Journal of Laboratory Chemical Education 2025, 13(2): 37-46
DOI: 10.5923/j.jlce.20251302.02

A Joint Adventure to Introduce Atomic Force Microscopy During “Experimenta con PREM” Summer Camp for High School Students

Stanislav Leesment[1], Marko Surtchev[1], Oleg Butyaev[1], Anamaris Meléndez[2], Melvin De Jesús[3], Idalia Ramos[2], Rolando Oyola[3,*]

[1]Surfmera America Inc., 5861 Kyrene Rd, Tempe, 85283, AZ USA
[2]Department of Physics and Electronics, University of Puerto Rico at Humacao, Humacao, 00792, Puerto Rico, USA
[3]Department of Chemistry, University of Puerto Rico at Humacao, Humacao, 00792, Puerto Rico, USA

Abstract “Experimenta con PREM” (meaning “Let’s Experiment with PREM”) is a two-week summer research program at the University of Puerto Rico for high school students (HS). Experiment with PREM showcases materials science as an inclusive discipline that covers diverse interests and competencies, including materials characterization, device fabrication, soft matter, crystallography, and both experimental and theoretical-computational approaches. Within this context, atomic force microscopy is one of the most valuable techniques for characterizing nanomaterials. For the 2025 summer camp, Surfmera America Inc. partnered with the University of Puerto Rico at Humacao to offer AFM experiences to high school students. The students prepared their AFM probes, characterized a surface with a bit pattern similar to a compact disk, and performed nanolithography. After completing the experimental acquisition, the students prepared a report that included a theoretical background and surface image analysis. A student survey reveals great satisfaction with the AFM experience. This partnership proved to be an enhanced experience for the future STEM students' development.

Keywords AFM, Laboratory Experience, Materials Education

1. Introduction

A summer research program for high school (HS) students, from grades 10 and 11, has been organized since 2005 by the NSF-funded program, UPR-PENN Partnership of Research and Education in Materials, at the University of Puerto Rico at Humacao [1]. The program name “Experimenta con PREM” (ECP, Spanish acronym), includes a week of immersion in hands-on laboratory experiences. Generally, participation in summer STEM programs as early as possible enhances the likelihood of pursuing a STEM career [2]. In addition, these early-career research experiences in STEM offer students the opportunity to engage in genuine scientific research, thereby exposing them to the work and perspectives of STEM researchers [3]. For many years, these activities have been successfully targeted at undergraduate students, as evidenced by the NSF-sponsored Research Experiences for Undergraduates (REU) programs [4].

Materials Science offers an ideal environment for high school research experiences due to its highly interdisciplinary and collaborative nature. It welcomes researchers with a diverse range of skills, including theoretical, computational, experimental, engineering, synthesis, and characterization. The creation and analysis of new materials, the immediate visibility of applications, and the experience of teamwork are key features of the discipline, which help guide HS students toward nanomaterials specifically and STEM disciplines in general. Expanding access to research opportunities has been recognized as a crucial strategy for diversifying the STEM pipeline [5,6]. Therefore, initiatives to provide STEM research experiences to these students are essential.

The ECP program is designed to mirror the comprehensive experience that students encounter in a REU Summer Program, spanning from the initial application to the presentation of their research findings. This year, Surfmera America Inc. joined efforts with ECP by providing one of the research experiences to HS students. Surfmera America Inc. is a company specializing in AFM instrumentation for cutting-edge nanoscience and nanotechnology research. AFM enables 3D surface topography imaging at nanometer resolution and measures surface properties, including roughness, grain size, and step heights. AFM is a fundamental technique used in Materials science (studying thin films, polymers, and nanomaterials), Biology (imaging cells, membranes, proteins, and DNA without staining or

