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RESEARCH REPORT

Do STEM teachers have the potential to become leaders in online education?

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Abstract
In 2022, the Taiwan Network Information Association found that 74.10% of distance teachers would rather not teach remotely after the pandemic. STEM teachers should be comfortable using technology in the classroom, and they seemed to enjoy online teaching. We can better understand STEM teachers' transition from face-to-face (FTF) to online teaching due to the COVID-19 pandemic, how they responded, and what changes were made. Case studies determined how well they responded and what changes were needed. Taiwan's science teacher and maker communities volunteer online. Nine Taiwanese STEM teachers were interviewed using modified Sintema questions (2020). Interviews took three steps. "#1 preparation time," "#2 early phase," "#3 late phase," and "#4 resumption of face-to-face teaching" were the data stages. STEM teachers' skills fall into three categories: pedagogical content knowledge, computational thinking, and self-efficacy, according to research. This study compared all changes in STEM online teaching method and characteristics to those before large-scale online teaching. We found that teachers had more issues than STEM ability, including "equipment," "student motivation," "class management," and "increased workload" (MOOCs). Lack of "FTF discussions" among STEM teachers during research caused unexpected issues. This difficulty may affect soft skill development. The study also found that STEM teachers face complex and varied challenges and that their online teaching experiences can be useful for other teachers.

Keywords: *Characteristics of STEM teachers, on-line teaching, STEM teacher*

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The outbreak of a new respiratory disease was confirmed for the first time in Wuhan, Hubei Province, PRC, at the end of 2019, and the virus had spread to Taiwan by January 2020 (Cheng et al, 2020). In addition to Taiwan, this outbreak of COVID-19 epidemic has caused an unprecedented large-scale suspension of normal school operations in many countries around the world. Countries are being forced to convert face-to-face (FTF) courses to online teaching in a very short period of time, and Taiwan has also been suspended entirely due to the threat of the epidemic.

In 2012, the National Research Council highlighted the importance of STEM education (National Research Council, 2012) as a subject that spanned multiple disciplines. It included science, technology, engineering, and mathematics. There were no teachers who specialized in STEM. They have superior information skills and more cross-disciplinary experience than all other teachers (Lewis, 2005; Schmid et al., 2021). STEM teachers would need to be familiar with the use of technology in the classroom and in fact they appeared to find online teaching very simple and natural. However, there were several challenges that had to be overcome in online teaching such as practice, creativity, and inquiry. As a result, we have an opportunity to get a clearer idea of the challenges that STEM teachers faced as they transitioned from FTF to the online teaching precipitated by the COVID-19 epidemic, how well they were able to respond, and what changes were implemented. The challenges faced in other fields are a subset of those faced by STEM teachers. This means that if it is possible to help STEM teachers overcome the challenges of online teaching, other teachers should easily be able to do the same. As an outcome, by investigating the breakthroughs in STEM teachers' online teaching dilemmas, it should be possible to provide a reference for other subjects' online teaching.

Theoretical Framework

The conundrum of urgent online education

Even in the face of mandatory distance learning during COVID-19 pandemic, higher education, which is the easiest country to adopt online teaching, is still plagued by technical and equipment issues, and the vast majority of students are unable to study online. The study also found that the problem of online teaching in rural areas is a lack of adequate network and equipment, and that the inability to have a suitable independent learning space has also caused problems in online learning. These problems made online learning difficult, and the social class divide has widened as a result of this situation (Verma et al, 2020). The unequal distribution of Information and Communications Technology (ICT) and the digital capability gap has exacerbated social inequality. Many technology companies offer educational discounts or assistance, providing services such as Google Classroom and Google Meet. However, this does not solve the most difficult aspect of online learning which is a lack of basic network equipment and fast and reliable network connection (Dhawan, 2020). Computers and other forms of communication equipment are the most basic requirements for online education, and most countries were unprepared for online teaching in these areas.

Despite the fact that many countries have long attempted to integrate technology into the higher education system, most schools are scrambling to find coping strategies after COVID-19 has been in place for a long time. Teachers began to take online teaching seriously after a period of time. Learn how to teach online on topics that may be covered throughout the semester (Donitsa-Schmidt & Ramot, 2020).

Ali (2020) used a meta-analysis methodology to examine the impact of higher education closures during the COVID-19 pandemic. The study found resources, staff readiness, teacher confidence, student accessibility, and motivation, to be the critical factors in the implementation of online teaching. Serhan conducted a study involving 31 students from a university in the United States and found that the most difficulty encountered by both teachers and unprepared students was the conversion from FTF interaction to Zoom distance exchanges. Students were dissatisfied with their learning experience, teachers were unfamiliar with the new platform, and many users encountered technical difficulties, such as poor internet connectivity. The main disadvantages of using Zoom, according to students, were easy distraction, poor interaction and feedback quality, poor quality content, and technical difficulties (Serhan, 2020). Many distance learning studies use students' perspectives to investigate how students feel. Aside from students, the teacher plays an important role in the teaching field. In the face of significant changes in the teaching situation, the teacher's teaching method influences students' learning. How should teachers respond to online learning? How teachers adapt their teaching strategies will have an impact on teaching and learning in the post-epidemic era.

The Problem of STEM Course Online Teaching

With the exception of courses that require practice, such as science, teachers in Israel have successfully converted FTF courses to online courses. (Donitsa-Schmidt & Ramot, 2020). According to current researches (Adnan & Anwar, 2020; Polat, 2022; Zainal et al., 2022), when online teaching is unavoidable, some disciplines face some challenges and continue to study. The course's quality, as well as the development of different literacy in the same subject, will present unique challenges (e.g. creativity, technical implementation). As a result, it may be more appropriate in online teaching to analyze the literacy that needs to be developed in the subject.
Chen et al. (2020) discovered that students with more mythological concepts dropped out at the beginning of an online MOOC astronomy course in the United States. Amunga's (2021) literature analyzed during the epidemic that the problems of online STEM education are nothing more than issues of fairness, quality, and student participation. Amunga proposed three alternatives. The government should take an active role in addressing the issue of hardware equipment such as

electricity in rural areas and other rural areas. Priority should be given to the needs of disadvantaged groups for online teaching based on social fairness and justice. Finally, some academics proposed the use of augmented reality and virtual reality. Technology aids in the implementation of online courses, but the demand for technology and hardware is even greater. It will take time to achieve universal application. It is proposed that some physical laboratories be set up for students to use in order to solve the current problem. It appears that it can be implemented immediately, but it will require the sharing of laboratory equipment, subsequent disinfection, and more teaching time for teachers. These invisibly multiplied workloads leave us as STEM teachers perplexed. Furthermore, due to funding and equipment constraints, STEM courses are frequently delivered in conjunction with research projects. In the educational research project section, Verma et al. (2020) discovered that the STEM course plan could no longer be carried out due to the epidemic. This may be related to the relatively high and stable demand for STEM courses in terms of funding and course time continuity.

However, online education is not without flaws. Knowledge-based courses, such as lecture-based courses, are ideal for online instruction (Agarwal & Kaushik, 2020). Liguori and Winkleu both agree that basic knowledge is well suited to traditional teaching. Teaching creativity may necessitate the development of new online teaching methods. The enormous challenge of "how to teach" puts teachers' agility and innovation to the test (Liguori & Winkle, 2020). Teachers' comprehension of concepts that students lose when taking online courses, practical course implementation, course continuity, teaching creativity... These are all issues that teachers may face if STEM courses are moved online.

STEM teachers' characteristics are changing as a result of changes in online education

Denton and Borrego (2021) reviewed the literature from 2011 to 2020 and found only 15 papers on STEM teaching research over the previous ten years. However, after 4.5 months of Google Scholar searches for "STEM" and "teacher" keywords, we discovered 165 papers between January and April 2021 (after which time the world began to suspend classes one after the other) (Figure 1). This was more than ten times the number in the previous ten years. This demonstrated clearly that the STEM fields would flourish in the near future. Amongst the documents found, 33 papers specifically mentioned the characteristics that STEM teachers should have. These traits were classified into three categories: computational thinking (CT), pedagogical content knowledge (PCK), and self-efficacy (SE). Yadav's team (2014) believed that CT includes CT1 (Relationship to other disciplines), CT2 (Integrating computational thinking into the classroom), CT3 (a View of computational thinking). PCK was defined by Magnusson et al. (1999) as Knowledge of Science Curricula (KSC), Knowledge of Students' Understanding of Science (KSUS), Knowledge of the Assessment of Scientific Literacy (KASL), and Knowledge of Instructional Strategies (KIS). This questionnaire was commonly used to assess the PCK of science

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teachers. According to Kao et al. (2011), there are six types of self-efficacy: personal interest, occupational promotion, external expectations, practical enhancement, social contact, and social stimulation. The study had questionnaires directly related to the development and evaluation of teachers. Typically, these questionnaires were used to investigate science teachers. Caton believes that in 2021 it was critical to better understand the challenges and obstacles faced by STEM field teachers to support those who were developing and implementing integrated STEM instruction (Caton, 2021). We can come to know about the characteristics that scholars believe STEM teachers should have before teaching online due to the epidemic from this search.

