their research site, work for 8 hours and then return to school. Research activities are conducted entirely during on-site research time. In contrast, remote research activities could be completed any time during the week, and many groups chose to complete their work the night before the meeting. Student comments included, "*I enjoyed how we could do our research asynchronously*" and noted that a virtual research experience was "*less demanding than an in person [experience] as you still have most of your [research] day free.*" Another reflected, *"I could have managed my time better and not procrastinated on weekly assignments, as my group and I were usually working on them till late at night.*"

Students generally viewed the weekly lab meeting presentations favorably as an opportunity to improve their presentation skills. One student also highlighted the weekly presentations as beneficial to developing self-efficacy: "*giving mini-presentations every week…helped me be more confident in what we were doing since I had to explain it to everyone else*." Weekly meetings seem to also have somewhat filled a social void created by remote schooling and work. One student commented, "*it was really helpful for all the groups to keep each other updated with their progress - I'm glad that we did it because there's a greater sense of unity among lab members*

When asked about the least helpful part of the experience, half of the students indicated dissatisfaction with the remote-only format. One student wrote, "*a lot of what I did this past year felt theoretical and not as applied as compared to if I would have been able to do the tests in the lab in person*." Many of the students had previously experienced in-person research and thus could compare the virtual format with in-person research. Individual students seemed to have mixed perceptions about the value of a virtual experience, with the same student saying that the research experience was "really helpful" and that they "learned a lot" but also saying that the virtual format was "really detrimental". Students noted that the lack of hands-on engagement decreased their understanding of how the experiments worked. "*I understood it conceptually, but…not being able to see the machinery and equipment used for the experiments…threw me off.*"

Students also identified some benefits to the virtual experience, including time savings, flexibility in working hours, and access to mentors from far locations. For example, "*a student would have to weigh the pros and cons of time spent traveling to an in-person* [research experience] *vs. saving that time and pouring it into virtual research.*" Others noted that the virtual experience emphasized different skills. "*With a virtual* [research experience], *since you won't be doing the actual experiments yourself that gives you more time to focus on other skills such as … data/statistical analysis and making graphs*." Another student found that spending less time on experiments allowed a greater depth of understanding of the field:

> *…a virtual [experience] can be extremely beneficial if you want to have a [research experience] that can introduce you not only to the work of a certain field but the ideas and concepts that reside within it. However, I would also say that if you want to have a more realistic idea of what laboratory work demands then an in-person [experience] might be the better choice.*

Additional Outcomes. The students each produced a valuable intellectual contribution to the research, which were reflected by six student authorships on two conference poster presentations. An unexpected but very positive outcome is that more than half of the students asked to continue their remote research over the summer or next year, despite having in-person SIR experiences available starting in the fall. This shows that students perceive the experience they received through remote research to be valuable enough that they chose to continue their existing remote research rather than starting an entirely new research project in person.

DISCUSSION

Comparing the Survey Instruments. Some of the items on the SES closely matched items in the SI, allowing direct comparison among the datasets to determine whether students' perception of improvement (endpoint) correlates with a change in their perceptions of competence before and after mentorship. The SI category "Reading and summarizing scientific literature" matches with SES categories "Reading for meaning" and "Making sense of scientific texts". Students indicated that these reading-related skills had improved both in the SI (change +0.60) and the SES (4.0 and 4.3, between "a lot" and "extensively"). The perceived improvements in this area were consistent between surveys and were the strongest signals observed in each survey. The SI category "motivation" (change -0.20) and the SES category "self-motivation" (3.7, between "some" and "a lot") both demonstrated low scores compared to other categories, which matches both the free-written responses and the literature indicating students struggled to stay motivated over the year of remote learning due to COVID-19 (Jeffery and Bauer, 2020). The SI categories "Proposing and justifying ideas in writing" (change 0.0) and "Describing results and conclusions in writing" (change 0.0) showed little change, but on the SES scale students reported that their writing skills improved "a lot" (4.0), possibly indicating that students had been overconfident in their own abilities prior to the research experience. The remaining items in the SI and SES did not examine the same areas and thus could not be compared.

Impact on Skills and Self-Efficacy. For this self-selected and highly motivated cohort of high school students, the SES data show that an online-only research experience did not negatively impact their scientific self-efficacy or aspirations for STEMM careers. Students perceived gains in their skills to be a direct result of their research experience. These findings concur with other studies that found that remote undergraduate research experiences developed students' skill confidence and increased their interest in STEMM careers (Speer et al., 2021; Yang Yowler et al., 2021).