* Corresponding author:
rolando.oyola@upr.edu (Rolando Oyola)
Received: Sep. 23, 2025; Accepted: Oct. 16, 2025; Published: Nov. 14, 2025
Published online at http://journal.sapub.org/jlce

fixation), Chemistry (in investigating surface reactions and functionalization), and Physics (understanding surface forces, mechanical properties, and nanoscale phenomena). AFM isn't just for imaging; it can measure mechanical properties (e.g., stiffness, adhesion), electrical and magnetic properties (with conductive or magnetic AFM modes), and chemical mapping (via force spectroscopy or functionalized tips). Unlike electron microscopy, AFM operates in ambient, liquid, or vacuum environments and is non-destructive, making it crucial for biological or soft samples. Proficiency in AFM is highly valued for careers in nanotechnology, biomedical research, the semiconductor industry, surface science, and engineering. For all these reasons, AFM remains a fundamental technique in nanomaterials science and is relevant for developing the next generation of scientists. Some teaching approaches have been designed to expose students to AFM and provide them with experiences in AFM, either through simulations or basic instrumental models [7]. One of the significant obstacles to exposing the students to AFM is the cost of the instrument and its availability. [8-10] In this regard, simulations and cost-effective instrumentation have been proposed. [8,10-14].

Among an extensive product line, Surfmera America Inc. offers the AFM model Spark, a multi-purpose research tool that is also an ideal instrument for educational purposes. Spark can work with standard AFM cantilevers, but it can also use other cantilevers made of etched tungsten wire. This reduces the microscope's operating costs, a significant advantage when it is used for educational purposes. Spark is a compact, robust AFM designed for small samples (up to 12 mm). It features key techniques such as Amplitude Modulation AFM, Electrostatic force microscopy (EFM), Magnetic force microscopy (MFM), Kelvin probe force microscopy (KPFM), and various spectroscopic modes.

This work describes the 2025 summer research experience for HS students that resulted from the partnership between ECP at the University of Puerto Rico at Humacao (UPRH) and Surfmera America Inc. Scientists from Surfmera America Inc. travelled to UPRH and participated in the ECP summer research program. The experience was programmed for a four-hour laboratory session and 3 hours to write a report. The experiment introduces the concepts of AFM microscopy, optical magnification, nanolithography, and surface analysis. These topics are relevant because the HS students lacked prior knowledge of the basic principles of AFM. We recognized that a day-long workshop does not make an expert in AFM, but for HS students, sparking the young generation's interest in the nanoworld is worth it. We also present the findings from a survey of the research experience. Altogether, the partnership complements ongoing efforts to provide HS students with access to nanoscience via AFM.

2. Materials and Methods

The students prepared the AFM probes by etching a tungsten (W) wire in 10% KOH (w/w) using an etcher [13,15]. The KOH was transferred to a petri dish and placed on the etcher to create a small meniscus around the "ring," where the W wire was sharpened by applying a constant voltage of 5V. The etcher features a built-in camera connected to a computer to display the tip-formation process. In this way, the students grasp the idea of how the tip is formed. After sharpening, the tip was transferred to the AFM Spark instrument to measure the surface, consisting of a bit pattern similar to a compact disc, using amplitude modulation mode. [12] In the second part of the experiment, the students used nanolithography to create the group team logo or any suggested image [16]. The nanolithography was performed on a high-density polyethylene sample. All data acquisition and image analysis were performed using proprietary software (Surfmera America Inc.). The overall workshop took approximately seven hours; therefore, organization, clear instructions, and continuous mentoring follow-up are essential to fulfill the objectives. Moreover, the required time for the workshop imposes a strict allocation of time.

3. Results and Discussion

High school students should be exposed to AFM because it fosters curiosity, develops future skills, links science to real-world innovation, and prepares the next generation of scientists. Observing how AFM is used to design better batteries, medical devices, or drug-delivery systems helps students connect science to real-world impact. AFM experiences introduce students to real nanotechnology, not just textbook science, and help them understand how scientists perceive atoms and molecules, sparking interest in research and STEM careers. Moreover, hands-on AFM experience enables students to visualize and understand the nanoscale, where many materials exhibit distinct behaviours. In this way, students recognize that tiny changes at the nanoscale can have a significant impact on how materials function (e.g., in electronics, biology, or medicine). Thus, introducing students to AFM at an early stage is essential because it provides nanoscale-level insight into the structure, properties, and behaviour of materials. In summary, learning AFM opens doors to cutting-edge research and technological innovation, equipping the students with the tools to explore and manipulate the world at the nanoscale.