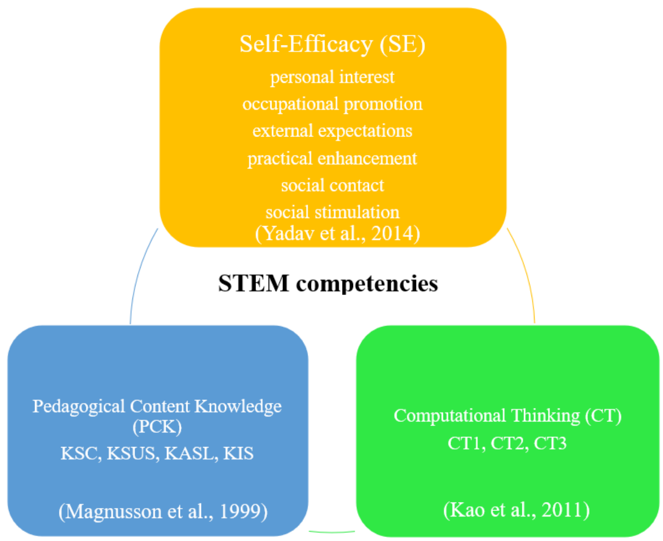

Figure 1. STEM teachers, according to academics, require competencies.

In this age of information overload, teachers need to discuss and use technology in addition to PCK. They need to expand the skills and knowledge required of them with a "holistic view." Mishra and Koehler (2006) proposed a need for technological pedagogical content knowledge (TPCK). In addition to adding technological elements, TPCK emphasized connection with the situation. When viewed individually, PCK can be considered a single component. According to TPCK, the overall sense was adjusted to the context and Thompson and Mishra renamed it TPACK in 2007. This emphasized it as a dynamic whole as well as the conceptual framework of teacher knowledge (Abbitt, 2011). According to transfer theory TPACK is made up of various aspects of knowledge that are interconnected. Personal experience will drive each knowledge component to form a complete individual (Abbitt, 2011; Angeli & Valanides, 2008; Niess et al, 2009). The more frequently the teacher used this method of learning, the easier it was to advance to the next level and integrate the cognitive architecture into TPACK.

According to Iswadi et al. (2020), the methods used to improve teachers' TPACK and STEM competencies are mixed and are influenced by materials, student characteristics, types of

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integrated technologies, and so on. STEM learning is learner-based and influenced by student characteristics. As a result, the teacher can correctly identify the students' characteristics. It could also be one of the required skills. Asempapa et al. (2021) provided assistance to college students in STEM fields in four areas: faculty mentor, peer mentor, industry mentor, and learning center research activities internships, and discovered that such multi-faceted care can indeed promote success. The development of students in the field of STEM demonstrates that the abilities and characteristics required of STEM teachers are very diverse. DeCoito and Estaiteyeh (2022) believe that in online courses, STEM teachers' performance in TPACK and self-efficacy is important because it influences the success or failure of online teaching. According to the literature reviewed, STEM teachers face numerous challenges in terms of the explicit and implicit knowledge and abilities required, and even TPACK has unique characteristics that are closely related to personal experience and cannot be attained overnight.

Methods

A qualitative design approach was used in this case study (Creswell & Guetterman, 2019). With classes suspended due to the epidemic, a total of 9 STEM teachers were interviewed, with each teacher being interviewed three times. The case study approach is appropriate for understanding how people interpret, construct, or create meaning from their world and experiences, frequently in a highly inductive manner (Crowe et al., 2011, Kahlke, 2014), and it was well suited for use in this study as a tool for understanding STEM teachers' experiences. In comparison to the collected literature, we hope to use this opportunity to better understand how teachers' characteristics will change in the face of a sudden shock (large-scale class suspension), and how teachers will adjust. The inductive method is used to analyze the articles in this study. After summarizing the findings Its differences from the theoretical framework of the literature.
The first interview occurred within the first week of classes were suspended throughout Taiwan. The interview lasted about 25-35 minutes per person. The goal of this study was to get a clearer idea of the challenges that STEM teachers faced as they transitioned from FTF to the online teaching precipitated by the COVID-19 epidemic, how well they were able to respond, and what changes were implemented.

Participants

The author asked interviewees in Taiwan's science teachers and maker communities an online question. The perspectives of nine teachers who agreed to be interviewed for this project are presented in the results section. The nine educators are all current official national and high school teachers who have previously taught STEM courses in Taiwan (Table 1).

Table 1.
Participants' teaching subjects

Subject	**S**	**T**	**E**	**M**	Natural Sciences: Inquiry and Practice
Participants	SP1, SP2, SP3, SP4, SC1, SE1, SB1	T1, M1, SP4	SP1, SB1	M1	SP2, SP3, SP4, SC1, SE1, T1

If the participant had a university degree and had taught the subject, we used the participant code as the primary teaching subject. There were four Physics (SP1-4) teachers, one Chemistry (SC1) teacher, one Biology (SB1) teacher, one teacher of Earth Science (SE1), one Information Technology Education teacher (T1), and one Mathematics teacher (M1). Two of the teachers received second-specialty credit class certification during the teaching process, so SP1 and SB1 also taught Technology, and M1 was enrolled in an AI course which included collaborative lessons with other teachers at the same school.

Another thing to note is that the Curriculum Guidelines of 12-Year Basic Education have been implemented in Taiwan since 2019, and include interdisciplinary inquiry and practical courses. SP2 and SP3, SP4, SC1, SE1, and T1 all taught inquiry and practical courses or the same type of interdisciplinary courses during this study.

Data aggregator

The primary data collector was a chemistry teacher in a senior high school with 18 years of teaching experience that included interdisciplinary courses. He had led more than 30 scientific projects and was experienced in the creation of STEM course plans. He used Google Classroom to collect homework and conduct differential instruction, and so on. He was also willing to learn new technology and software in his spare time to help with teaching and also allowed students enough leeway for the inclusion of a range of learning styles and presentations. During the project he engaged in online teaching and also the return to FTF courses.

Procedure

A qualitative research method based on Sintema's interview questions (2020) was used in this study. The first interview was conducted over the phone, while the second was conducted using a Google form with follow-up questions based on the telephone response. The third interview was FTF or conducted by phone, see Figure 2. However, before each interview, participants were interviewed outline. Recordings were made with the participant's prior consent. The interviews were semi-structured and participants were asked to discuss their preparations for teaching at the time and previously (before the pandemic) and also to discuss

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their feeling about the matter. The interviews went deeper (based upon response) to explore the participants' insights and concerns.

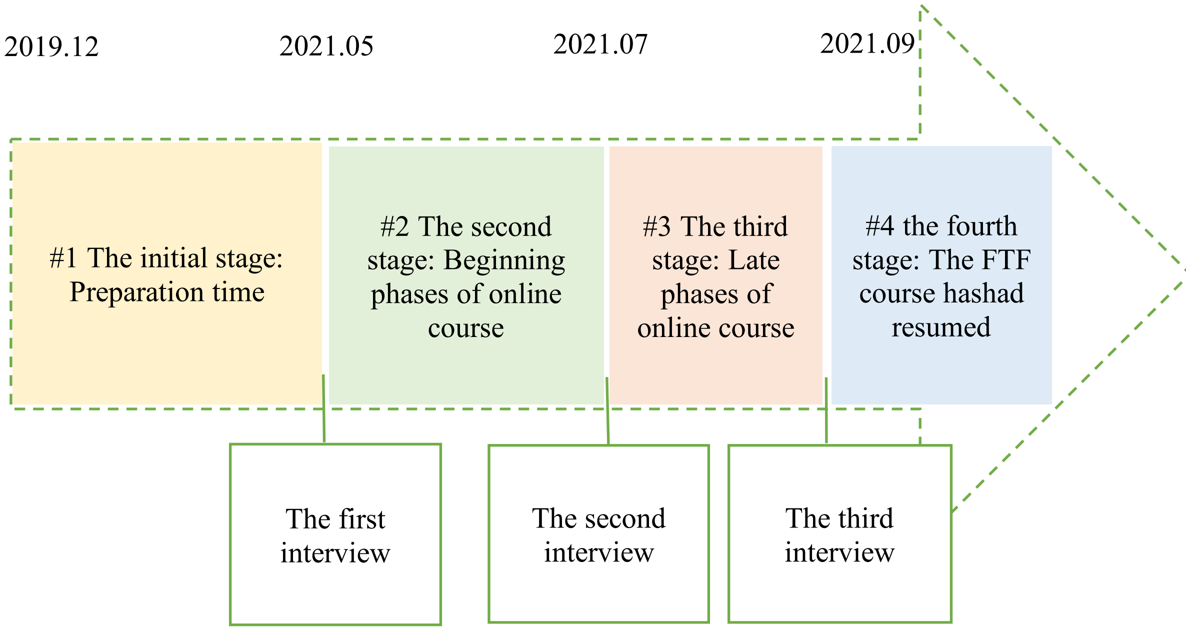

Figure 2. Schedule for data collection

Data Analysis

Data were transcribed and analyzed using the appropriate qualitative data analysis techniques. To avoid bias, data transcription and coding were performed by the researcher and one other independent person. Any discrepancy or inconsistency was discussed and resolved.

Induction was used by researchers to conduct qualitative analysis of the data collected (Peräkylä, 2005). An iterative analysis process was carried out by the author and another researcher. The data was examined independently by each after the first iteration before a meeting was held to generate classification that characterized the range of patterns observed in the data set. The data were then given another round of independent analysis, during which re-examination was done based on emerging themes to develop consensus codes based on the literature and data. Finally, the data and inter-code reliability were reviewed independently by the researchers and found to be greater than 0.85 for each data source, as measured by the Cohen α coefficient.

