The Biophysicist

Authentic Science Learning During COVID-19: The Adaptive Design of a SEM Outreach Activity

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ABSTRACT Before March 2020, with the outbreak of the COVID-19 pandemic, remote instruction of science was only moderately developed compared with more traditional approaches for learning science. Since the outbreak, however, all formal education systems have been carried out in remote mode, and outreach activities that take place in a research or academic setting have usually been canceled, or there has been a search for innovative approaches to shift to digital space. Therefore, the development of learning and teaching strategies has currently focused on remote activities. In this study, a design-based approach was applied to transform an existing authentic science activity using a scanning electron microscope (SEM) from face-to-face to remote learning mode. The remote mode activity included the remote operation of the SEM by the participants. The goal was to formulate a general approach to transform authentic outreach activities from face-to-face to remote operation. To evaluate the design, we compared learners' perceived authenticity in the 2 modes and reflected on the process. Data were collected with a Likert-type questionnaire regarding participants' perceived authenticity. The results suggest that items of authenticity related to the experience of learning content have a positive potential for use in remote mode. The learners' experience of connecting with the scientists is an apparent disadvantage in remote mode. However, changes in communication technology or in the pedagogy of remote teaching is a promising direction for improving social experience.

KEY WORDS authentic science; remote learning; informal science education; remote science education; scanning electron microscope; design-based research

I. INTRODUCTION

A. Use of SEM in science and science teaching

The scanning electron microscope (SEM), which has been made available for scientific research since the early 1960s, is an exciting method for characterizing surfaces (1). SEM has the ability to reach nanoscale (10^{-9} m) resolution, which is about 250 times the magnification of the strongest light microscope. This power of SEM, together with its versatility, especially regarding contemporary scientific research, make it of particular interest in science education, because it can be used to introduce contemporary topics to school students (2, 3). The concept of "characterization methods" refers to observing, imaging, studying, and manipulating the size of nanomaterials (4). Several studies with different approaches indicated

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characterization methods as a fertile context for communication of contemporary science in secondary education (5–8).

Similar to computers, SEM over the past few years has undergone a process of miniaturization. Even though one can still find a "room"-sized SEM in research laboratories that requires expert operation, desktop SEMs, the size of a computer, are also available. These desktop SEMs can be used for updating high school laboratories or science classes, as was done with light microscopes and desktop computers a few decades ago. The use of such equipment by teachers and students can provide a realistic image of science research and can influence students' motivation and enthusiasm (9–14). In science education, the SEM can serve as a "multitool" because of its multidisciplinary relevance. It can be used in the instruction of biology, physics, and chemistry in ways that it is used in research laboratories. This way of applying SEM, with its other qualities described here, is why SEM is considered an appropriate setting for an authentic science learning experience (15).

Understanding the physics underlying biological processes requires a deep understanding of structure-function relationships in biological systems. However, the structure of biological systems is very complex because it is organized in a hierarchical manner with dimensions that span a few orders of magnitude, from the visible down to atomic level. In this regard, electron microscopy plays a crucial role, because it is the only method that has an inherent ability to visualize and resolve structures from millimeters to atomic dimensions. Indeed, our current understanding of biology and biophysics would not have been the same if not for the detailed descriptions of cells, organelles, and molecular complexes that were derived from electron microscopy observation and analysis. These achievements of electron microscopy were reflected in the receipt of the Nobel Prize in physiology and medicine awarded in 1974 and in chemistry in 2017 (16).

Currently, school-level educational use of SEM is still not common and can be found mostly as part of an outreach activity in research institutes. Research on informal science, technology, engineering, and mathematics outreach programs established in recent years has resulted in increased student motivation, enthusiasm, ambition, and interest (17–20). These programs also contributed to a better understanding of science, process skills, and pursuing science, technology, engineering, and mathematics careers (21, 22).

B. Authentic science experience

The term "authentic science" means to experience science as it really is, rather than to promote a mythic, textbook notion of science (23). The conceptual foundations of authentic learning are linked to the theory of situated cognition, from a study of highly successful learning interactions that occurred in actual working environments (24). Science authenticity can be experienced in a research laboratory, whether in a school laboratory or in a research laboratory located in an academic institute. The second option is considered in the literature as an informal science learning setting. The research literature includes many records of such experiences with various benefits for learners—for example, in contributing to students' engagement in and motivation to learn science (9, 25, 26). Another well-established benefit is in better communicating the nature of science and science technology, and society issues (27–29). A scientist in an authentic setting can best communicate these issues to teachers and students. Additionally, if learning science is considered by many as becoming a part of the scientific community (30), an authentic science experience can be a means to an end. Being a part of the scientific community can be achieved by experiencing science authentically and being able to engage in authentic scientific activities.