The experiment begins with a brief introduction to microscopy and magnification. The diffraction limit was introduced as the limiting factor of optical magnification to characterize nanomaterials. Thereafter, the introduction of scanning electron microscopy (SEM) was presented to establish the requirement to measure nanoscale materials. The pros and cons of SEM are first discussed, followed by a discussion of AFM principles and experimental procedures. A brief experimental procedure is presented to help students understand the basics of measuring an AFM image. Afterward, the hands-on experience starts by preparing the probe tip by etching a tungsten (W) wire in KOH (10% w/w) with an etcher.

The students then measured the topography of the provided sample, which consisted of a bit pattern like that of a compact disc. Figure 1 shows an example of the obtained topography image by one of the student groups. A clear surface pattern with an oval form, characteristic of a bit sequence, is observed. Image analysis was performed using the proprietary software. For example, the green line shown in Figure 1 yields a bit width and depth of 418 and 13.6 nm, respectively.

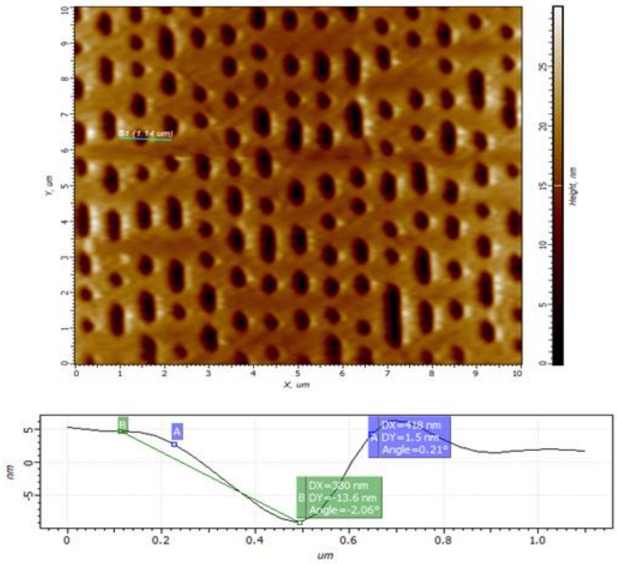


Figure 1. Top) AFM image of the CD surface. Bottom) illustration of the analysis of a bit with a 418 nm width (DX value blue marker) and 13.6 nm depth (DY value green marker), serving as an example of image analysis

Next, the students analyzed the image and calculated the surface roughness. Surface roughness in AFM is a key parameter used to quantify the texture and irregularity of a surface at the nanoscale. AFM provides 3D topographical data, allowing precise measurement of surface height variations. In these contests, the students determine the roughness of the CD surface using image analysis software, yielding a value of 2.43 nm. Further image analysis was performed using the grain analysis threshold method, which enables quantitative extraction of surface features, such as grains, particles, or domains, from AFM images. This analysis is critical in materials science, nanotechnology, and surface characterization. A typical grain threshold analysis from the HS student groups is shown in Figures 2 and 3. These analyses require higher-level statistical knowledge, which HS students do not have. However, we opt to discuss the results in terms of the physical morphology interpretation of the surface. On the final hands-on experience, the students employed nanolithography to modify the sample surface (write on the surface). In this experiment, the HS students use their imagination to draw an image on a high-density polyethylene substrate using the prepared tip. Figure 4 shows examples of nanolithography performed by the HS students. The nanolithography images are the ECP, a star, and a microwave, representing the group's name. Additionally, the students measured the width and depth of the channels created using cross-sectional measurements. This is important because the student understands the feeling of working at the nanoscale. we opt to discuss the results in terms of the physical morphology interpretation of the surface. On the final hands-on experience, the students employed nanolithography to modify the sample surface (write on the surface). In this experiment, the HS students use their imagination to draw an image on a high-density polyethylene substrate using the prepared tip. Figure 4 shows examples of nanolithography performed by the HS students. The nanolithography images are the ECP, a star, and a microwave, representing the group's name. Additionally, the students measured the width and depth of the channels created using cross-sectional measurements. This is important because the student understands the feeling of working at the nanoscale.

