Biology teachers' reflections on the benefits and challenges of using scanning electron microscopes in a biology classroom

Bat-Shahar Dorfman, Anat Yarden
Bat-shahar.dorfman@weizmann.ac.il, Anat.Yarden@weizmann.ac.il
Weizmann Institute of Science, Israel

Abstract: Calls have been made to give K–12 teachers and students access to current methods used in biological research, including advanced microscopy. The scanning electron microscope (SEM) is a powerful tool that can be used for either remote or onsite inquiry experiences for students. To use this microscope in a way that promotes students' understanding of biological concepts, teachers should be informed about its capabilities, benefits and limitations as an instructional tool. Therefore, we introduced SEM to in-service biology teachers through a teacher-training workshop where they experienced activities using the SEM. We then assessed their views on the possible benefits and challenges of the SEM in high-school biology class, and particularly while teaching the relationships between structure and function. The participants' insights are described and discussed here, shedding light on what biology teachers should take into consideration while planning and engaging their students in activities using the SEM.

Introduction

Scanning electron microscopy in biology and science education

The scanning electron microscope (SEM) is a powerful tool used by scientists from various disciplines to observe and chemically analyze the surface and near-surface regions of specimens down to the nano level. Similarly, the SEM may allow teachers and students to investigate the finest details of biological structures, thereby facilitating exploration of the relationships between structure and function—a central concept in many biology curricula worldwide (reviewed in Zer Kavod, 2018). Unfortunately, there are many structural aspects pivotal for the understanding of biology that cannot be observed directly by teachers and students, as they are at the micro level. Scanning electron microscopy can reveal the micro (and even nano) structures, enabling an exploring of their possible relationship to function. This can enrich the teachers' toolbox and allow them to provide their students with more complete information. For example, concrete observations of real cells followed by a modeling process enabled students to explore the different functions of the cellular structures and complex interrelations within the cell (e.g., Verhoeff et al., 2008). Direct observations of biological structures by scanning electron microscopy may also allow students and teachers to experience authentic scientific practices, which is one of the goals of many policy documents worldwide (e.g., European Commission, 2011; National Research Council, 2012).

Like other authentic scientific research technologies, the SEM is usually not available to school teachers. With the ease of use and reduced size and cost of the newer SEMs, together with a higher awareness of the value of such authentic technologies to science teaching, scanning electron microscopy is finding its way into high-school programs. However, despite various projects aimed at using SEMs to acquire content knowledge, most of the published papers discussing them refer to chemistry and earth science activities, and only a few to biology (e.g., Cady et al., 2015). Furthermore, most of the published papers report only the affective gains of using the SEM, such as increased engagement, motivation and interest in science, or increased inquiry skills (e.g., Cady et al., 2015; Childers & Jones, 2017). There is a lack of information on the SEM's possible contributions to teaching biology or on the challenges of using it. Providing teachers with opportunities to experience a certain technology first-hand, learn about it, and observe its pedagogical benefits can help shape their attitudes and views toward applying that technology in their classroom (Mishra et al., 2019). We therefore exposed biology teachers to the SEM so that they could gain first-hand familiarity with this technology and evaluate its pedagogical potential. We assessed their views regarding the SEM—its benefits and the challenges that it poses. This is particularly important considering the lack of information in the literature regarding these aspects of using the SEM.

Goals of the study

The main goals of this exploratory study were to introduce the SEM to biology teachers, and to assess these teachers' views on the potential benefits and challenges of using the SEM as an instructional tool for teaching biology in high school, following their own experience with the SEM.
The context of the study

Participants and workshop description
Participants included 10 high-school biology teachers (6 females, 4 males) who participated in a teacher-training workshop on scanning electron microscopy. The teachers came from different schools in Israel and had 5 to 31 years of teaching experience. All the teachers voluntarily chose to participate in the workshop and in the accompanying research.

The workshop was part of a more comprehensive 4-day, 30-hour professional development (PD) course during the summer vacation (2019). The 4-day course was designed to expose 10 high-school chemistry and 10 biology teachers to the SEM as an instructional tool, and to involve them in developing SEM activities for students (Yonai et al., 2022). On the first day, all of the teachers familiarized themselves with the SEM (the Thermofisher Phenom desktop SEM). Each day they experienced a different workshop with a different activity. Some of the activities were chemistry-oriented and one was biology-oriented. After experiencing each activity, the teachers were asked to provide their inputs and to suggest how to adapt the activity to high-school students. The current study refers only to the 10 biology teachers' insights following the biology-oriented activity.