C. Remote science teaching

The COVID-19 outbreak created circumstances in which higher education institutions implemented new technological capabilities and shifted to online teaching (31). The Weizmann Institute of Science, for example, enabled online teaching, similar to many other academic institutions worldwide (32, 33). In this situation, informal science outreach activities proposed by research institutions were cancelled unless they could be conducted by remote means. From the literature, remote activities may replace face-to-face (f2f) outreach activities because: (a) remote learning enables access to novel tools and to advanced laboratory equipment (e.g., SEM), (b) remote learning enables communication with scientists (13, 34–36), and remote learning allows learners to conduct experiments and engage in scientific inquiries (e.g., observing, questioning, collecting, and analyzing data, as well as interpreting the results) (35).

The use of remote access for an outreach activity in a contemporary science setting has many practical advantages, as well, one of which is accessibility. Owing to the low effort and high flexibility in arranging a remote activity, it may be a suitable solution for learners that do not live in the vicinity of a research institute. Additionally, with COVID-19 restrictions, the remote outreach activities can serve as a platform to preserve the relationship between science research institutes and science students and teachers. However, results are mixed and complex regarding the benefits of f2f learning, simulation, and remotely operated laboratories (36). Debates have emerged as to whether simulation and remotely accessed laboratories are as conducive to science learning as f2f laboratories.

D. Research questions

This study aims to reveal the pedagogical considerations needed to design a remote authentic activity. Our goal is to transform and adapt SEM laboratory work to remote mode and still achieve an authentic experience. We attempted to transfer and maintain the aspects of authenticity that appear in f2f activities to the remote activities of a similar nature. From the literature, we tried to address the shortcomings of the remote learning mode and to use its advantages regarding experiencing authenticity.

Two research questions were generated to describe and evaluate the design and the teachers' authentic experience:

(a) What design considerations should be taken to adapt an authentic SEM activity from f2f to remote mode?
(b) To what extent do participants in face-face and remote SEM outreach science activities report experiencing authentic science?

II. SCIENTIFIC AND PEDAGOGICAL BACKGROUND

In 2019, the Weizmann Institute of Science purchased a SEM for educational use. This SEM is a user-friendly desktop instrument dedicated to outreach education activities. A group was established to lead and navigate the SEM project that includes various members with different roles: research scientists from various faculties and researchers from the Department of Science Teaching. The project aims to bring teachers and their students to the research institute and to conduct a hands-on activity with the SEM.

By March 2020, 50 teachers and about 442 students had participated in SEM f2f activities. Since the COVID outbreak, remote learning has become the only option for scientific outreach and for learning science generally (37). With the second wave of the outbreak, in September 2020, the national policy shifted toward remote learning only. Namely, we were unable to continue to conduct the SEM outreach activity with school teachers and their students. We decided to develop a remote learning mode for the SEM to engage teachers and students in authentic research outreach activities, even in times of a pandemic. Thus, in September 2020, a transition was initiated from f2f to a remote mode of operation.

The process of adaptation to remote mode is presented thoroughly in section IV.B. After the initial design of the remote SEM activity, it was implemented with teachers during teacher workshops. The first workshop took place in August 2020 with 6 teachers and the second in February 2021 with 11 science teachers. Be-

Table 1. The main characteristics of design-based research (38) and how they are employed in this study.

DBR characteristic	Explanation	In this research
Pragmatic	The value of theory is appraised by the extent to which principles contribute to and improve practice.	The theory is implemented by designing the activity in light of authentic design principles that are improved from one activity to another.
Grounded	Design is conducted in real-world settings.	The design process is embedded in and studied through an authentic SEM learning environment.
Interactive, iterative, and flexible	Designers are involved in the design processes and work together with participants. Processes are an iterative cycle of analysis, design, implementation, and redesign.	Both explanations directly describe this research. The researchers are part of the instructional team in the SEM learning environment. In this paper, we present separately 2 activities that result from consecutive cycles of the process.
Integrative	Mixed research methods are used to maximize the credibility of ongoing research.	This study relies on pre- and postactivity questionnaires with several parts that are described in section III. Additionally, open feedback of participants and instructors is used to support the data of the questionnaire.
Contextual	Research results are connected with the design process and the setting.	This is the basic narrative and the purpose of this paper.

DBR, design-based research; SEM, scanning electron microscope.

tween the 2 workshops, the data of the first workshop were analyzed, and the activity underwent another cycle of adaptation and revision. The teachers experienced the adapted remote SEM activities of the 2 workshops (RSEM1, RSEM2) and provided extensive feedback regarding adapting the activity for learners and for their own needs and shared their experience with remote instruction during COVID-19. In section IV.B, we present data collected from the RSEM activities, focusing on teachers' perceived authenticity. These results are compared with data collected from 16 science teachers that participated in an f2f course conducted in the summer of 2019 (that will be published elsewhere).

III. MATERIALS AND METHODS

A. Design-based research

Design-based research is a methodology that has potential to support the design and research of technology-enhanced learning environments (38). It is a practical research methodology that could effectively bridge the gap between research and practice (39). Design-based research is appropriate for this study because it is situated in a real educational project: the SEM learning environment. Additionally, as is appropriate for design-based research, this research focuses on the design and testing of a significant intervention. Table 1 lists the main characteristics of design-based research (38) and how they were employed in the current design of the remote SEM outreach activity.