The pre/post self-reported skill scores in the SI did not reflect overall improvement in STEMM self-efficacy or in individual categories. Wester et al. also observed unchanged self-efficacy during the first semester of remote learning and viewed this as troubling evidence of a lack of student cognitive engagement in the classroom (Wester et al., 2021). It is initially alarming that students' self-perceived competence in the SI decreased in so many areas. Some areas can be explained by the unique difficulties imposed by the pandemic. For example, other sources have reported a decrease in motivation, difficulty with time management and organization, and lack of an ability to connect with others due to the work-from-home environment (Erickson and Wattiaux, 2021; Jeffery and Bauer, 2020; Schultz and Demers, 2020). However, skills such as statistical analysis and drawing conclusions from data should be independent of the learning environment. These skills were taught, modeled and practiced throughout the year, and significant improvement in students' ability to analyze data was evident. It is known that difficult circumstances associated with the COVID-19 pandemic have caused anxiety and depression among students (Wang et al., 2020). This may have manifested in a pessimistic perception by students of their own skill level. This interpretation is supported by the coded SES responses and free-written prompt responses which indicate that their confidence increased over the research experience despite their unchanged perceptions of self-efficacy. For example, a decrease in the SI score often paired with "a lot" of improvement reported in the SES for comparable categories. Students reported a perceived improvement in their skills in the free response section, which aligns with the instructor's observations. Thus, students' unchanged self-efficacy scores likely reflect initial overconfidence paired with accumulated pessimism later in the year rather than a loss of engagement.

Gender Differences. Female and non-binary students proposed less ambitious projects. This can be interpreted as reluctance to expend their social capital with an authority figure by making a large request (van Esch et al., 2021) and reflects known communication and negotiation tendencies with males being more assertive and females more conciliatory (O'Neill and Colley, 2006; Toosi et al., 2019). Gendered differences in interacting with research mentors have also been documented (Aikens et al., 2017). These differences could also be attributed to the females having lower self-efficacy and confidence in STEM fields (Macphee et al., 2013), though the sample size of this study was too small to detect such an effect. The surprisingly clear divide in this study highlights the need for mentors to remain mindful of gender differences.

Student Perceptions. The breakdown of student response categories most closely mimics the results from an advanced undergraduate course in which the students are a self-selected cohort who are intrinsically motivated and driven to work through challenges (Jeffery and Bauer, 2020). Because IMSA students are selected by a competitive admission process and the SIR experience was voluntary, the students are highly motivated and strongly interested in STEMM fields. Thus, it makes sense that the students who chose to engage in research are motivated and driven, but still occasionally struggle with a lack of the structures to which they are accustomed. Although some students found the lack of structure freeing, others, fitting into the Structure Seeking category, expressed difficulties with motivation, organization or time management due to the lack of structure. Further research should explore how mentors can help students remain motivated and organized in unstructured or asynchronous environments

Frequent mentions of the social aspect of lab meeting highlights that students attached importance to maintaining a sense of community despite the lack of physical presence. This is corroborated by a recent report that social presence is of particular importance in student satisfaction with remote learning (Erickson and Wattiaux, 2021). A loss of student-to-student interactions has been cited as a major factor contributing to decreased student motivation and negative emotional responses during the pandemic (Jeffery and Bauer, 2020). Zoom meetings among undergraduate researchers and their mentors was described as improving student motivation by promoting bonding among participants (Jensen-Ryan et al., 2021). Admittedly, the lab meeting setting lacked the informality of spontaneous in-person exchanges (Speer et al., 2021). However, the mere opportunity to interact with each other routinely seems to help students remain engaged, motivated and emotionally healthy.

Mixed perceptions of remote research are likely attributable to existing negative beliefs about the value of online vs. in-person experiences and to a failure to adjust expectations formed from in-person opportunities to match the realities of a virtual format (Erickson and Wattiaux, 2021; Speer et al., 2021). Despite disappointment with the remote format, students highlighted some benefits, often noting complex trade-offs between remote vs. in-person research. Multiple comments about not being able to see the experiments, taken together with the low number of views on the posted video protocols, indicate that the students under-utilized the GoPro lab videos. However, even when videos are fully utilized, students express that physically engaging in experiments is crucial to developing a complete understanding of the laboratory work (Jeffery and Bauer, 2020).

Reflections and Suggestions for Future Implementation. Most of students' dissatisfaction with virtual research stems from their expectation that the virtual experience would be the same as an in-person experience. A remote-only experience has its own benefits and drawbacks, is certainly not the same as an in-person experience. For example, students are unable to directly participate in data collection (Jensen-Ryan et al., 2021), and there is less opportunity for informal interaction with mentors and peers (Scott Price et al., 2020). Therefore, the mentor should begin by guiding students toward reasonable expectations for the virtual experience. It should be clearly communicated that remote research is not meant to be a lesser version of an in-person research experience, but a distinct experience altogether. To best prepare students to be satisfied, the mentor must emphasize that the virtual experience focuses on different skills and knowledge than an in-person experience and highlight the value of those skills (Speer et al., 2021).

Schultz and Demers have wisely pointed out the difference in classroom learning between an emergency remote scenario and a carefully pre-designed remote experience: "Hastily moved content to the online format by so many institutions could inadvertently create the misconception that online course- work equates with a weak option in comparison with class- room instruction." (Schultz and Demers, 2020). Similarly, remote research should not be judged by initial experiences with emergency remote laboratory mentorship. The experience described in this and similar recent work was an emergency adaptation of an existing research program and, in some respects, does not represent an ideal remote research program. However, even these emergency remote experiences have provided benefits to students, demonstrating the potential of this technique. Going forward, the community of research mentors must learn from these experiences and begin to intentionally build remote research opportunities that are designed, from the ground up, to best fit the remote modality. These intentional remote research opportunities may look quite different from in-person experiences or even from the "emergency remote" options described here and elsewhere.

