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Development of a Single-point Optical Scanning System for Teaching Transmission Electron Microscopy Principles

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ABSTRACT

Transmission Electron Microscopy (TEM) is an important scientific imaging technique; however, students often find its underlying principles difficult to understand because of the abstract nature of electron optics and the limited availability of microscopy equipment in educational settings. This study developed and evaluated a low-cost Single-Point Optical Scanning Instructional System designed to demonstrate the fundamental principles of TEM through hands-on and visualization-based learning.

The prototype utilized a laser module, optical sensors, stepper motors, a turntable mechanism, an Arduino Uno microcontroller, and image reconstruction software to simulate scanning, signal detection, and image formation processes. A mixed-methods project-based research design was employed involving ten Grade 12 STEM students. Participants completed pre-test and post-test assessments to measure conceptual understanding before and after exposure to the instructional demonstration. Results showed an increase in mean scores from 8.20 to 12.40, representing a 51.22% improvement.

A paired-samples t-test indicated that the increase was statistically significant, $t(9) = 8.20$, $p < 0.001$. The findings suggest that the developed instructional system effectively improves students' understanding of TEM principles while providing an affordable alternative to expensive microscopy equipment. The study highlights the potential of low-cost, interactive STEM instructional tools for enhancing science education in resource-limited learning environments.

INTRODUCTION

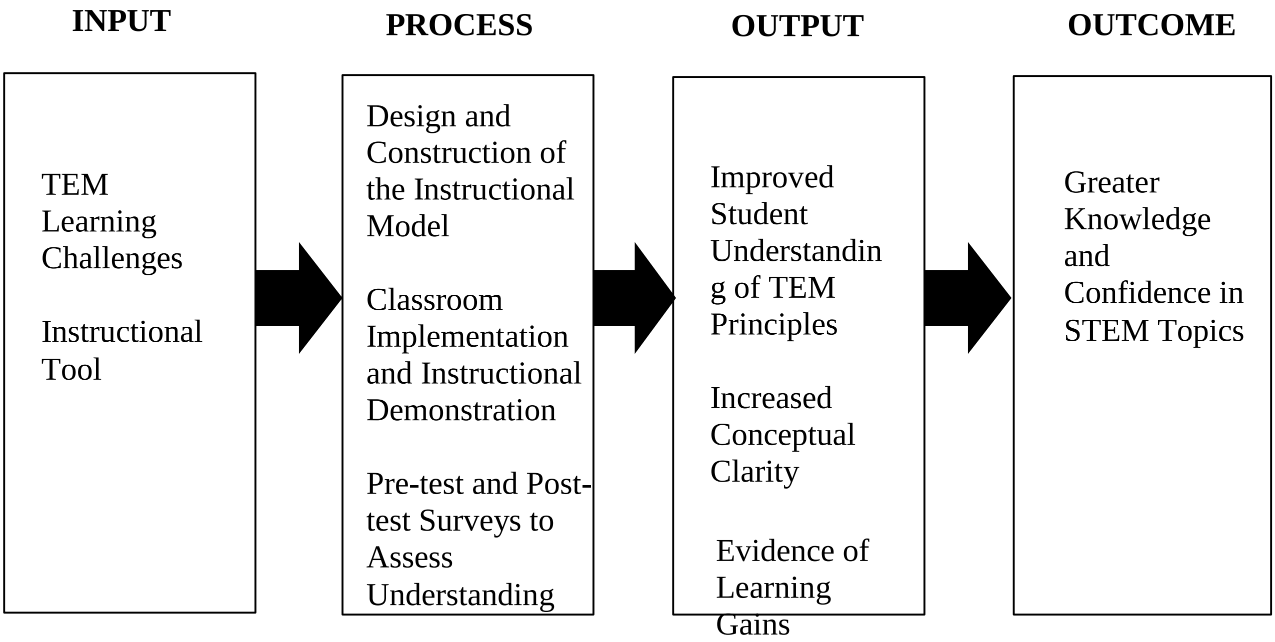
This study explored the challenges students face in understanding the imaging principles of Transmission Electron Microscopy (TEM), particularly scanning, signal detection, and image reconstruction, due to the abstract nature of electron optics and limited access to microscopy equipment. To address this educational gap, the researchers developed a single-point optical scanning instructional model that uses visible-light components such as lasers, sensors, and stepper motors to simulate TEM imaging principles on a macro scale.