B. Research tools

The central instrument used to collect data in this study is a questionnaire that was administered to teachers shortly after their remote and f2f activity with the SEM. The questionnaire measured their perceived authenticity. In addition to the questionnaire, we collected written feedback from the teachers.

1. The perceived authenticity questionnaire

The perceived authenticity questionnaire was developed by Boll (40) and was translated into Hebrew. The purpose of the questionnaire is to evaluate learners' experience of authenticity after a science laboratory activity. The questionnaire was filled out by all teachers after both the f2f and remote SEM activities. The reliability of the translated questionnaire was calculated on the responses obtained from students that participated in SEM activities during the years 2019–2020 (N = 175, α =

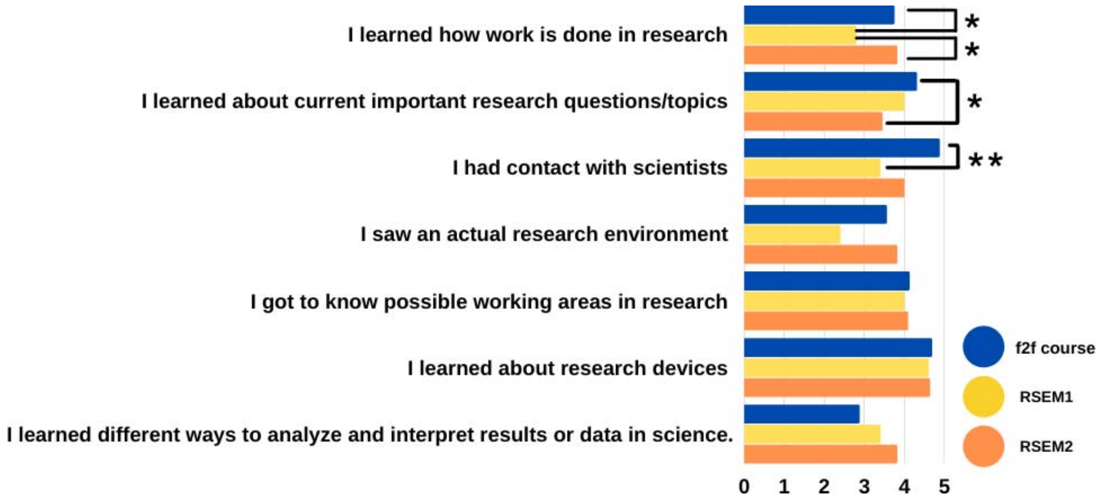

Fig 1. Average responses for the perceived authenticity questionnaire of the face-to-face teachers' course ($N = 16$) and 2 remote workshops, RSEM1 ($N = 6$) and RSEM2 ($N = 11$). Significantly different at $^{*}P < 0.05$ and $^{**}P < 0.01$ (44).

0.8053). After considering the calculated reliability to be appropriate, we used this questionnaire for the teachers' study as well. The smaller sample size in the teachers' study resulted in a similar value for the questionnaire's reliability coefficient ($N = 33$, $\alpha = 0.8019$).

The questionnaire includes 7 items presented in Figure 1 in section IV. One item (*I had contact with scientists*) refers directly to communicating with scientists. Five of the items present some possible experience of learning content (e.g., *I learned about research devices*; *I learned about current important research questions*). All of the items can be attributed to authentic context, authentic tasks, and access to expert performance (Fig 1). Additionally, teachers were asked to provide open feedback to items like: *Describe your experience during the SEM activity*.

2. The researcher as a participating observer

In this design-based study, the researcher (E.Y.) is the source of various and significant data presented in this paper, is present, and is in fact a member of the instructional and development teams that work closely with scientists and teachers during the teachers' activities. This position provides the researcher with a few additional channels for data collection, including observing and documenting different interactions and significant events in the activity (e.g., the participants, the scientists, and the subject matter), and collecting teachers' comments on processes that are recognized from quantitative data or by previous observations. These "spontaneous" comments from teachers or scientists during the SEM activity are aimed to support the findings and even add information that is missing to describe a process (41).

All data obtained from the researcher are kept in the research log. Some of the data collected is presented in this paper as context for the quantitative results from the authenticity questionnaire. The selection of the qualitative data from the log and the connection to the quantitative results were validated by a second researcher. The Institute Review Board of the Department of Science Teaching at the Weizmann Institute of Science approved the data collection, as did the Chief Scientist of the Ministry of Education.