The structure provided by the school's pre-established writing assignments was very helpful. Written products and deadlines helped maintain a sense of normalcy and structure that students were used to from previous experiences. The progression from annotated bibliography to proposal, progress report, abstract, presentation and final paper was logical, with each step building off the previous step and scaffolding skills for the next step. Assignments also provided a written record of the students' growth and contributions to the project. While this specific lineup of assignments may be infeasible during a shorter summer experience, others have reported a conceptually similar use of assignments to structure and scaffold summer remote research experiences (Jensen-Ryan et al., 2021; Scott Price et al., 2020).

Grouping students both provides opportunities to a larger number of students within the same logistical constraints and helps students develop the teamwork skills which are vital in research careers. An unforeseen additional benefit to group work was to ease the social isolation students experienced during the year of remote schooling. The benefits of groupwork during remote research have also been highlighted by others (Jensen-Ryan et al., 2021; Scott Price et al., 2020) and should be incorporated into future designs of remote research experiences.

Applicability Beyond the COVID-19 Pandemic. Although the work on remote research mentorship published here and elsewhere focuses on the remote modality as a non-ideal emergency adaptation forced by the constraints of a global pandemic, remote research experiences are in fact a valuable option in their own right. Remote research can increase the accessibility of research experiences to students who are unable to come into a laboratory, whether due to a pandemic, rural location, disability or other constraint (Johnson et al., 2020). Additionally, remote research allows students and mentors to focus on developing higher-level cognitive skills such as scientific reading, writing, thinking, and troubleshooting, while spending less time on developing procedural mastery of fundamental laboratory skills. Finally, lack of a physical student presence in the lab decreases the resources needed to mentor each student, allowing more students to receive mentorship within the constraints of the same resources. In the future, remote research may function best as a partnership between a high school teacher (the mentor) and a doctorate-level researcher or technician (the researcher). These partnerships could be local in nature but need not be limited by geographical constraints. Depending on the resources available to the high school, some experiments may even be performed in-person in a high school laboratory under supervision of the mentor.

Research science procedures are increasingly becoming automated as advanced robotics become more affordable. In the not-too-distant future, it is feasible that very little of a researcher's time will be spent performing experiments because robots are able to perform these tasks more efficiently and with less error. Instead, tomorrow's scientists will increasingly focus on designing experiments, troubleshooting unexpected results, and interpreting data. However, these skills are rarely taught effectively to undergraduates. Most laboratory classes taught at the undergraduate level use contrived, well-validated protocols to produce a known result and do not require students to read primary literature, design experiments or troubleshoot failures. It is not until students attend graduate school (if they make it that far) that they can expect to have an authentic research experience or to learn these foundational research skills.

Although there are opportunities for undergraduate and even high school students to conduct authentic work in research laboratories, these are often the exception for highly motivated students rather than the norm for all students of science. This is largely because constraints on budgets, lab space and researchers' time prevent a universal availability of laboratory research experiences. The success of remote research experiences demonstrates that the key skills of science can be taught and practiced effectively even without a physical student presence in the laboratory. The method described above allows a single research mentor to provide an authentic experience to many students in the virtual format. Because the assignments are preestablished, the time commitment required for the mentor role was minimized, requiring 1-8 hours per week of preparation and 4-8 hours per week of meetings with students. Because the students' experiments are designed in line with the ongoing research, their inclusion requires only modest additional effort and minimal disruption to existing research plans. In an ideal situation, the mentor may guide the students to design an experiment which the researcher has already decided to do or even already carried out. In contrast, with an in-person student presence, the researcher's time is usually spent supervising students as they learn and practice fundamental skills. Student presence in the lab also increases the cost of scientific research because experiments often give unacceptable results due to the inexperience of the student researcher and must be repeated. The lack of student presence in the lab alleviates constraints on budget, lab space and mentor time, allowing participation of a larger number of students than could feasibly participate in an in-person experience.

The COVID-19 pandemic and rapid remote adaptation of many aspects of life has certainly provided an unprecedented challenge in education. It is to be hoped that scientific and educational communities will not discard or forget the benefits of these novel modalities once a full return to in-person activities is possible. With sustained effort, we can develop and implement evidence-driven remote research experiences that unlock unique avenues to engage the upcoming generation of scientists.

ASSOCIATED CONTENT

Supplemental material mentioned in this manuscript can be found uploaded to the same webpage as this the manuscript.

The videos provided to students are found at https://youtube.com/playlist?list=PLOvjjf1xHWbZR7yJAYNDqRwhCQIrDqXrF

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ABBREVIATIONS

IMSA: Illinois Mathematics and Science Academy; SES: Self-Efficacy Scale; SI: Skills Inventory; SIR: Student Inquiry and Research; STEMM: Science, Technology, Engineering, Mathematics and Medicine

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