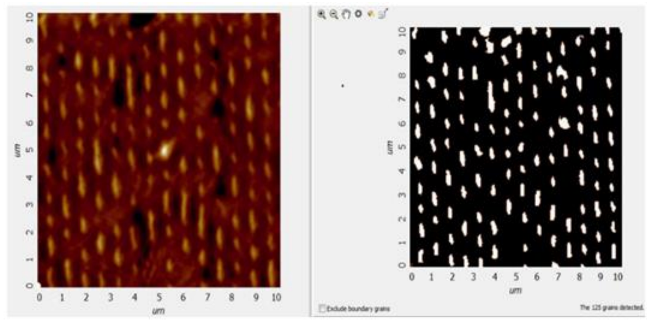


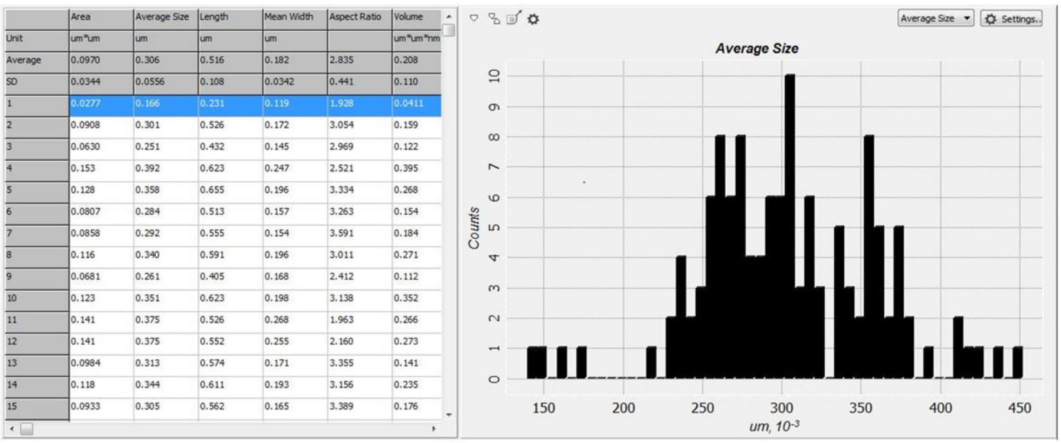
Figure 2. Grain analysis of the CD surface. Inverted topography (left) and the detected grains/holes (right)

A post-workshop survey was administered to assess participants' experience and satisfaction (see supplement S1: Post-Workshop Survey). The survey included both quantitative and qualitative items across several categories, including prior participation in similar events, overall satisfaction with the workshop, perceived relevance of the topic, content quality, facilitator/trainer performance, group activities, materials provided, use of technology, and time management. Quantitative items were rated using a five-point scale: "Very Satisfied", "Somewhat Satisfied", "Neither Satisfied nor Dissatisfied", "Somewhat Dissatisfied", and "Very Dissatisfied". The overall satisfaction rating for the AFM workshop was 4.88 out of 5.

Notably, 94% of participants (16 out of 17) attended a similar seminar for the first time, highlighting the program's role in expanding access to scientific instrumentation and hands-on learning for high school students.

Figure 5 summarizes student responses to other key workshop components. In all the categories, the students rated elements as either "Very Satisfied" or "Somewhat Satisfied". The highest-rated aspects were the use of technology and the quality of the materials provided.