IV. RESULTS

A. The f2f SEM teachers' course for 2019

The SEM teachers' course was planned by a group of scientists established from different faculties, including science teaching. The design of the course is centered on using SEM as a window for contemporary science. Scientists offered high-level and multidisciplinary content and introduced current research from their own lab. Additionally, assignments of a pedagogical

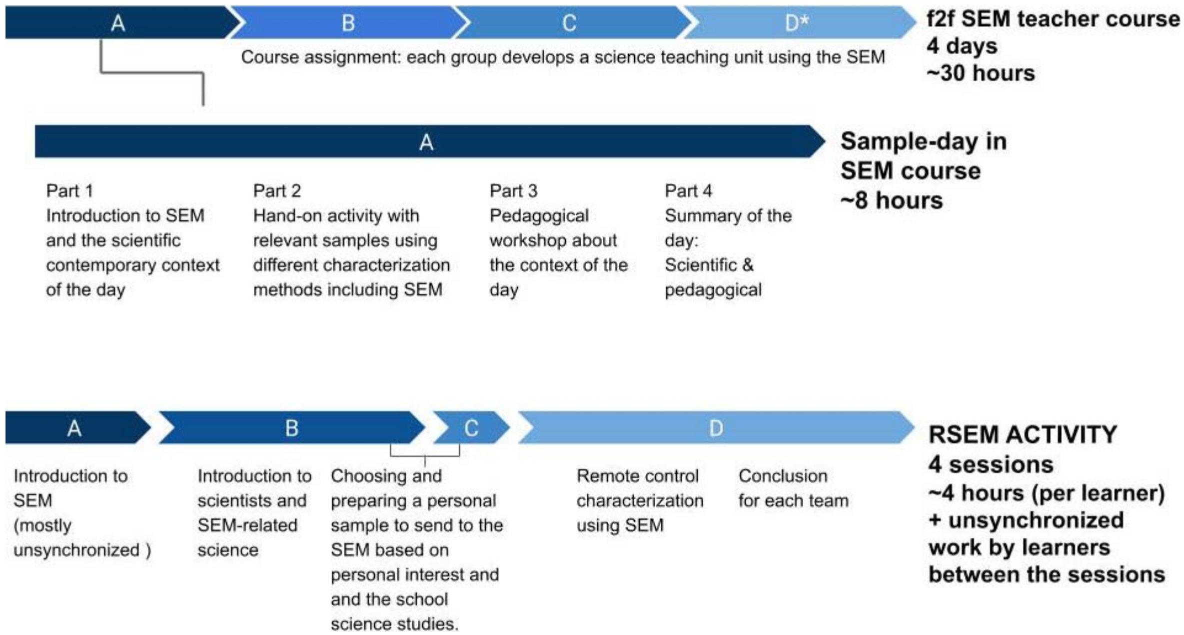

Fig 2. The general structure of the scanning electron microscope and remote scanning electron microscope outreach activities with teachers. The second part of the last day of the course was dedicated to teachers' presentations of their course assignment.

nature were given to teachers to support the creation of connections between the SEM images and contemporary science, as well as the school science curriculum. The course took about 30 hours to complete over 4 consecutive days. Data collected in this course were used in this paper to compare data from the remote workshops.

B. Adaptation process used for designing remote SEM activity

The adaptation cycles for the remote SEM activity were derived from the literature about remote science activities that include advanced characterization methods; this information was combined with our previous experience with the f2f SEM activity (unpublished data). The design was aimed to maintain the authenticity of the activity while leveraging some of the logistic advantages of remote learning.

The 2 cycles of adaptation conducted—RSEM1 and RSEM2—took place about 6 months apart, and each was conducted with a small group of chemistry teachers.

Transition to a remote activity includes adaptation in 4 aspects of the activity: structure, content, communication technology, and pedagogy. The remote activities differ from the f2f activities regarding these aspects. The main differences between the activities, along with their explanations, are described below and are summarized in Figure 2 and Table 2.

1. Activity structure

A change in the structure of the activity for the f2f course in the transition to remote mode was essential to better suit the constraints of the remote mode, as well as to utilize its advantages. The original f2f teachers' course was planned for 4 full days for about 30 hours combined (Fig 2).

For the remote mode, a workshop approach was selected instead of a course to reduce the hours of synchronized learning. The workshop included 4 different sessions spread over about 4 weeks. This structure supports learners' engagement with SEM content and scientists over an increased period of time. There is evidence that several outreach meetings have a more significant influence on the participants (42). Additionally, this spacious schedule requires learners to be independently involved between the sessions to complete the workshop.

By separating and spreading out the sessions, we used the accessibility advantage of remote mode. Accessibility of a learning

Table 2. A summary of the main differences between the f2f SEM course and RSEM1 and RSEM2.