Results

#1 The initial stage: Preparation time

The nine teachers had never used online teaching before, but they were all familiar with online video and audio and also used it in the classroom. Because some countries have closed

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their schools, the school required all teachers to create an educational version of Google accounts (100%), practice using Google Classroom to send homework assignments (100%), students also had enough practice submitting homework online (89%). Each school also looks into whether students had enough equipment (computers or tablets) as well as satisfactory access to the Internet.

Teachers needed to learn to use several different programs on different software platforms as part of their preparation. Regular FTF meetings have been converted into online video conferences allowing them to be continued and also allowing teachers to become acquainted with the use of online communication platforms. The majority of the online teaching platform options have been chosen by the schools and during the preparation period, most of the teachers involved set up student LINE groups to facilitate communications.

The real time for teachers to prepare their online classes is from the afternoon of the day after the announcement of suspension to the following day. After the announcement of the suspension of classes, each school assigned special times for the instructor to carry out the last one or two classes and entrusted them to remind students about the need to study online and help them to do it, sometimes the whole school practiced online operations at the same time. Students who had equipment or network issues could also pick up an iPad and a network interface card at school and take them home. Those who did not feel pressure before starting the online course were the information teachers, because the others had not really done any online teaching all day. When it came to preparing for online courses, the majority of the sources that helped teachers overcome online teaching difficulties were peers and school administrators.

After the information from the teacher interviews had been complied, the insights and concerns the teachers had about in the interview materials, were summarized. Attempts were made to assemble the insights into characteristics the STEM teachers had discussed in the literature and a new construct was created, see Table 2.

Table 2.
What are teachers most concerned about during preparation?

Interview data	Insight	Construct
... I was afraid that the students would miss the lesson and not come online... (SE1-1-P-w1)	Concerned about students not using the internet.	Learning Motivation/ Classroom management
Our school is in an aboriginal community... I am concerned that their equipment will not be adequate to support online learning. (SP3-1-P-w1)	Concerned about internet speed and equipment available to students.	Devices and Equipment for Students

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Interview data	Insight	Construct
I'm concerned that students will not be able to concentrate.... Or perhaps they are off doing their own thing. (SP1-1-P-w1)	I'm concerned about whether or not the students are paying attention.	Learning Motivation
Blackboards are used to teach mathematics in FTF classes, Online tools such as the Jamboard may not be adequate and operation may not be so easy. (M1-1-P-w1)	Concerned about the teacher's equipment and knowledge	Devices and Equipment for Teachers

#2 The second stage: Beginning phases of online education

In terms of online teaching, all case teachers used Google Meet, and the vast majority (89 %) used Google Classroom or Google Drive to send homework or materials. The majority of them were graded on Google Classroom homework and in-class answers. Teachers' concerns during this time period were roughly classified as described below and followed by the Interview data and our summarized construct:

1. Concerned that students will not interact with the teacher, and dampen the teacher's enthusiasm for the class. (n=4, 44%). The following is an excerpt from the interview data:

    Students cannot keep the camera on for extended periods because it consumes a lot of power... There appears to be no response... We can't tell what others are thinking... If this is the case, I'm afraid I'll become depressed. (SP3-1-B-w1)

This is a component of Knowledge of Students' Understanding of STEM (KSUS) and Knowledge of Instructional Strategies (KIS)

2. Group discussions are not permitted for inquiry and implementation. (n=4, 44%)

    In a FTF class, you can appreciate what is going on and hear what the entire class is discussing. It is clear that a discussion is going on in a group... but online, everything is goal-oriented... when is a group discussion going on? We have no idea. (SP2-1-B-w1)

This should be classified as Knowledge of Instructional Strategies (KIS). There are others in addition to these: "difficult student grouping" (n=4, 44%)", the issue with writing on the blackboard" (n=4, Approximately 44%), "roll call is time-consuming" (n=5, Approximately 55%), "I was unable to sense the students' learning from facial expressions and body language" (n=3, 33%), "there are no materials, equipment, or tools to be purchased, and a few programs must be paid for" (n=4, 44%), "there is no way to stick to the original teaching schedule (the mode needs to the changed)" (n=3, 33%), "The effect of students using various classroom equipment" (n=2, 22%).

In addition to being concerned about online teaching, all the case teachers recognized the benefits of online teaching, but only 67% of them could clearly articulate those benefits. Including

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the high rate of attendance, some classes have higher attendance than the original FTF classes, and students become more attentive in class, there is more mutual assistance, instant delivery of videos, notes, and assessments, improved classroom atmosphere, and a more comfortable teaching environment for teachers.

#3 The third stage: Late phases of online education

Case teachers reached a stage in online teaching where final exams had to be changed for online processing. The teachers faced more challenges and their concerns evolved and were of the following nature:

1. Concern about unjust assessment. (n=7, 77%). The following is an outtake from interview data:

There is no way to hold a traditional exam, and I am concerned that the validity of online exams will be limited (SP4-2-L-W1)

This should fall under the categories of Knowledge of Instructional Strategies (KIS) and Learning Effectiveness.

2. There is no FTF communication with students. (n=4, 44%)

Students who refuse to study in class cannot be interviewed in person (SP2-2-L-W1)

This should be in the category of classroom management.

There are others in addition to these: “Because the implementation cannot be evaluated, you should focus more on task-based work” (n=7, 77%)”, strategy for online education” (n=7, 77%), “integration of resources, teaching fluency, and a shift in class rhythm” (n=7, 77%), “Interaction with students” (n=5, 55%).

#4 the fourth stage: The FTF course has resumed

Table 3.
The evolution of teachers' concerns prior to and following online instruction

	#1 The initial stage	**#2 The second stage**	**#3 The third stage**	**#4 the fourth stage**
Technology Equipment for Students	3	7	5	6
Technology Equipment for Teachers	2	3	1	0

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	#1 The initial stage	**#2 The second stage**	**#3 The third stage**	**#4 the fourth stage**
Classroom management	1	5	5	1
Learning Motivation	7	1	8	3
Learning Effectiveness	0	2	7	4
Knowledge of Assessment of STEM Literacy (KASL)	0	0	4	0
Knowledge of Students' Understanding of STEM (KSUS)	0	4	1	3
Knowledge of Instructional Strategies (KIS)	0	4	7	3
Knowledge of STEM Curricula (KSC)	0	5	5	1
Integration and application of technology and disciplines	0	4	2	0
Personal Interest (SE1)	0	3	1	0
Workload expansion	0	2	4	0

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Note: The higher the curve, the more concern has been expressed by the teachers. A concern is only recorded once even if it has been expressed multiple times in a period and each item involves a maximum of 9 case teachers for each period.

Table 3 was used to organize the evolution of teachers' concerns prior to and after online instruction. Everyone is concerned about how to implement online courses during the initial stage and the second stage. They are concerned about the information technology used by students and teachers. Teachers focus on the equipment required for students in the early and late stages of online teaching. Purchase or replacement of appliances, software, and machines. The teachers were still concerned about the equipment after the FTF course resumed. They were concerned about having to deal with new students if the class was suspended again. The equipment new students had was not necessarily reliable and they sometimes had no idea how to reach them. Furthermore, teachers were well aware that when exploratory experiments were being conducted using students' equipment the environment under which the students were doing the work was not the same as that of the laboratory. How could such experimental results be compared? This was a serious issue of concern for the teachers. DeCoito and Estaiteyeh (2022) also talked about the importance of face-to-face interaction in their online course for STEM teachers. They believe that this problem can be solved through social media, but through our more detailed survey, we found that the inability to face-to-face affects the STEM field. There are more details of the impact, I am afraid that it cannot be solved by simple social software.

After online teaching, teachers frequently mention "FTF Interaction." "People" to "people" including teachers to students, the entire class to a student, a group to a group, and so on. The lack of face-to-face interaction with students had caused the teacher's enthusiasm and motivation to dwindle. Case teachers know that student's smiles increase their motivation to teach. If they have met before and there is a friendly or warm connection between the teacher and the student a smile is an easy thing to promote. Teaching students you have never met online is a huge challenge in the face of an unstable epidemic. The absence of FTF interaction also has a significant impact on the teacher's interpretation of the state of a student’s gain of knowledge.

> *…. I noticed a student with a puzzled expression after I finished teaching a concept. He didn’t ask a question, but turned and whispered to the student beside him, …Then I guessed that the concept he had just now heard presented a problem, so I simply repeated what I had said and the student showed an expression of sudden realization. I could not have seen this during an online class… (SC1-3-F-W2)*

In addition to the emotional benefits of being able to speak directly with students FTF contact allows teachers to see if homework has been completed at a glance. More importantly, the teacher believes that being in front of the students encourages them to learn more rigorously.

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In all the cases mentioned by teachers a common concern was that teachers were "not sure if they're paying attention." Determination of the degree of attention a class is paying is difficult and teachers can no longer be certain about this, making a determination about whether methods are effective or not was a very difficult task. These methods include the calling out of names, and other class management methods, such as real-time tests, and changes in teaching strategy. The lack of "FTF interaction" has a real impact on the quality of the class discussions and questions. Online, you can only see the finished products of other groups, not the process by which they have been achieved. Teachers believe that online teaching in the context of inquiry and practice can only achieve near-passable results.