To further assess the workshop's educational impact, students were asked whether the activities and theoretical components were helpful for their learning. This item received an average rating of 4.5 out of 5.0, suggesting that participants found the content valuable and accessible. However, responses also reflected some uncertainty about how this experience might influence their future academic or career paths.



	Area	Average Size	Length	Mean Width	Aspect Ratio	Volume
Unit	um*um	um	um	um		um*um*nm
Average	0.0970	0.306	0.516	0.182	2.835	0.208
SD	0.0344	0.0556	0.108	0.0342	0.441	0.110
1	0.0277	0.166	0.231	0.119	1.928	0.0411
2	0.0908	0.301	0.526	0.172	3.054	0.159
3	0.0630	0.251	0.432	0.145	2.969	0.122
4	0.153	0.392	0.623	0.247	2.521	0.395
5	0.128	0.358	0.655	0.196	3.334	0.268
6	0.0807	0.284	0.513	0.157	3.263	0.154
7	0.0858	0.292	0.555	0.154	3.591	0.184
8	0.116	0.340	0.591	0.196	3.011	0.271
9	0.0681	0.261	0.405	0.168	2.412	0.112
10	0.123	0.351	0.623	0.198	3.138	0.352
11	0.141	0.375	0.526	0.268	1.963	0.266
12	0.141	0.375	0.552	0.255	2.160	0.273
13	0.0984	0.313	0.574	0.171	3.355	0.141
14	0.118	0.344	0.611	0.193	3.156	0.235
15	0.0933	0.305	0.562	0.165	3.389	0.176

Figure 3. The results from the Grain analysis are presented in a table with data for each grain/hole, as well as in a histogram

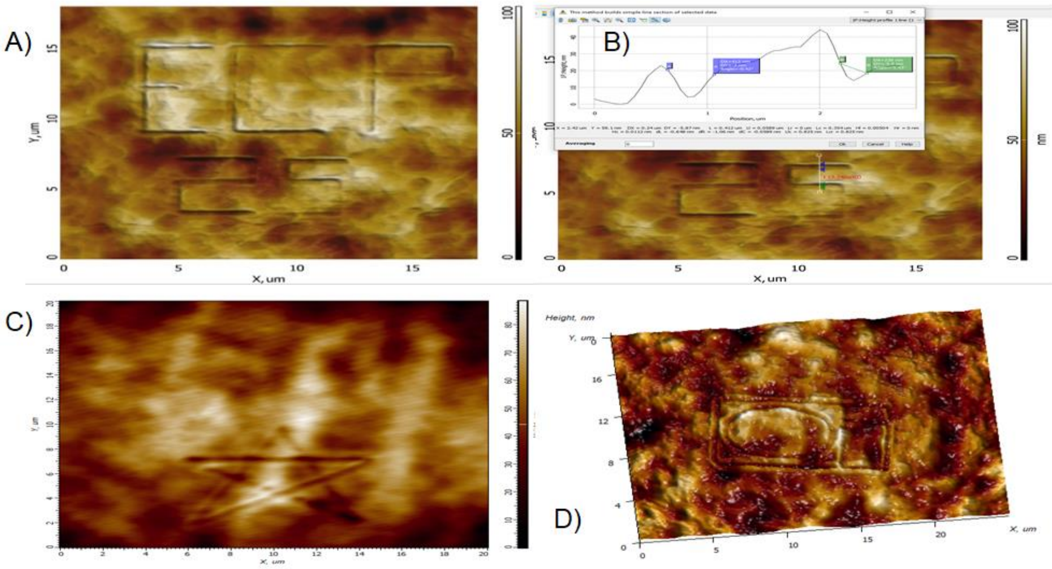


Figure 4. Examples of nanolithography from different HS student groups. A) summer ECP program logo, B) size analysis of the channels produced in the ECP 2025 logo, C) “nanocheetos”, and D) “nanoondas” team group logos