Change	f2f teachers' course 2019	RSEM1	RSEM2
Structure	Each day includes a learning module with different contemporary topics.	A workshop with 3 or 4 parts (sessions), with independent learning expected between the sessions	A workshop with 3 or 4 parts (sessions), with independent learning expected between the sessions.
Content	Each day has a different contemporary science context. For the course's final assignment, the content is selected by the teachers with support from instructors.	Most of the content is connected to a central topic of contemporary science.	Most of the content is selected by the teachers with support from instructors.
Communication technology	f2f activity was not mediated with technology.	Remote instruction and SEM operation with zoom while the participating teachers sat together in the same classroom.	Remote instruction and SEM operation with zoom while the participating teachers were at their homes.
Pedagogy	The main pedagogical aspects of each day of learning were: (part 1) experiencing the SEM as learners, (part 2) analyzing the experience as science teachers, (part 3) promoting personal interest and skills with the course assignment, (part 4) contemporary science enrichment.	Teachers independently perform a structured experiment with local supervision and then send the samples they prepared. Teachers remotely control the SEM to characterize their samples.	Teachers select their own samples with support from instructors. Teachers need to provide the scientific background and indicate what they expect to see.

f2f, face-to-face; SEM, scanning electron microscope; RSEM, remote SEM in 2 workshops.

environment is often a bureaucratic or geographical barrier. Remote activities reduce logistic considerations and allow flexibility in setting a time and date for an activity, which may contribute to a more meaningful experience and affect its effectiveness.

2. Content

The SEM device holds the potential of opening a window into contemporary science for teachers and their students (6). The SEM f2f course used this potential to present selected contemporary work done at a research institute. The leading scientists of the research were usually involved with preparing the presentation and were often present in the teachers' course. Each day was centered on a different scientific work; the teachers completed a learning cycle, starting with an introduction to the subject matter. Next, teachers performed semi-structured hands-on activities with samples relevant to the subject matter. The activities incorporated different methods of characterization, with SEM as the main method, as well as chemical reactions with surface samples or syntheses. In the second part of each day, teachers discussed the contemporary context and the hands-on activity, pedagogically turning from learners to colleagues in the SEM learning environment. Each day ends with a summative session that highlights the main pedagogical and scientific points of the day. During the course, the teachers are asked to develop their own unit for instruction with the SEM as a course group project. The teachers used the scientific and pedagogical knowledge they gained and developed during the course to construct their unit. The course schedule was relatively flexible and included multiple breaks to allow independent work, which helped teachers develop their units during the course. Teachers often consulted course instructors and scientists regarding their units. On the last day, teachers briefly presented their units to the group and instructors.

In RSEM1, teachers performed a structured experiment together in their own school lab and sent the samples they had prepared to the SEM at the Weizmann Institute. In RSEM2, the remote activity was made for learners participating from their homes. A new hands-on activity in RSEM2 was intended to provide learners with the requisite scientific background for their selected samples. This activity required the teachers to search for relevant scientific knowledge and learn independently. The remote operation of the SEM was the central hands-on component of the workshop and its climax. Additional resources were developed for unsynchronized learning sections about the SEM device and SEM science. Learners were asked to review these resources between sessions to acquire the scientific concepts needed to follow the activity and understand it (e.g., electron source, resolution, and x-rays). Examples of such resources include a SEM online simulator, a video of SEM scientists talking about work with the SEM recorded by the team, an online exhibition of SEM images, and more.

Because of the time and activity constraints described above, the focus of the remote SEM activity differed from the f2f teachers' course. In the remote activity, the goal is to take a single image with the SEM and to accompany it with a scientific story related to the learners' discipline. This goal resembles the final assignment (Fig 2) of the teachers' course, since teachers select their own sample. Therefore, in their work, they can express their professional knowledge, personal interests, and pedagogical understanding. Contemporary content is still provided by the scientist instructors when they share their research, and it is also provided as introductory resources for unsynchronized learning sessions.

3. Communication technology

The main feature of the f2f SEM activity was the hands-on access to the SEM by students and teachers. This feature received the most emphasis in the postactivity questionnaire, and it was the most common answer to the question: *What will you remember from the activity in 10 years*? About 60% of learners that indicated they will remember the activity in 10 years wrote that using the SEM to acquire images will be the thing they remember the most (43). As a result, it was essential to maintain the immediacy of the SEM for the activity to remain authentic and memorable.

The important feature is that participants will be able to connect remotely to the SEM and remotely control the operation of the device from their own home. With the help of the Weizmann information technology team and remote operation software provided in the Zoom platform (Zoom Video Communications, Inc., San Jose, CA), the SEM was prepared for remote operation with a speed and synchronization rate that was sufficiently close to that of directly operating the SEM. Additionally, the laboratory was equipped with a high-function camera (Polycom; Poly Inc., Santa Cruz, CA) connected to Zoom, which provided learners with the point of view as if they were sitting beside the scientist operating the SEM.

4. Pedagogy

In the f2f course, the pedagogical approach was used with teachers at 2 levels:

(a) As science content learners, this level was reflected in the first part of the day. The teachers were referred to as interested and advanced students, and the activities they performed with the SEM were the same as the ones offered to their students. These activities included contemporary science content, hands-on investigation of relevant samples with the SEM and by other methods, sharing of SEM pictures, and discussions.
(b) As science educators, in the second part of the day, the teachers evaluated the pedagogical value and possible applications of the activity they had experienced in the morning. The dynamics with the instructors more resembled that of colleagues, because science education issues were openly discussed.

The changes made in other aspects of the remote workshop activity also led to changes made in the pedagogical approach used for the activity.