Teachers put a lot of effort into "realizing" synchronized online courses in the early stages of online teaching and pay attention to learning motivation in the later stages of after they think the students have become accustomed to the rhythm. Online education is not a new idea and teachers and are experimenting with new strategies because they are concerned about effectiveness of the present ones. When teachers returned to FTF teaching their main concern was the effectiveness of the lessons the students had received online. The teachers also believed that the students were looking forward to school and to seeing the teacher and their friends. However, many students appeared agitated and old normal behavior was not resumed. Teachers will need more task-oriented activities in the curriculum if they are to maintain concentration for an extended period of time. All the case teachers agreed that online teaching widened the degree gap between students. Active students and those with self-learning ability were improving, but those who do not discuss or participate were deeper into retreat.

Discussion and Implications

Our lives, as well as our teaching, have been altered as a result of the epidemic. In response to the epidemic, the Taiwan Network Information Association (2022) conducted a survey from February 14th to March 15th, 2022, and discovered that 21.6% of the public still used remote work or distance teaching during that time period. At the same time, as many as 67.48% of remote workers and 74.10% of distance teaching teachers expressed a desire to stop working or teaching remotely after the epidemic.

The findings of this project have shown that many of the anticipated difficulties were not as had been expected. Of course, there were numerous benefits that could only have been appreciated after they had been experienced. Researchers will discuss teachers' PCK (or TPACK), SE, and CT characteristics, just as they had done before the epidemic (Denton & Borrego, 2021). However, the aspects of online teaching that most concerned the teachers were "equipment," "student motivation," "class management," and "increased workload". We discovered that, similar to online learning in MOOCs, STEM teachers of online courses must be very familiar with the misconception of students (Chen et al, 2020). Preparation for various types of interactive use, such as experiments and question periods, are frequently required in STEM courses (Crawford, 2012). According to Evagorou and Nisiforou (2020), preparing for online or blending teaching will be a significant and growing challenge for STEM teachers. In our findings, the difficulty of online classes or blending teaching in STEM courses is greater than that of general practical courses because "each student's experimental environment is different and it is difficult to control the variables." More thought must be given to curriculum design in order to solve this problem.

STEM employers believe that STEM talent requires the following soft skills: teamwork, collaboration, leadership, problem solving, critical thinking, work ethic, perseverance, emotional intelligence, organizational skills, creativity, interpersonal communication, and conflict resolution. Otherwise, as technology advances, people who lack these soft skills will be surpassed by machines (Karimi & Pina, 2021). Employers' requirements are quite high and diverse, as can be seen from these needs. In the STEM field, in addition to knowledge and skills, many soft skills must be developed in the curriculum. With such high demand in the back-end industry, do we, as front-end educators, have enough capacity to meet it? According to Aykan and Yildirim 's (2021) research, teachers have some negative attitudes toward distance learning. These considerations should be taken into account by researchers when designing future studies. They should also concentrate on blended learning, where teachers struggle to incorporate STEM fields into their lesson plans due to knowledge gaps. Original PCK (or TPACK) emphasis had been on how to "realize the desired course requirements online." In this study, the case teacher did not discuss the CT, which has been discussed and valued throughout. In comparison to the previous study (Aykan & Yildirim, 2021), our study discovered unexpected difficulties as a result of a lack of "FTF discussions" among STEM teachers during the research process. And this difficulty may have an impact on the development of soft skills. In comparison to DeCoito and Estaiteyeh (2022), we all investigated the coping strategies and feelings of STEM teachers when classes were suspended for the first time due to the epidemic. Despite the fact that our research methods differed, we both used TPACK and SE as theoretical frameworks for testing. Our research has clearly seen the changes of teachers in various stages of coping after three interviews, and we have also made deeper discoveries about the plight of many teachers.

After returning to FTF interaction with their students most teachers were of the opinion that certain parts of online teaching were advantageous and should be retained to supplement FTF course teaching. The case teachers were also of the opinion that their flexibility had increased, and they could now accept more diverse homework and teaching styles than previously. Even teachers with many years of experience accepted these changes and hoped to make use of the many newly discovered online benefits to supplement their teaching.

The best friend and worst enemy of a STEM teacher is “resilience”. Teachers had plenty of leeway in STEM teaching in terms of teaching materials, tools, and methods, but STEM

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restricted to the Internet necessitates more consideration and support in the selection of the type of activity and materials.

Conclusion

This study demonstrates the difficulties and concerns experienced by teachers as a result of the pressure generated by the rush to popularize online teaching in such a short time. However, two days after classes had been suspended, almost all schools in the country began to formally synchronize online teaching, and student attendance was surprisingly high. In fact, participation was almost the same as for normal FTF teaching and this was something that had not been anticipated.

STEM teaching is limited by the availability of the devices and services needed for its implementation. Students and teachers are also faced with other significant challenges and difficulties which need to be discussed. For example, curriculum changes or rearrangement seriously tests the familiarity and adaptability of the teachers involved and this aspect needs attention. The study also discovered that the challenges that STEM teachers face are quite complex and diverse, and that STEM teachers' online teaching experiences can indeed become an important reference for teachers of other disciplines.

In this study all the changes in method and characteristics elicited by online teaching of STEM were compared with those in use before the advent of large-scale online teaching. STEM educators were able to use these differences to make changes to the methods and make the adaptations necessary for STEM teaching in the new world of online teaching. Taiwan has now returned to FTF teaching and everything appears to have returned to the familiar teaching mode. We seem to be more like the original us, but there are now some differences. When research data is discussed and analyzed these days it is done by people who are interacting personally. However, they often use Google Meet to share information for discussion across the table between them. This is now the way that information can be shared and records made. These new habits, that are in wide use now, should have been in use years ago.

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RESEARCH REPORT

A comic-based conservation lesson plan diversifies middle school student conceptions of scientists

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Abstract

Role model interventions that are tied to place based-learning and classroom curricula may be effective tools for promoting diversity in STEM. To evaluate this premise, we developed a sixth-grade lesson plan that focused on teaching environmental conservation and highlighting diverse women in science. Our curricula used a three-touch educational model consisting of comic-based lesson plans, a local "field trip" to Cabrillo National Monument, trading cards featuring 19 diverse women scientists, and a conservation capstone poster presentation - all aligned to Next Generation Science Standards - to create a meaningful experiential and project-based module. To evaluate the program, we used a mixed-methods, change over time model, including the Draw-a-Scientist test (DAST) to assess if student perceptions of scientists were altered from the curricula. Overall, thirty-three students completed the DAST before and after participation, and we found that science stereotypes held by students decreased after participation in the lesson plan. By using innovative tools such as art and comics for science education/outreach that feature characters representing a diverse array of scientists with intersectional identities, educators can help shift student perceptions on who can be a scientist, potentially increasing diversity in scientific fields.

Keywords: *Draw-a-scientist, middle school, biology, place-based learning, scientist stereotypes*

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Recent reports have reinvigorated prioritizing equitable K-16 science, technology, engineering, and mathematics (STEM) education (National Academies of Sciences, Engineering and Medicine, 2021). STEM education is considered critical for promoting inquiry, innovation, and lifelong learning (Tanenbaum et al., 2016). Encouraging young students to pursue STEM careers is necessary to meet increased demands in the STEM labor workforce (President's Council of Advisors on Science and Technology, 2012), to meet the unique scientific challenges of the 21st century, and to ensure that all students have opportunities to succeed in STEM fields (AAAS, 2011). Increased representation of historically marginalized groups provides one avenue of meeting increased workforce needs of STEM talent. Representation and inclusion of historically marginalized individuals in the STEM workforce is a matter of equity and social justice (Briggs, 2017; Geesa et al., 2021).

While representation of women and historically excluded individuals (Black or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives) in STEM has increased in recent years, inequities still exist in a number of fields (NCSES, 2021). For example, while biology is typically noted as reaching gender parity, subfields such as ecology and evolutionary biology are notable for their lack of inclusion of individuals with underserved ethnic backgrounds, particularly those holding intersectional identities (NSF, 2018). There are a myriad of reasons for this sustained lack of diversity, including historical exclusion from STEM fields and current challenges to inclusion and sense of belonging (O'Brien et al., 2020). One important aspect of increasing the number of women and historically excluded individuals in STEM careers is by encouraging students at early ages to pursue interests in these sectors.

Student interest in STEM

Students' conceptions of scientists and perceptions of scientific careers are solidified during elementary and middle school, and may have impacts on their long-term interest and retention in STEM (Buldu, 2006; Mohtar et al., 2019; Wyss et al., 2012). Indeed, student interest in STEM by the start of high school is a predictor for their interest at the end of high school (Sadler et al., 2012), and eighth grade students who expect to have careers in the life sciences are 1.9 times more likely than their peers to earn life sciences baccalaureate degrees (Tai et al., 2006). However, middle school students hold limited knowledge about the diversity of careers in STEM (Blotnicky et al., 2018). A review of STEM education in primary school found that children are engaged in STEM learning, but that a number of barriers including lack of time or professional development make it challenging for teachers to incorporate in the classroom (Wan et al., 2021). Studies of children indicate that student interest in STEM increased if the students were male, came from higher socio-economic backgrounds, had prior achievement in reading and numeracy, and if they had a parent with a job in STEM (DeWitt et al., 2013; Holmes et al., 2018). School is a place where all students can access information about STEM careers, which is critical for students who do not

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have family members working in STEM occupations. As students' interest in STEM can increase when provided with information about STEM careers (Wyss et al., 2012), middle school becomes a critical period for attracting students to STEM.