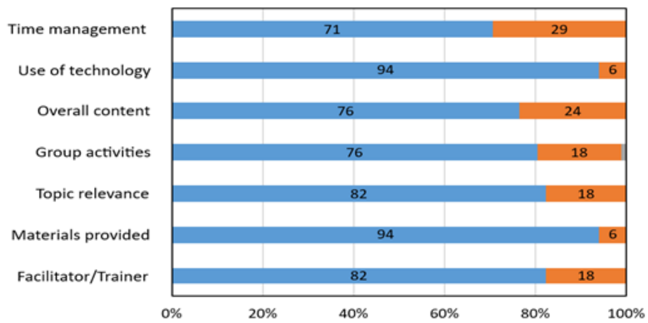


Figure 5. Results from the post-workshop survey show participant satisfaction across key AFM Workshop components. Responses are presented as percentages for each rating category: Very Satisfied, Somewhat Satisfied, Neither Satisfied nor Dissatisfied, Somewhat Dissatisfied, and Very Dissatisfied. In all categories, the responses were “Very Satisfied” (blue bars) or “Somewhat Satisfied” (orange bars)

Responses to the open-ended question “What did you like most about the AFM workshop?” were unanimously positive. Participants highlighted various aspects of the experience, including: “I loved the AFM”, “I enjoyed the experience of working and connecting with highly educated scientists", “I liked the experiments and how well we all worked as a team”, “the perfect combination of theory and practice, and how we were guided to use the AFM”, and “I enjoyed the most creating the probe for the AFM etching device”.

One question was: What did you like best about the workshop? Some answers were “Overall I like the workshop by how it is, but if I had to pick I'd still say the software”, “I liked the best creating the probe”, “Preparing the samples”, “Being able to see things that I can't see with my naked eye, showing me how amazing is the science”, and “Being able to work with unique equipment”.

Another open-ended question asked “What did you like best about the workshop?” elicited similarly enthusiastic responses, such as: “Overall I liked the workshop as it was, but if I had to pick, I'd still say the software,” “I liked best creating the probe,” “Preparing the samples,” “Being able to see things that I can't see with my naked eye—it showed me how amazing science is,” and “Being able to work with unique equipment.”

These responses demonstrate strong engagement with both the practical and conceptual components of the workshop, highlighting its effectiveness in fostering students' appreciation for scientific tools and methodologies.

4. Conclusions

During the laboratory research days of the ECP2025 summer camp, HS students had the opportunity to participate in a laboratory offered by Surfmera America Inc., an international company based in Arizona that specializes in the development of advanced scientific technologies in partnership with the UPR-Humacao. Surfmera America Inc. scientists travelled to UPR-Humacao to provide HS students with the experience of using a compact AFM (Spark model), which enabled them to visualize materials at the nanoscale, a key observational level in modern materials research. This activity exemplifies how collaboration between industry and academia can open doors for young people to access cutting-edge technology and experience the highest level of science. Moreover, it provides a sparkling experience of the nano-world for HS school students, which is difficult to achieve under normal conditions.

Supplementary Material: Post-Workshop Survey

ACKNOWLEDGEMENT

This work was supported by NSF-DMR-2122102, NSF-MRI-2320039, and Surfmera America Inc. (Tempe, AZ, USA)

DISCLOSURE

The authors declare no competing financial interest.

REFERENCES

[1] I. Ramos, J.O. Sotero-Esteva, V. Bansal, D. Barrionuevo, F. Bezares, E. Fasoli, M. Licurse, R. Oyola, N. Pinto, J. Santana, E.A. Stach, A. Wallace, Experimenta con PREM: Outcomes and best practices from a two-decade materials research summer program for underrepresented high school students, MRS Advances 9(19) (2024) 1486–1493. https://doi.org/10.1557/s43580-024-00939-5.