In this approach, the teachers were the focus of the learning as learners. The means to achieve this included enhancing learners' ownership of the samples (10, 11) and engagement with the SEM. Experience with the f2f SEM activity showed that participants were most engaged while they examined samples they had suggested or brought from home with the SEM. This engagement was also increased if the

Table 3. A summary of statistical tests performed on the collected data.[a]

Item	f2f course $N = 16$		RSEM1 $N = 6$		RSEM2 $N = 11$			Significant multiple comparison
	Mean	SD	Mean	SD	Mean	SD	χ^{2b}	
I learned how work is done in research	3.750	0.577	2.833	0.753	3.818	0.982	6.07*	f2f ≠ RSEM1 RSEM1 ≠ RSEM2
I learned about current important research questions/topics	4.313	0.704	4.000	0.000	3.455	1.036	5.94*	f2f ≠ RSEM2
I had contact with scientists	4.875	0.342	3.333	1.366	4.000	1.265	9.49**	f2f ≠ RSEM1
I saw an actual research environment (actual research lab)	3.563	0.964	2.333	1.211	3.818	1.250	5.72	
I got to know possible working areas in research	4.125	0.619	4.000	0.894	4.091	0.944	0.16	
I learned about research devices	4.688	0.479	4.667	0.516	4.636	0.924	0.42	
I learned different ways to analyze and interpret results or data in science	2.875	0.957	3.333	1.366	3.273	0.786	1.03	

[a] f2f, face-to-face; RSEM, remote scanning electron microscope in 2 workshops.
[b] Significantly different at $*P < 0.05$, $**P < 0.01$ (44).

sample resulted in a surprising or aesthetic image.

C. Activity feedback: perceived authenticity and observations of the activity

The participants of the different SEM learning environments reported their responses on the perceived authenticity items immediately after finishing the workshop or course, as summarized in Figure 1 and Table 3. Authenticity aspects in the f2f and the 2 models of remote SEM outreach activity are compared below:

I learned how work is done in research and *I saw an actual research environment*. These 2 items show a similar behavior in the shift to remote learning. Both the f2f SEM course and RSEM2 had similar high average scores, whereas RSEM1 was 30%–35% less. However, only the first item, *I learned how work is done in research*, was considered statistically significant, whereas the second, *I saw an actual research environment*, has borderline results. Teachers showed a greater connection with the SEM and actual research environments while participating from their homes rather than from a remote classroom. Eventually, the RSEM2 results for these items resembled more those of the f2f course, rather than the previous RSEM1 activity.

I learned about current important research questions/topics. This item is the exception to RSEM1 being the weaker of the 2 remote activities. The results reflect well the time spent in each mode regarding presenting and discussing contemporary research. It can be seen that RSEM2 focused on samples and content that the teachers suggested, which naturally would not be connected to contemporary science.

I had contact with scientists. This activity was evidently a central issue of authentic instruction of science in particular (10). For this item, the f2f SEM course received a score that approaches the maximum. Only 2 teachers gave less than a score of 5 to "contact with scientists." For RSEM1 and RSEM2, the results are 3.4 and 4, respectively. This item revealed the largest difference between the remote and f2f activity. In RSEM2 the perceived contact with scientists was higher than with RSEM1, which may be connected to several observations during RSEM1 and RSEM2:

(a) Technology. In RSEM1, teachers were connected to most sessions from a classroom, in contrast to each being connected from their home in RSEM2. Therefore, in RSEM1 the instructor was able to see the learners on a screen from a distance. It was difficult to address someone or even to recognize who was speaking. A significant discussion was only possible when learners were in small groups operating the SEM with the instructor. In RSEM2, each teacher was "in his/her own Zoom square," with their name written and their square highlighted when they spoke. This setup supports a clearer and more meaningful communication between learners and instructors.

(b) Pedagogy. RSEM1 was mediated more by the leading teacher, compared with RSEM2. In RSEM2, teachers had more direct communication with the scientist during the preparation sessions in breakout rooms without the leading teacher.

I got to know possible working research areas. This item received similar average scores between 4 and 4.13. The scores are high relative to the scale (out of 5) and relative to the other items. This result showed that learning about possible working areas was frequently experienced in the SEM learning environment, similarly to the f2f course and an online workshop. However, it was not investigated whether the possible working areas learned are the same, but the impression is similar. Therefore, students do not really have to travel all the way to the research institute to experience quantitatively the scientific work.

I learned about research devices. This item received the highest score of all 7 items in the questionnaire, which supports the design of the SEM learning environment, both in the f2f course and in the remote workshop with SEM at the center as a research device. What teachers learned about the device might be different, but their perception of learning about the device was similar, including for 2 groups who were never in the same room with the SEM.