Representation of STEM and the Draw-a-Scientist Test

Middle school is also a key time for fostering interest among diverse students, and for addressing gender stereotypes about scientists. There is a wealth of literature exploring gender stereotypes (of people of all ages) and scientists, but particular focus is given to secondary students and when stereotypes are formed.

In 1957, researchers Mead and Metraux conducted an analysis of secondary school students' responses to a prompt asking them about what they think of when they think of scientists. Through this research, the authors identified the stereotype of the scientist as an old white man wearing a white coat, glasses, and working in a laboratory surrounded by equipment such as glassware, microscopes, and chemicals in test tubes (Mead & Métraux, 1957). In order to explore when these stereotypes of scientists emerge in children's thinking, subsequent researchers developed the Draw-a-Scientist Test (DAST) where students are asked to "draw a picture of a scientist" (Chambers, 1983). Researchers selected seven stereotypical indicators of scientists, and coded for the presence/absence of each category. In their analysis of student drawings, the researchers coded for: 1) lab coats, 2) eyeglasses, 3) facial hair, 4) symbols of research, including scientific instruments and lab equipment, 5) symbols of knowledge, primarily books, 6) technology, and 7) relevant captions such as formulae or taxonomic classifications (Chambers, 1983). In their analyses, the presence of multiple types of categories (for example, two scientists with eyeglasses) would be coded as one indicator (eyeglasses).

Subsequent studies have modified the DAST tool, adding rubrics and questionnaires to further quantify and probe student perceptions (Farland-Smith, 2012; Finson et al., 1995; McCann & Marek, 2016). For example, the DAST-C created a checklist of the seven indicators from Chambers (1983) and added an additional eighth element: alternative images, which was comprised of eight other items including: if the drawing included a white male older scientist, had indications of danger or secrecy, lightbulbs, included work conducted indoors, or included mythic stereotypes such as Frankenstein creatures or "mad" scientists (Finson et al., 1995). More recently, Farland-Smith (2012) developed a rubric scoring drawings and follow-up questions collecting richer details from the students themselves regarding their drawn scientists' appearance, the location of work, and scientists' activities.

Overall, decades of research using DAST have revealed that children consistently and overwhelmingly stereotype scientists as men (Ferguson & Lezotte, 2020; Miller et al., 2018). A meta-analysis of 79 published studies that used the DAST over the past 50 years revealed that while there has been an overall decrease in gender stereotyped drawings, students of different

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genders and ages have decreased in their stereotypes held at different rates, with girls on average drawing 58% of scientists as men and boys drawing 96% of scientists as men. The researchers also found age effects, where girls between the ages of 10 and 11 switch to draw more male scientists. Similarly, a separate meta-analysis of 30 studies that used the DAST-C published between 2003-2018 found that the most consistent stereotypes and perceptions of scientists included symbols of research (scientific instruments and lab equipment) and male scientists (Ferguson & Lezotte, 2020). However, direct use of the DAST-C rubric poses a challenge in that some stereotypes such as “secrecy” and “light bulb” symbols may be outdated (Ferguson & Lezotte, 2020), and unrecognizable gender identities in drawings pose challenges for interpreting student drawings (Losh et al., 2008). Overall, while the DAST has numerous advantages such as being a quick tool that is easily administered, researchers are limited in the amount of information that can be collected from drawings (Reinisch et al., 2017). To address these limitations, the use of questionnaires to accompany student drawings allows for greater incorporation of student voice in coding drawings (Farland-Smith, 2012).

Conceptual framework

Our research was informed by the Gender Schema Theory, which posits that children use observations of their environments to associate genders, in particular maleness and femaleness, with attributes (Bem, 1981). This theory has been used as a framework to explore a range of research topics, including stereotyping (Starr & Zurbriggen, 2017). According to Gender Schema Theory, children receive information from their social environments, and organize the information into their beliefs, attitudes, and preferences (Liben & Signorella, 1993). The observations children make result in stereotypes that influence their behavior and decisions well into adulthood (Martin et al., 2002; Steinke & Long, 1996). Family, teachers and peers at school, and the media all influence how children learn sex-role behavior. For example, exposure to TV clips depicting stereotypical female roles (clips of preteen girls discussing boys, clothes, and fairy godmothers) activated stereotypes, and resulted in elementary school girls reporting higher interest in stereotypical career paths such as being a teacher, florist, or stay at home parent (Bond, 2016). Role model interventions typically aim to expose students to counter stereotypical role models, and are generally viewed as a successful means to reduce gender stereotyping in early childhood (Halpern et al., 2007; Olsson & Martiny, 2018), and increase the sense of belonging for girls, women, and racial minority groups in STEM (Casad et al., 2018). As gender stereotypes are linked with interest in STEM (Barth & Masters, 2020), decreasing stereotypes is a priority for increasing girls’ interest and persistence in STEM.

The effects of representation on STEM interest are most notably documented by the “Scully Effect”, which witnessed an uptick in female scientists due to the fictional TV character Dana Scully from ‘The X-Files’ (Geena Davis Institute on Gender in Media, 2018). For many young

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girls, Dana Scully was their first indication that a career in STEM was possible. Collectively, this suggests that who is represented as a scientist is greatly linked with who will be encouraged to become a scientist in the future.

This study

In order to shift student stereotypes, STEM role model interventions typically feature real-life STEM professionals who represent diverse backgrounds (Farland-Smith, 2012; O'Brien et al., 2016; Schinske et al., 2016; Steinke et al., 2021). The classroom intervention used in this study was informed by Lent et al., (1994) Social Cognitive Career Theory (SCCT), which describes relationships between students' career-related goals and behaviors and factors such as student self-efficacy, outcome expectations, and interests. Additionally, the model posits that personal characteristics, background factors, and learning experiences influence career choices and has been used to frame numerous informal and formal educational interventions (McDonough et al., 2021).

In order to provide learning experiences that connected content to the real world and provided representation of living scientists, we developed two comic-based lesson plans. Comic-based lesson plans have been shown to be an effective teaching tool for complex biological concepts (Hosler & Boomer, 2011; Norton, 2003; Spiegel et al., 2013). Through creating, STEM comics can aid in new concept retention (Hosler & Boomer, 2011; Quillin & Thomas, 2015) as well as help reveal misconceptions in the material. Through reading, STEM comics not only engage both verbal and visual learners, but also have the potential to highlight the diversity of people behind the science. Additionally, in order to provide role models, we developed 19 trading cards featuring diverse real-life women in science, with careers spanning fields in biology and climate science. Finally, the lesson plans included a virtual poster session where students presented research on a species of their choice and made conservation recommendations. These sessions were moderated by 16 women in STEM. Student research and creation of posters is in line with problem-based learning pedagogy in science, technology, engineering, art and mathematics (STEAM) lesson plans, which in turn fosters student innovation and curiosity (Quigley & Herro, 2016). Thus by shifting teaching these science lessons to STEAM via the inclusion of art, our comics and trading cards aimed to allow a broader spectrum of students to envision themselves as scientists and carry that interest forward in their lives.

This case study represents analysis of data after implementing the *In Their Eyes* lesson plan. We hypothesized that exposure to a diverse array of female scientists would impact middle school students' drawings of scientists.

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Methods

Module team

Our team included a science educator at Cabrillo National Monument, a science illustrator, and an education researcher. We consulted with two middle school teachers to ensure that the materials were age-appropriate and consistent with Next Generation Science Standards (NGSS). Collectively, we aimed to develop a module that would use art (in the form of comic books and trading cards) to teach biological concepts aligned with the NGSS. The module is available at https://www.nps.gov/cabr/learn/kidsyouth/ite.htm. Specific NGSS standards addressed are outlined in Table 1. An additional goal was to impact student perceptions of scientists through exposure to real-world role models.

Table 1.
Next Generation Science Standards addressed in project.

Learning Objective	Details
From Molecules to Organisms: Structures and Processes	
MS-LS1-4	Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants, respectively
MS-LS1-5	Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms
Ecosystems: Interactions, Energy, and Dynamics	
MS-LS2-1	Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem
MS-LS2-2	Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems
MS-LS2-4	Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations
MS-LS2-5	Evaluate competing design solutions for maintaining biodiversity and ecosystem services

Note. MS-LS denotes middle school life science standards

Module overview

The *In Their Eyes* conservation and comics module consisted of a three-touch model including 1) interactive lessons in the classroom, 2) a science education field trip to Cabrillo National Monument, and 3) a scientific poster showing for friends, family, and the public.