The rationale of the biology-oriented activity
The activity was developed by a team of life scientists and science education researchers. The goal of the activity was to investigate the motility of the emmer wheat’s seed-dispersal unit, based on research by Elbaum et al. (2007), which demonstrated structure–function relationships. In their study, using scanning electron microscopy, Elbaum et al. (2007) identified the mechanism underlying the unit's movement, as the awns move in response to the day–night changes in humidity, thereby dispersing the seeds.

The activity was designed to address the major obstacles to implementing new technologies in the educational system: lack of teachers' familiarity with the technology, and the need for teachers' recognition of its contribution to their work (Mishra et al., 2019), and following the guidelines suggested by Luft & Hewson, 2014. We constructed the SEM activity while taking into consideration the following design principles: (1) Choosing a biological phenomenon that can be observed at the macro level, but whose underlying structure is only observable at the micro level; (2) choosing a topic that would be new and intriguing to the teachers, even the more experienced ones, yet can be related to the biology curriculum; (3) making the SEM an essential tool for exploring the phenomenon (observing the micro-level structures with another tool would not provide a complete explanation); (4) making room for teachers' own ideas, based on their pedagogical experience and the context of their schools; and (5) creating an activity that the teachers could perform with their students in a biology class (after adaptations to suit students' cognitive abilities and knowledge). The activity included four different hands-on tasks, each of which was a key to understanding an aspect of the explored phenomenon. Each task was accompanied by a set of instructions and questions designed to evoke the participants' thinking about the likely relations between the structures they were observing and their possible contribution to the seed's motility (function). Two tasks included macro-level observations, and two tasks focused on micro- and nano-level observations, using binoculars and the SEM. The process was guided by a scientist, who showed the participants how to operate the SEM, and when needed, where to look and what they were seeing. In the summary session, the conclusions from the different tasks were brought together to create the complete picture of the motility of the wheat's seed-dispersal unit. The scientist also discussed the implications of the phenomenon for current research and challenges faced by society.

Data collection and analysis
Open-ended pen and paper questionnaires were used to assess the participating teachers' views on using the SEM as an instructional tool for teaching biology in high school. The questions, adapted from Margel et al. (2004), asked the teachers: Based on your experience in the PD and in class, (1) what is the unique value (benefits) of using the SEM as an instructional tool for teaching biology: (a) for the teacher? (b) for the students? (c) for teaching the relationships between biological structure and function? (2) what difficulties (challenges) could students encounter while working with the SEM? The questionnaires were voluntarily filled out by all of the biology teachers (n=10) in the summarizing session of the course. The teachers' answers to each question were categorized, and the categories were counted to identify the most prevalent themes. In order to anonymize the analysis of the questionnaires, each teacher was assigned an identifying serial number (#1-10). When we refer to statements of teachers, we follow those teachers’ statements with their serial numbers, within parentheses.
Results

Teachers' views of the SEM as an instructional tool for teaching biology

SEM's unique value and benefits for teachers and students
When describing the possible benefits of using the SEM for their teaching, the most prevalent theme was that the SEM is valuable for the teaching of biology, as it enables visualizing biological structures that are otherwise abstract or only visualized in pictures. Some teachers (#2, 3, 6, 8, 9) wrote that seeing objects in "real time" would make the data more credible for the students and would help them understand the learned biological phenomena better. The following frequent theme was that the SEM allows teachers to deepen or expand their explanations of phenomena. For example, a discussion about structures and mechanisms involved in the phenomenon at hand, referring to the chemicals involved (using SEM’s ability to perform chemical analyses). Some referred not only to content knowledge but also to describing past and current research. Several teachers wrote that using the SEM may allow them to engage their students with cutting-edge, authentic technology (#5,7,9,10). They wrote that this, and the ability to see the real biological structures, can help them evoke their students' curiosity and excitement (#2,3,7,8,10). When asked about the value of the SEM for the students, most of the teachers wrote that using the SEM may allow students to better understand the learned phenomena and the relationships between structure and function. It may allow them to form a more coherent view of the content knowledge, to connect the pieces of data in a more realistic way. They attributed this to the ability to observe the structures with their own eyes, not only through models or learning about them theoretically (#3,6). Some teachers referred to high engagement of students, in contrast to passive learning (#3,5,8,10), and the affective gains of using the SEM (these were referred to as benefits both for the teachers and for the students).