I learned different ways to analyze and interpret results or data in science. This item received some of the lowest scores in the questionnaire for all modes. Analysis and interpretation of SEM images and electron dispersive spectroscopy results require skills, experience, and professional knowledge, which is exemplified by a scientist during a meeting. While operating the SEM with the scientist, often the conversation focused on the strong visual experiences, the aesthetics, and taking unique pictures, which kept the scientific discussion on a superficial level. Using electron dispersive spectroscopy often results in a more complex scientific discussion.

Generally, it appears that the f2f SEM course and RSEM2 resemble each other more than do the other modes. The design-based research approach enabled us to improve the first design (RSEM1), as can be seen by most of the scores regarding perception of authenticity. The results are supported by The Kruskal-Wallis 1-way analysis of variance by ranks and multiple comparisons between treatments (42). This test differentiates between items for which there was no significant difference between groups and other items that did not conform to this rule. All values of significance are summarized in Figure 1 and Table 3.

V. DISCUSSION

This work results from the emerging constraints of 2020, focusing on the COVID-19 pandemic. These constraints resulted in 2 research questions that could be addressed within the context of authentic science activities with a SEM. The questions were as follows:

(a) What design considerations should be taken to adapt an authentic SEM activity from f2f to remote mode?

(b) To what extent do participants in a face-face and remote SEM outreach science activity report experiencing authentic science?

To address these questions, the results were presented in 3 parts.

Part A provided a short description and context for the 2019 f2f SEM course for teachers. The next 2 parts directly focused on the respective research questions: the adaptation process used to design the remote SEM activity (part B) and activity feedback, or the perceived authenticity and observations of the activity (part C).

In this discussion, we aim to interpret the meaning of the results of the remote SEM experience within the literature of science authenticity. Specifically, we attempted to connect the 2 research questions and their results. These connections may contribute to advancing our understanding of the relationship between activity design and experiencing authentic science in the remote mode. To bring this experience closer to actual practice, the discussion is organized according to 5 aspects of laboratory work that are suggested to be essential for authentic activities (44): (a) ill-defined problems, (b) the social nature of scientific work and knowledge, (c) learning driven by the current state of knowledge, (d) experiencing science as part of communities of inquiry, and (e) drawing on the expertise of other more knowledgeable people, whether they are peers, advisors, or teachers.

Next is a short summary of each of these aspects and an explanation of how they appear with regard to the 2 research questions.

1. Ill-defined problems

The transition to remote mode has led to changes in the structure of the activity from a full week-long course to a workshop of short sessions spread over a month. This limited and refined the remote SEM activities and restricted them to their most unique features: hands-on work with the SEM, obtaining aesthetic images of different samples, and discussing the images with scientists. These features were significant in the f2f teacher course and became the center of the remote workshop, especially in RSEM2. These changes led to a very simple major task for the remote workshop: to select a sample that will reveal interesting information under the SEM, to obtain a good image of the sample with the SEM, and to discuss how the image is relevant to science taught in school, to contemporary science, or both. This task is an ill-defined problem. Ill-defined problems are defined as problems that are open to multiple interpretations; students are required to identify by themselves the tasks and subtasks needed to complete the major task (45). In the remote workshops, learners were free to choose their own scientific topics of interest by choosing samples, presenting questions in the discussions, and discussing the related scientific knowledge they utilized to complete the task.

Evidence from the perceived authenticity questionnaire provide a possible effect of the ill-defined nature of the RSEM activity. The results showed that students similarly experienced learning about the research devices in the remote workshops and in the f2f course. Additionally, they experienced less learning about current important research questions and topics and experienced the same learning about data analysis and interpretation in the workshops. The only significant difference in authentic content learning implies that less learning of contemporary content was experienced as the workshop became more “learner centered” and more ill defined.

2. The social nature of scientific work and knowledge

The social aspect is a difficult aspect to adapt to the remote channel because the social nature appears to be different in f2f and remote mode (46). According to the literature, the formation of communications and socialization in online learning is different from what is experienced in the f2f mode of learning (47). The social nature of scientific work is established through negotiations at local, laboratory, and global levels (44). A remote level should be added to this scheme, giving the unique features of remote science communication.

To engage in scientific remote negotiations, mutual scientific knowledge should be established between the scientist instructor and the learners. This knowledge is concerned with the scientific context of the SEM and its activity; it is used to support future discussions and social interactions between scientists and learners (7). This knowledge includes SEM and its related concepts (e.g., electron source, resolution, and x-rays) presented to learners in an introductory session and in online resources developed especially for SEM unsynchronized learning. This established knowledge was an essential part of all modes of activity with the SEM.

For the perceived authenticity items, we observed a significant drop in perceived contact with scientists from the f2f course to RSEM1 but an improvement in RSEM2. This appears to be a weak characteristic of remote activity (i.e., the connection between people). Part of the social experience is lost with remote communication, and the perception of a connection is decreased. However, as the social negotiations change, content is still transmitted to learners according to their responses to items of authenticity regarding their learning. Some types of learning are perceived similarly in f2f and remote mode, and some even favor the remote activity.