The classroom lessons were designed to take place over a minimum of four class periods. During the first class period, students completed a modified version of the Draw-a-Scientist test (mDAST) following instructions outlined in Farland-Smith (2012). In the mDAST, students were asked a series of open-ended questions: "I am a boy/girl; was the scientist you drew a man or woman; was the scientist working outdoors or indoors; what was the scientist doing in your picture?" We further modified these questions by using open-ended questions for gender, including a question about the drawn scientists' age, and adding an additional question asking about the inspiration behind why students selected their scientist that they drew (Table 2). Students then began the lesson by playing a Quick-Draw vocabulary game, reading a comic book (focused either on Shaw's Agave, *Agave shawii*, or Belding's Orange-throated Whiptail, *Aspidoscelis hyperythra beldingi*) with a crossword activity to reinforce vocabulary, and received a packet of 6 trading cards each, from a pool of 19 scientist trading cards. Each trading card included a drawing of the woman scientist on the front with their name and job title, and on the back a short (1-2 sentence) description of their work and hobbies (Figure 1). Fourteen of the scientists featured on the trading cards identified as biologists, and seven identified as working on climate change research or conservation (five scientists identified as both biologists and either climate change researchers or conservationists). The comic books' protagonists were two biologists who were also featured among the trading cards. Students were encouraged to trade cards, and were informed that two of the cards included scientists highlighted in the comic books and that the other cards featured scientists that they would be meeting during both the virtual field trip as well as virtual poster-session. The scientists featured on the cards were selected due to the type of research they conducted with a focus on scientists a) with research that could be applicable to ecosystems at Cabrillo National Monument, b) with a tie to the If/Then Ambassador program in order for teachers to have access to additional free classroom materials and c) with diversity in age, racial/ethnic identification, and identifying as a woman in STEM.

During the second class period, students participated in a virtual field trip to Cabrillo National Monument, where they learned about the ecosystems and organisms highlighted in their comic books. During the third class period (this period was extended over several days), students worked in pairs to create a scientific poster that communicated local conservation science by selecting a native focal species, threats, and helpful conservation actions. They presented these posters during a virtual poster-session attended by their friends and family as well as 16 women scientists, including 8 who were highlighted on their trading cards (including co-authors SW, JCG, and CLM). Each scientist moderated a breakout room with four student presenters, giving students time to interact individually with a scientist. Finally, students concluded the module by again completing the Draw-a-Scientist test. Students completed the program during hybrid instruction (due to the COVID-19 pandemic), and the module was designed to support virtual as well as in-person instruction. In order to ease participation for teachers, we created an orientation video reviewing a teacher packet of instructions (disseminated to teachers in hard copy and electronic formats).

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Figure 1. Two example trading cards. Each card depicts a scientist and includes a description of their work and personal interests.

Participants

Participants were 6th grade students who were enrolled in four classrooms at a Title I school on the west coast that used the *"In Their Eyes"* conservation and comics lesson plans during Spring 2021. Total classroom enrollment was 112 students.

Data collection

This research was approved by an Institutional Review Board: University of California, San Diego protocol #202009SX. We used a one-group pretest-posttest design in order to maximize our limited sample size and for ease of implementation for teachers during hybrid instruction.

Of the 112 enrolled students who participated in the module, a subset of students filled out a pre- (92 students) and post- (94 students) intervention survey. Prior to the start of the program we collected parental consent, and during each round of data collection we collected student assent. We removed students from the research study whose parents did not consent to share their children's responses for research, and who did not assent to share their responses for research. If students withdrew their assent to share responses for research, we removed their

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drawings and responses from the study. After this process, we kept 36 students who had completed the Draw-a-Scientist test prior to implementation of the *In Their Eyes* lesson plan in April 2021, and 36 students after implementation of the program in June 2021. Of these students, 33 students completed both the pre- and post- drawings. Students were provided a prompt for the Draw-a-Scientist activity and responded to a series of questions about their drawings (Table 2).

Table 2.
Draw-a-Scientist activity instructions

Instructions:	Imagine that tomorrow you are going on a trip (anywhere) to visit a scientist in a place where the scientist is working right now. In the space below, draw the scientist busy with the work this scientist does. Add a caption, which tells what this scientist might be saying to you about the work you are watching the scientist do. Do not draw yourself or your teacher and do not use the internet or other resources to help you draw your scientist. After you have created your drawing and colored it, upload a photo of your drawing to the box below. You may use plain white paper and the colored pencils (from your supply bag), or a digital drawing tool if you prefer. When you are done, answer the questions on page 2.
Caption:	What is the scientist saying to you about the work you are watching the scientist do?
Open-response questions:	What is the gender of the scientist you drew? Was the scientist you drew working outdoors or indoors? Was the scientist you drew old or young? What was the scientist doing in your picture? Why did you select this scientist to draw? Is there anything else you would like to share about your scientist drawing?

The inclusion of questions allowed students to share aspects of their scientists' identities, details about what the scientists were doing and their motivations for their drawings. While previous DAST analyses made assumptions about scientists' gender (Losh et al., 2008), by directly asking students we were able to minimize using stereotypical attributes to assign gender during the coding process.

We asked students a voluntary open-ended question "Which gender identity do you most identify with?", and a closed-ended question asking students to identify their race/ethnicity. Self-report demographic identification is included in Table 3. According to USnews, the school's demographics include 67% minority students, 48% female students, and 52% male students. Our dataset includes 16 (57%) students from racial/ethnic backgrounds traditionally underrepresented in STEM, which may be an underestimate of the larger classroom population.

Table 3.
Student self-report demographics from students who completed both the pre- and post- drawings.

Demographic variable		Number of students
Gender		
Male		13
Female		12
Other/non-binary		1
No gender reported		7
	Total	**33**
Race/ethnicity		
American Indian or Alaska Native, or other Indigenous group.		1
Asian or Asian American		3
White		11
Hispanic or Latinx		15
Other or prefer not to answer		3
	Total	**33**

Data analysis

We used the ggalluvial package (Brunson & Read, 2020) in RStudio to construct Sankey diagrams visualizing patterns in student conceptions of scientists, and the Fisher's Exact Test function in RStudio to evaluate contingency tables and test for significance in the distribution of scientist genders drawn in the pre- and post- drawings. We used the effsize package (Torchiano, 2020) to calculate the effect size (Cohen's D) for student stereotype scale scores in the pre- and post- drawings.

Although there are coding schemes for the Draw-a-Scientist test, coding schemes such as the DAST-C are known to be limited in scope and are critiqued as being outdated (Ferguson & Lezotte, 2020). We sought to use students' drawings themselves to inform our analyses in order to capture more information while coding. Additionally, we included student responses to a series of questions (Table 2) during our coding process. First, we coded student descriptions of the gender of the scientists drawn, the location of work of the scientist, and the scientist's age. The three remaining questions and figure caption asked students about what the scientists were doing, why they selected their scientists to draw, and if they had any additional information they wanted to include. We used a grounded theory approach while coding drawings and student responses to these prompts in order to identify emergent themes (Strauss & Corbin, 1990). First, we reviewed the drawings for concepts that were repeatedly present. Three co-authors (CLM, JH, and SN) used inductive coding to develop a codebook based on these concepts to characterize the drawings. In order to test the codebook, the coders independently coded 32 student drawings and responses and compared results while discussing any differences. This process was done

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iteratively until the average Fleiss's Kappa score for intercoder reliability across codes was 0.92 for pre-drawings and 0.88 for post-drawings. We used Fleiss's Kappa for intercoder reliability, as this statistic is appropriate for three or more coders (Hallgren, 2012). All individual codes reached a minimum of Fleiss's Kappa score of 0.8, and a minimum percent agreement of 90%. Codes and coding results are presented in tables 4 and 5. We grouped the new codes derived from this process into overarching categories (Table 5).

Results

Students drew fewer stereotypic images after the intervention

The student drawings and corresponding follow-up questions (Table 2) were used to identify student conceptions of scientists before a classroom intervention that highlighted diverse women in STEM and environmental conservation topics. Each student provided a description of the scientists' actions, and provided information about their drawings (example post-drawing in Figure 2). We first used a checklist to code for stereotypical scientist attributes in both pre-intervention and post- intervention drawings (Table 4). Within each category, the presence of at least one component counted as a score of 1, and additional components did not add to the score. For example, if one student drew a scientist in a lab coat, they received a "1" for the category "protective gear", and a student who drew a scientist in both a lab coat and goggles would also receive a "1." The largest change was in traditional scientific equipment, with 66% of students drawing microscopes or beakers with chemicals and liquids before the intervention compared to 36% of students after.

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Caption: *What is this scientist saying to you about the work you are watching the scientist do?*

Type here
The scientist is talking to me about all the cool sea life she gets to see at work.

Follow-Up Questions

Instructions: *Answer the questions about your drawing. Make sure your answers are written in full sentences and answered completely.*

1. What is the gender of the scientist you drew?

The gender is female.

2. Was the scientist you drew working outdoors or indoors?

indoors.

3. Was the scientist you drew old or young?

old.

4. What was the scientist doing in your picture?

She was showing me pictures of all the animals/species she gets to work with.

5. Why did you select this scientist to draw?

I tryed to draw the scientist from my breakout room at exhibition.

6. Is there anything else you'd like to share about your scientist drawing?

Nothing else.

Figure 2. Example student drawing and responses to questions. This drawing was completed after the intervention activity.

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Table 4.
Stereotypical scientist attributes.