[2] J.A. Kitchen, G. Sonnert, P.M. Sadler, The impact of college- and university- run high school summer programs on students' end of high school STEM career aspirations, Science Education 102(3) (2018) 529–547. https://doi.org/10.1002/sce.21332.

[3] National Academies of Sciences, Engineering, and Medicine. Undergraduate research experiences for STEM students: successes, challenges, and opportunities., The National Academies Press, 2017. https:// doi.org/10.17226/24622.

[4] C. Speroni, National Science Foundation's international research experiences for undergraduates: a comparative analysis of the IRES and REU programs, National Science Foundation, Alexandria, VA, 2021. https://nsf-gov-resources. nsf.gov/2022-06/IRES- REU-f ull% 20rep ort. pdf.

[5] H.-Y. Chan, H. Choi, M.F. Hailu, M. Whitford, S. Duplechain DeRouen, Participation in structured STEM-focused out-of-school time programs in secondary school: Linkage to postsecondary STEM aspiration and major, Journal of Research in Science Teaching 57(8) (2020) 1250–1280. https://doi.org/10.1002/tea.21629.

[6] S. Hurtado, N.L. Cabrera, M.H. Lin, L. Arellano, L.L. Espinosa, Diversifying Science: Underrepresented Student Experiences in Structured Research Programs, Research in Higher Education 50(2) (2009) 189–214. https://doi.org/10.1007/s11162-008-9114-7.

[7] N.A. Burnham, Perspectives on Atomic-Force Microscopy Education, Microscopy and Microanalysis 23(S1) (2017) 2298–2299. https://doi.org/10.1017/S1431927617012156.

[8] D. Taylor, H. Smaje, P. Moriarty, A LEGOTM dynamic force "macroscope", American Journal of Physics 88(11) (2020) 906–917. https://doi.org/10.1119/10.0001700.

[9] T.A. Engstrom, M.M. Johnson, P.C. Eklund, T.J. Russin, A Computer-Controlled Classroom Model of an Atomic Force Microscope, The Physics Teacher 53(9) (2015) 536–538. https://doi.org/10.1119/1.4935764.

[10] G. Planinšič, J. Kovač, Nano goes to school: a teaching model of the atomic force microscope, Physics Education 43(1) (2008) 37. https://doi.org/10.1088/0031-9120/43/01/002.

[11] [R. Mok, C. Li, B. Comeau, E. Welsh, N.X. Fang, J. Liu, An Educational Simulation for Understanding Atomic Force Microscopy Image Artifacts, in: A.S.f.E. Education (Ed.) The Future of Engineering Education, Portland, Oregon, 2024.

[12] S.F. Bancroft, M.A. Ali, P. Kohli, An Inquiry-Based Introduction to Atomic Force Microscopy Techniques through Optical Storage Disc Surface Imaging, Journal of Chemical Education 99(8) (2022) 3030–3038. https://doi.org/10.1021/acs.jchemed.2c00291.

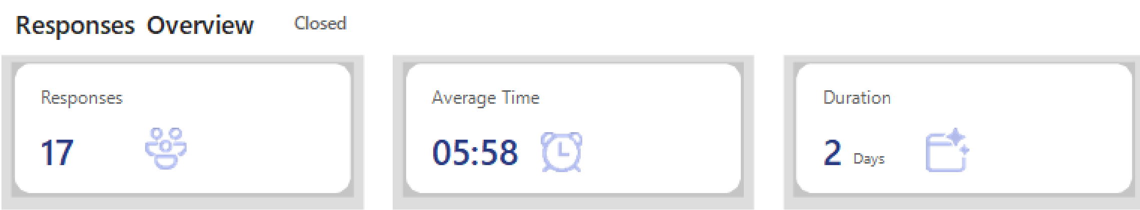
[13] R.K. Prasad, D.K. Singh, Low-cost electrical probe station using etched tungsten nanoprobes: role of cathode geometry, Nano Express 1(2) (2020) 020042. https://doi.org/10.1088/2632-959X/abb6c4.