3. Learning driven by the current state of knowledge

This aspect suggests that learning by participating in the activity is predicated on and is driven by the learners' current knowledge state (44), as was realized in the remote workshop (more in RSEM2) by allowing the learners to select samples for the SEM according to their own interests. In this way, the learners actually decided on the context of most of the scientific discussions during the workshops.

However, most of the contemporary content was removed from the activity when transitioning to the remote mode. The scientist instructor provided support and guidance to the learners when they had to characterize their selected samples. However, the samples that learners are curious about can be far from the scientists' expertise, thus limiting any potential discussion.

In comparing RSEM2 to RSEM1, special emphasis was put in RSEM2, on consultation between the scientist instructor and the teams of learners regarding the sample selection and special phenomena. In these consultations, teachers had an opportunity to ask specific questions and discuss specific phenomena of interest. A fruitful consultation may lead to additional self-directed learning afterwards. These special efforts may be connected to a higher sense of communication with scientists, as expressed in the authenticity questionnaire of RSEM2 compared with RSEM1. However, this is also reflected in the results for the item *I learned about current research questions and topics,* which decreased in the remote workshops. In an authentic science environment, learners have an opportunity to discuss contemporary science topics and practice. However, leaving the choice of context to the learners with their current knowledge limits the extent to which contemporary science can be adequately discussed.

4. Participants experience by themselves as part of a community of inquiry

The course assignment in the f2f course, which later became the central task in the remote mode, provided the learners with an opportunity to perform some kind of an inquiry. Learners could use the SEM device and the resources of the learning environment (instructors, scientists, laboratory, time) in almost any way for learning science. The ill-defined task is open for interpretation and is directly affected by the teachers' choice and interest. Many teams chose to perform inquiry or to involve elements of inquiry in their assignments.

There is a difference between conducting an inquiry and feeling connected to the community of inquiry. In remote mode, one can never be fully independent in a SEM operation because of a need for the physical presence of an instructor to insert the SEM sample into the device. We first considered the possibility that the scientist would prepare the sample, to reduce the special efforts needed to deliver the samples from the teachers' school or homes to the Weizmann Institute. However, this effort may contribute to a greater sense of learners' ownership toward the sample and their assignment (10, 11). It also maintains some kind of a physical connection between the learners and the sample, because they are familiar with it. They have prepared and touched the sample, and the SEM is not just a virtual image on a screen but also an image of a physical thing. These kinds of connections were changed and refined between the 2 remote activities. However, to estimate the effect of this physical connection reliably, a further study with a suitable control group is required.

Sending a sample for characterization by an external provider is part of the authentic practices of scientists nowadays (24). Providing the same opportunity to science learners in secondary education is akin to a passage into the community of inquiry.

5. Draw on the expertise of others more knowledgeable, whether they are peers, advisors, or teachers

The SEM activities in both remote and f2f were always open for anyone who was interested in contributing to the learners. Often relevant scientists dropped by during the f2f course and participated in discussions or even gave a short presentation. In the f2f mode, scheduling was always a barrier, which can be simply overcome in remote mode. Relevant scientists can easily join the activities' Zoom sessions and give their input spontaneously according to the part of the activity, regardless of whether it is an introductory session or a remote SEM operation session. The visiting scientists can also show their laboratory over Zoom or share their screen with SEM pictures or other interesting and relevant measurements. Additionally, scientists can also review and comment on learners' suggestions for samples not connected with the actual sessions.

This approach was somewhat employed in RSEM1 and RSEM2. A more extensive use may help to close the gap between f2f and RSEM activities for items related to learning about current research and contact with scientists.

To sum up this discussion, with every process of adaptation and transition from one medium to another, remaining true to the nature of the source activity and adapting to the constraints of the new environment is often a struggle. Experiencing authentic science is the means of assessment we have chosen to analyze the differences. This assessment reveals differences because authenticity refers to "ordinary" and "natural" practices and involves experiencing an authentic science culture (24) through the environment. If the learning is considered situated, then the remote and f2f situations are fundamentally different; hence, an activity should be fundamentally changed to be considered authentic in both situations.

Although we report these results in an early stage of the study, we believe that the results and, especially, the design aspects of the remote outreach activity can contribute to the emerging discussions and to different efforts that are being invested worldwide in promoting remote education (48, 49). The main contribution and application of this work is to highlight the issue of social interaction and to experience a connection in remote activities having a scientific nature. This issue emerges as essential when transitioning to remote instruction, and it constitutes a major obstacle when attempting to replicate the experience of f2f activities. Other content or skill-related issues of remote instruction show similar and often even more superior results, and they can often be influenced by design. However, the social aspect, as this study suggests, is the weakest aspect; consequently, it should receive major efforts in educational research, in policy making, and during instruction.

Currently we are continuing our remote SEM activities with school students along with a return of some f2f activity. Remote SEM activities have shown great promise in science education. They may also have value, even in post-COVID science education, especially for schools with a low budget for science trips and for schools from a geographic periphery. We are continually adapting to new constraints and obstacles, focusing on the goal of providing an authentic science experience by providing adequate remote instruction.

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