Category	Coding	Pre N	Pre %	Post N	Post %
Gender	If Male	15	45.5	10	30
Age*	If old	9	27	8	24
Location*	If indoors	27	81	24	73
Protective gear	If wearing lab coats, safety goggles, or other protective gear	14	42	6	18
Traditional scientific equipment	If there are microscopes or glassware with liquids	22	66	12	36
Scientific knowledge equipment	If there were computers, clipboards, or other knowledge equipment	13	39	14	42

Note: N = 33 students.
*coded from student descriptors instead of student drawings

We used a Sankey diagram to visualize potential shifts in the gender of scientists drawn (Figure 3). In this diagram, the size of each flow is proportional to the percent of students who drew scientists of different gender backgrounds before and after the intervention. Initially, equal percentages (45.5%) of students drew women and men as scientists. Overall, 22 students (66.67%) did not shift in the genders of scientists drawn. However, after the intervention, a smaller percentage (30%) of students drew men while a larger percentage (58%) drew women as scientists. Five students who initially drew men as scientists drew women after the intervention. Additionally, the percentage of non-binary scientists increased from 3% to 9%. A small subset of drawings could not be classified as one gender (6% before the intervention, 3% after). We grouped these drawings into a group "Other" which included students who indicated all genders, drew multiple scientists representing multiple genders, or stated that they did not know. While we identified a shift away from male drawings, this trend was not significant using Fisher's exact test for significance.

For each student, we generated a summary score based on the number of types of stereotypical scientist attributes found in their drawings, with each item from Table 4 representing a score of 1. With six checklist items, students had a potential maximum of 6 stereotypic components in their drawings. Student scores decreased between the pre-drawings ($\bar{x}$ = 3.03 ± 1.26) and post-drawings ($\bar{x}$ = 2.24 ±1.37), $t(32) = 2.8$, $p = 0.008$ (Figure 4). Overall, this represented a moderate effect size (Cohen's d = 0.62) (Cohen, 1988). Additionally, for each student we calculated the change in their score by subtracting their pre-score from their post-score. The average student drew one fewer stereotypical attribute after the intervention ($\bar{x}$ = -0.79 ±1.5).

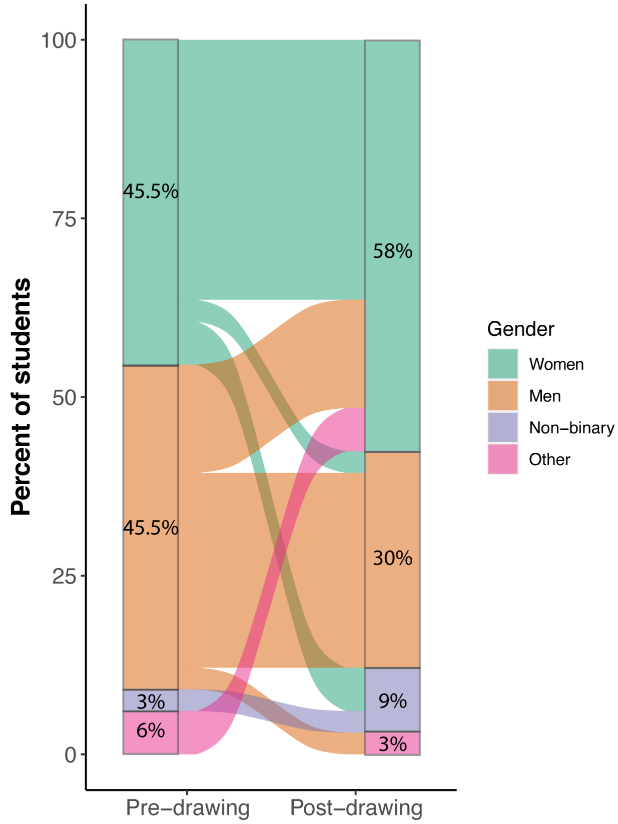

Figure 3. Sankey diagram displaying individual (N = 33) student shifts in the scientists' gender of their drawings.

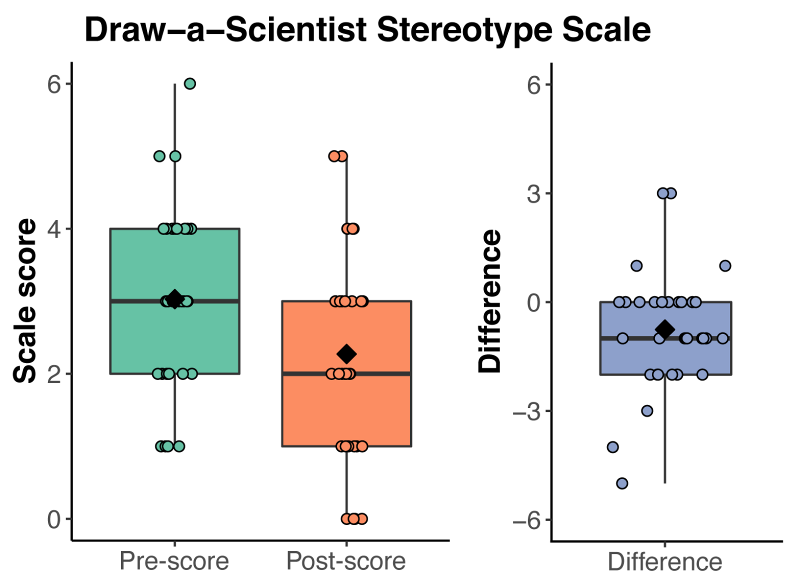

Figure 4. Boxplot of students' scale scores before and after participation in the module. Black line = median; diamond = mean; each circle = score for one student.

Students shifted in some conceptions of science

In addition to coding for stereotypic images, we coded drawings for discipline, and coded open-response questions asking what the scientists were doing in the students' drawings as well as what inspired their drawings. We coded field and field equipment for the presence/absence of a discipline or field equipment. For open-response questions, we used inductive coding and found that students' responses regarding the scientists' actions fell into three main categories: two actions, communicating science and conducting science, and a motivational category consisting of helping (Table 5). We coded for the presence of each code, and most responses included a single code. However, there were responses that included multiple codes, such as one from a student who "*recently saw a video by Veritasium on youtube explaining [Schrodinger's cat], and I realized that I was very interested in physics, specifically quantum mechanics*." This response was categorized as being inspired by both media and student interest. Students' inspirations for their drawings revealed that their conceptions of scientists came from personal preferences, outside influences, or came from other factors including the first thing that came to mind.

After the intervention, which highlighted multiple women in STEM but primarily focused on conservation biology, 28% more students drew biologists (Table 5). Students' captions and descriptions of their drawings revealed that their scientists' areas of research ranged from animals and plants to fungi or molecular biology, indicating the breadth of interests within biology across the student population. Additionally, student drawings became more specific. Initially, 39% of students drew scientists teaching about general scientific concepts. After the intervention, this decreased to 14% of scientists teaching, while the number of scientists conducting research slightly increased.

Students cited a variety of inspirations for their drawings (Table 5). The percentage of students citing media (e.g. TV) or family members did not change after the intervention, which is to be expected as the intervention was not rooted in these sources. Notably, six students (17%) drew scientists they were introduced to from the module in their post-drawings, with four of these students explicitly citing they had learned new information. For example, one student wrote that "*I tried to draw the scientist from my breakout room at exhibition*", and another student wrote "*I chose this scientist because I think that Herpetology is really fascinating and I really like reptiles and amphibians are cool and amazing creatures/animals*", indicating that the intervention impacted their conceptions of scientists and their interests in various fields. Student responses to open-ended questions about their scientists' motivation also suggest influence from the modules, with one student sharing that their scientist was *"asking the lizard if she can help the lizard."* One of the two scientists highlighted in the lesson plan comic books was a herpetologist studying Belding's Orange-throated Whiptail lizards.

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A few students (one in the pre-drawings, three in the post-drawings) expressed motivation to convey personal beliefs through their drawings. Interestingly, the one student who expressed a belief in the pre-drawings noted that they drew their scientist studying vaccines because*"…I didn't know what else to do but I drew a woman because I think when little kids think of scientists they just think of men and males but i wanted for people to know that women can do whatever boys can do too."* This student had already considered gender stereotypes prior to exposure to the lesson.

Table 5.
Other codes

Category	Sub-category	Code and Definition, with example student quotations	Examples:	Pre		Post	
				N	%	N	%
Field		If Biology		16	48	25	76
		If there was field equipment		2	6	3	8
Action done by the scientist	Verbal	Teaching and/or demonstrating about scientific concepts (when it's unclear it is data that the scientist has generated). Includes general advice	***Example figure caption:*** *"The scientist is cracking open a geode and telling me about the different rocks that make up a geode"*	14	39	5	14
		Communicating their own research (for example showcasing their study organism)	***Example figure caption:*** *"He is telling me that he is studying a bioluminescent fungus and you can see the fungus on one of his tables in my drawing."*	5	14	3	8
	Experimental	Observation research (there's no "experiment", the scientist is just collecting observation data with the goal of increasing knowledge)	**Example response to "what was the scientist doing in your picture?"** *"The scientist was looking at native plants."*	7	19	14	39
		Basic research - there is an experiment/independent variable (e.g. mixing chemicals; testing) with the goal of increasing knowledge. This includes testing to find cures	**Example response to "what was the scientist doing in your picture?"** *"Testing the pinch force of a new species of fish"*	15	42	10	28