[14] R. Blonder, E. Joselevich, S.R. Cohen, Atomic Force Microscopy: Opening the Teaching Laboratory to the Nanoworld, Journal of Chemical Education 87(12) (2010) 1290–1293. https://doi.org/10.1021/ed100963z.

[15] A. Bani Milhim, R. Ben Mrad, Electrochemical etching technique: Conical-long-sharp tungsten tips for nanoapplications, Journal of Vacuum Science & Technology B 32(3) (2014). https://doi.org/10.1116/1.4873700.

[16] Y. Yan, S. Chang, T. Wang, Y. Geng, Scratch on Polymer Materials Using AFM Tip-Based Approach: A Review, Polymers 11(10) (2019) 1590. 10.3390/polym11101590.

Supplementary Information: Post-Workshop Survey

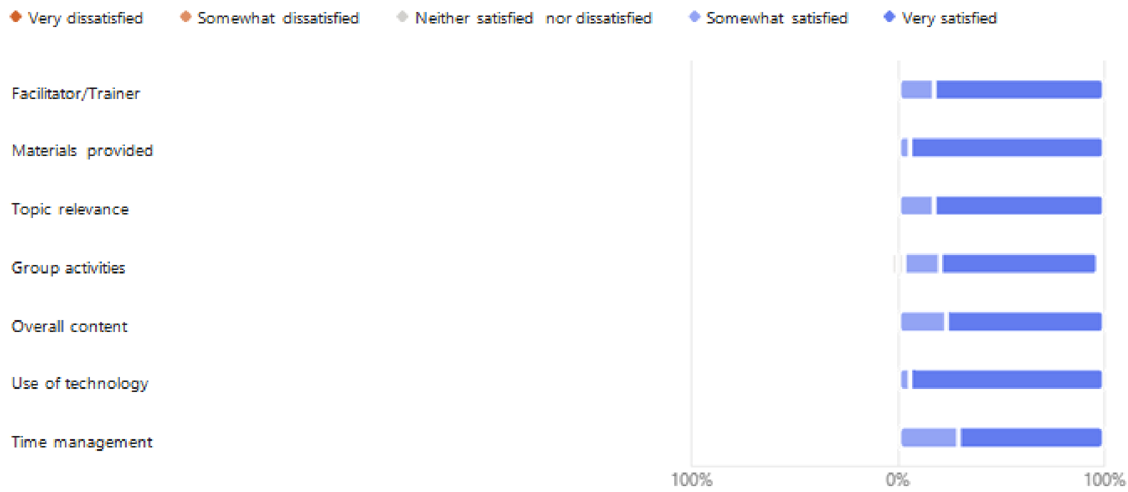


1. Overall, how satisfied are you with the AFM Workshop?

2. Is this your first time attending events like this?

3. How would you rate the following for the facilitators or trainers?

4. How satisfied are you with the following aspects of the AFM Workshop?



5. How likely are you to recommend the AFM workshop to a friend?

6. Were your expectations of the AFM workshop met?

7. What did you like most about the AFM workshop?

17
Responses

Latest Responses
"I loved the AFM"
"I enjoyed the experience of working and connecting with highly educated scientist."
"I liked the experiments and how well we all worked as a team."
. . .

8. How could the AFM workshop be improved?

17
Responses

Latest Responses
"NOTHING"
"Maybe by explaning the reason for the experiment and workshop better"
"In my opinion, the AFM workshop is already perfect."
. . .

9. Were the activities and theoretical aspects useful for your learning?

10. Was the pace of the AFM workshop appropriate?

11. Was the AFM workshop relevant to your career future decision?

12. What did you like best about the workshop?

17
Responses

Latest Responses
"Everything"
"Being able to work with unique equipments."
"I liked the teamwork."
. . .

13. Do you have any other comments or suggestions?

17
Responses

Latest Responses
"No"
"Well organized and educacionalworkshop."
"N/a"
...