All of the teachers wrote that use of SEMs in a structured activity is important for a deep understanding of structure–function relationships. They wrote that in the activity, the structures and their relationships to function become observable and therefore more vivid. For example, teacher #9 wrote that "many properties are not observable using a light microscope. Students compensate for this by learning from pictures or videos, but it is not in real time, like scanning electron microscopy observations, and therefore less effective for understanding the structure–function relationships." Nevertheless, three teachers restricted their answers by noting that scanning electron microscopy may contribute to this understanding only with proper direction from the teachers, and that using scanning electron microscopy is beneficial, but not necessary. Some suggested exploring the structure–function relationships underlying specific processes, mostly plant-science related, such as the way the unique microstructure of each pollen contributes to its distribution.

The challenges of using the SEM – possible student difficulties while learning biology with the SEM
Describing the challenges of using the SEM for their teaching, the majority of the teachers wrote that their students may experience technical and technological difficulties operating the SEM or preparing the samples. All of the teachers referred to difficulties resulting from the highly detailed images produced by the SEM: Some wrote that the image contains too much information (#2, 4). Most of the teachers anticipated that students would be confused and disoriented by the visual overload and would not be able to understand what they are seeing without guidance (#2, 4, 5, 6, 8, 9). According to the teachers, this may distract them from the structure and phenomenon that are the focus of the lesson. Some teachers (#3, 5, 10) referred to difficulties in understanding orders of magnitude and scale. A few teachers (#8, 9) wrote that students may have difficulties relating the structures they observe at the micro level to the observations and phenomena at the macro level. Teachers wrote that considering these challenges, it is important to prepare the students in advance as to what they are expected to see, to provide them with particularly accurate instructions for the activity, and to closely guide them through the process.

Discussion and implications for practice
In view of the calls for using technology in biology class, many initiatives aim to provide students with access to cutting-edge technologies, including SEMs. Our findings imply that while biology teachers see the unique value and contributions of the SEM as an instructional tool, they also predict several challenges for using it in their classroom. These challenges are not often discussed in the literature, and thus this study may assist in filling this gap. The main benefits that biology teachers attributed to the SEM suggest that teachers can harness its visualization abilities to increase their students'—and their own—better understanding of biological phenomena. Particularly of the relationships between structure and function, and topics for which there are not enough opportunities for hands-on activities, or which are typically less interesting for students, such as plants (Krell & Schmidt, 2020). However, based on the challenges that the teachers themselves experienced during the activity, our findings indicate potential challenges for students working with the SEM, which may inhibit their learning
process. This stresses the importance of using the SEM only if its benefits are substantial and necessary for the learning process. Otherwise, it may not contribute, or may even inhibit students' understanding, due to cognitive overload (Sweller, 1994). Therefore, it is recommended that the teachers and other activity developers make the SEM essential for discovering the discussed biological phenomena. For example, when teaching about a biological phenomenon involving structures that can only be seen by the SEM. Teachers can use scanning electron microscopy for concepts that they have already discussed with their students but lacked the means of visualization, or compare the images obtained from the SEM with the simplified models. To minimize the difficulties and increase the educational gains from activities with the SEM, the teachers expressed their need to construct accurate and detailed instructions and be able to offer close guidance to their students. Teachers' guidance throughout the process is pivotal to preventing student confusion or disorientation. Teachers should explicitly communicate to the students the aim of the activity and what it is that they are seeing, and discuss the relationships between the structures seen by the students and function. Thus, this study reaffirms the teachers' central role in exposing and mediating technologies and their uses to their students (e.g., Waight & Abd-El-Khalick, 2018). Therefore, teachers should be trained to use the SEM, both technically and pedagogically, while explicitly discussing the possible benefits and challenges, such as those presented above. Teachers can also take part in designing activities and adapting them to their students' needs, to their teaching goals, and to their curricula (Luft & Hewson, 2014). The insights from this study can give teachers a better view of the benefits and the challenges of using it from their peers' point of view, which may encourage teachers to use the SEM and support their teaching practice.

References