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		Planning - experimental design	**Example response to "what was the scientist doing in your picture?** *"Calculations to see how he can improve the covid vaccine"*	1	3	2	6
		Learning about other research that's been done before	**Example figure caption:** *"The Scientist is showing me how to find accurate information on a species."*	1	3	2	6
Scientists' motivation	Helping	Helping animals	**Example figure caption:** *"She is asking the lizard if she can help the lizard."*	0	0	3	8
		Improving lives (e.g. curing diseases)	**Example response to "what was the scientist doing in your picture?"** *"Discovering cures or something"*	7	19	4	11
		Improving the environment	**Example response to "what was the scientist doing in your picture?** *"She was trying to make big mushrooms that cure air pollution"*	1	3	4	11
Inspiration for drawing: student responses to "why did you select this scientist to draw"	Preferences	Future goals/job that they want	**Example response:** *"Because i want to do some thing just like that when i grow up"*	5	14	1	3
		Student expresses preference (liking) a field or scientist (this can include thinking something is cool)	**Example response:** *"I chose this scientist because I think that Herpetology is really fascinating and I really like reptiles and amphibians are cool and amazing creatures/animals."*	11	31	10	28
	Based on Outside Influences: *includes the student being inspired to draw their*	TV/movies/videos	**Example response:** *"I see a lot of movies and when I see scientists in them I see them wearing a gas free suit"*	2	6	2	6
		Famous scientists	**Example response:** *" Because he reminds me of my old school and also we*	2	6	1	3

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	scientist by someone/ something		*talk a lot about him and he is really famous. My scientist is Albert Einstein"*				
		Family members	**Example response:** *"He is a chemist like my dad"*	1	3	1	3
		Scientists from the module	**Example response:** *"I tried to draw the scientist from my breakout room at exhibition"*	0	0	6	17
		Students wanting to convey a message or their personal beliefs through their drawings	**Example response:** *"Well I chose to draw her finding a cure for a bug cause I didn't know what else to do but I drew a woman because I think when little kids think of scientists they just think of men and males but i wanted for people to know that women can do whatever boys can do too."*	1	3	3	8
	Other	Not knowing what scientists do	**Example response:** *"Because I don't really know what other scientists do."*	1	3	1	3
		First thoughts that came to mind or what students think of when they think of scientists	**Example response:** *"I selected her because it was the first image that came to my head."*	15	42	11	31
		Recently learned information	**Example response:** *"I was thinking about the scientist at our math and science exhibition."*	0	0	6	17
		Other	Example response: *"The scientist is generic without much detail so there was no real defining traits"*	0	0	3	8

***Note:* N = 33 students**

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Discussion

We implemented the *In Their Eyes* conservation and comics module and characterized students' drawings of scientists. We found that student conceptions of scientists shifted (Table 4). Overall, students drew fewer stereotypical attributes after exposure to real-world scientist role models through trading cards, comic books and guest scientists (Figure 4).

Shifts away from traditional conceptions of scientists

In our study, student drawings both before and after the intervention included fewer stereotypical scientist attributes than previous DAST studies. In particular, before implementation of the program only 45.5% of students drew male scientists, and less than a third drew middle aged or older scientists (Table 4). Previous meta-analyses have found that studies consistently find that the majority of students draw male scientists (Ferguson & Lezotte, 2020), although this has been decreasing in recent years (Miller et al., 2018). Of note, the students participating in the module were enrolled in four classes with two women teachers, all from one highly diverse Title I school. Previous studies have shown that teacher gender can mediate girls' concerns about being negatively stereotyped in the classroom (Master et al., 2014). The students' science classroom environment may have impacted their pre-existing perceptions of scientists. However, our findings are consistent with a recent finding that fewer students are including gender as a defining feature of scientists when they draw scientists (Gormally & Inghram, 2021). Collectively, our study adds to the growing body of literature supporting a general shift away from traditional conceptions of scientists.

Our coding revealed additional trends in students' drawings (Table 5). The percentage of biologists included in students' drawings increased from 16 (48%) to 25 (76%). This shift supports the influence of the module, as all of the scientists featured in this study were in the biological or climate sciences. Additionally, six students drew scientists from the module. Collectively, this indicates to us that exposure to real life scientists influenced students' perceptions of scientists. Interestingly, the number of students who described the scientists drawn as conducting observational research doubled, from 7 (19%) to 14 (39%). This corresponded with a decrease in traditional scientific equipment (Table 4), indicating that students' perceptions of what constitutes scientific research had been broadened. These codes were based off of student captions and responses to questions asking them to describe what the scientists were doing. Other recent studies have shown shifts away from traditional perceptions of science, and have found that in light of the ongoing COVID-19 pandemic a sizable percentage (28%) of elementary school aged children are representing scientists as medical researchers (Quílez-Cervero et al., 2021).

Role model interventions are wide-spread, with goals of increasing the representation of women in STEM (Casad et al., 2018). Exposure to female scientists through career talks in schools increases girls' preferences for STEM (González-Pérez et al., 2020). Science outreach often uses in-school visits (e.g. a scientist-in-the-classroom model) for exposure to scientists (Laursen et al., 2007). This type of outreach significantly positively influences student attitudes towards science, in particular for underrepresented students (Gall et al., 2020). However, barriers such as access to guest scientists can prevent their use in the classroom. Our findings support the efficacy of online guest scientists and trading cards and comics as effective low-cost tools that can influence student conceptions of scientists.

Limitations and recommendations for future studies

There are certain limitations to consider when interpreting the results from this study and that should be considered in future work. First, the module was implemented during the COVID-19 pandemic, and consequently took place remotely. The pandemic resulted in documented negative impacts for student engagement and learning (Darling-Aduana et al., 2022). We did not collect data about student engagement online, for example if students used the comic books and trading cards beyond their remote synchronous class periods. Future implementations of this program should include focus group interviews with students to identify student perspectives about each aspect of the program, in particular the influence of the trading cards, comic books, and interactions with scientists.

Due to a variety of factors, including consistency of lesson plans for teachers during hybrid instruction, this study design consisted of pre-post measuring changes in conceptions for students after exposure to women role-models in STEM. A significant limitation of this work is that with a one-group pretest-posttest study design we were unable to include a control group. While it is promising that the percentage of women scientists in drawings increased after the intervention, this trend should be compared to drawings when students receive curricula with both men and women. Future iterations with a larger sample size should use a randomized control design in order to measure the effects of the intervention compared to exposure to a control (Dimitrov & Rumrill, 2003). For example, the curriculum could be implemented with randomly assigned classrooms receiving all-male representation of scientists throughout the comics, trading cards and educational aspects, other classrooms receiving all-female representation, and still other classroom receiving a mixture of scientists in the materials.

Relatedly, as the intervention involved multiple aspects that included a focus on women in STEM (including women being featured in comic books, trading cards, and a virtual poster session with guest scientist moderators), it is unclear which aspect of the module contributed most to the changes in student conceptions of scientists. Meeting role models and having live interactions may have differential impacts than reading about role models (Kearney & Levine, 2020). Additionally, due to the limitations of virtual poster sessions the students were all introduced to the guest scientists during a whole-class discussion but spent the majority of the

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poster session in a breakout room with one scientist moderating their presentations. In-person instruction would allow for students to potentially have more meaningful interactions with other scientists. It will be important for future work to explore if the program holds similar impacts when implemented through in-person instruction, and to explore each aspect of the module individually to assess impacts of individual components, in particular for educators who may prefer to implement fewer aspects of the module.

An additional limitation of this case study is the small sample size. Although there were 112 students enrolled in the participating classrooms, we were only able to collect and analyze 33 of these students' drawings and responses, for a participation rate of ~30%. We compared self-reported student demographics (Table 3) to publicly available school demographics, which suggested that our sample may be representative of the classroom. However, with these low participation numbers we encourage caution when generalizing our findings beyond the included sample of students.

Finally, the DAST itself and questionnaire provide limitations to the information we can gather from student drawings. The questions we posed asked students to identify their scientists' gender, location of work, and provide descriptions of what they were doing, but we did not ask about other demographic variables such as scientists' race and ethnicities. Moreover, we did not ask students to draw non-scientists, and so we cannot explore from this dataset alone if students perceived scientist genders differently from other professions. Future iterations of this program should include interviews with students to explore these ideas in more depth. Interviews could explore nuances in the types of actions being done by scientists, and should include targeted questions about students' motivations and influences for their drawings.

Recommendations for educators

As part of our module development, we created a free resource guide ("Teacher Packet") and provided materials at https://www.nps.gov/cabr/learn/kidsyouth/ite.htm. We encourage educators to view the Teacher Packet, which includes options for virtual and in-person instruction.

These materials were designed for place-based education with schools in San Diego, but could be adapted for other environments, ecosystems, and contexts. For example, educators could have students design their own trading cards based on local scientists, or their own comic books based on local organisms and parks.

In the design of our program, we reviewed the DAST literature and found that past literature had used checklists that were limited in scope and potentially out-of-date (Ferguson & Lezotte, 2020). We modified questions used in previous studies (Farland-Smith, 2012) and used inductive coding in order to identify additional codes that more holistically captured students' inspirations for their drawings and descriptions of scientists' actions (Table 5). These codes

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should be tested in additional contexts, but could be used by other educators as a way to categorize student drawings.

With the ongoing COVID-19 pandemic, this module was adapted for hybrid instruction which introduced challenges for assessing student engagement. Additionally, with our small sample size we are cautious to make generalizable statements about our findings, but we encourage educators to implement aspects of the module and use our codebook (Table 5) to identify changes in student conceptions of scientists.

Conclusion

This study provides support that comics are an effective teaching tool in the classroom, and that exposure to real world role models through trading cards and virtual classroom visits impacts students' conceptions of scientists. Educators can use the -module in their classrooms. As we scale the program, we intend to develop lesson plans for multiple age ranges that are aligned with NGSS, and a larger set of trading cards to increase the diverse pool of representative scientists.

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