The study emphasized the importance of hands-on and visual learning approaches in improving conceptual understanding of complex scientific topics, especially in resource-limited educational settings in the Philippines. The project aimed to determine whether the developed model could improve students' understanding of TEM concepts through interactive demonstrations and pre-test/post-test evaluation methods (Smith et al., 2022; DOST, 2021; Zaman & Patel, 2023).

The Objective of this paper was to design a system where TEM learning can be achieved easier and better through a hands-on experience.

Figure 1

Conceptual Framework



REVIEW OF RELATED LITERATURE

Ruska (1987) translated electromagnetic theory into practical high-resolution imaging by demonstrating that magnetic fields could act as electron lenses, leading to the first operational transmission electron microscope. However, despite such technological advances, Adi and Azra (2023) found that many high school students still struggle with the abstract concept of atomic structure, underscoring the need for more engaging instructional materials. This difficulty is compounded by findings from Liu and Lesniak (2016), who observed that while understanding topics like chemical reactions develops in a predictable sequence from sixth to twelfth grade, individual learning rates vary, highlighting the importance of adaptive teaching methods to guide students through different stages of abstract thought.

Freed et al. (2020) showed that interactive online electron microscopy platforms with lectures and virtual lab practice can replicate many benefits of in-person training, enhancing accessibility and engagement. Complementing this, Kumar et al. (2022) found that while digital tools support learning, students still benefit greatly from interactive, experiential methods that simulate real lab activities; without such tools, learners may struggle with complex TEM concepts like beam interaction and image formation. Wolf et al. (2020) further demonstrated that remote-access microscopy programs boost STEM engagement and conceptual understanding among preteen learners by allowing virtual interaction with advanced equipment. Building on these insights, Liu (2025) proposed an integrated teaching framework for TEM lab education that combines theory with guided practical experimentation, improving comprehension of abstract microscopy principles.

In the context of educational application, recent literature confirms that microscopy technologies and model-based instructional tools significantly enhance science learning and student engagement. Lim et al. (2024) developed a low-cost educational CT scanner prototype using optical scanning to simulate tomographic reconstruction, showing how interactive visualization aids understanding of complex imaging mechanisms. Similarly, Panganiban (2020) found that indigenous and low-cost teacher-made science materials improved academic performance and attitudes among high school students, serving as effective alternatives to traditional lab apparatus. Likewise, Low et al. (2025) demonstrated that virtual 3D SEM technology increased student motivation and conceptual retention by making microscopic imaging more interactive and accessible. Extending these findings to related imaging technologies, Waheed et al. (2024) designed a portable compound microscope for interactive bioscience education, further proving that low-cost, portable imaging devices can improve accessibility and hands-on scientific learning in classroom settings.

Despite advances in virtual microscopy and model-based STEM instruction, few studies have developed a low-cost physical system that demonstrates TEM scanning, signal detection, and image reconstruction using visible-light components. This gap motivated the development of the proposed Single-Point Optical Scanning Instructional System.

METHODOLOGY

This study employed a mixed-methods project-based research design involving the development of a Single-Point Optical Scanning Instructional System and the evaluation of its effectiveness as a teaching aid for Transmission Electron Microscopy (TEM) principles. The study was conducted at Mindanao State University–Maigo School of Arts and Trades. The primary participants of the study were ten (10) senior high school STEM students who completed the pre-test and post-test assessments. Science teachers were also invited to observe and evaluate the instructional model; however, only student assessment scores were included in the quantitative analysis. The research instrument consisted of a pre-test and post-test questionnaire designed to measure participants' conceptual understanding of TEM principles, including scanning mechanisms, signal detection, and image reconstruction. The questionnaire contained 10 items in multiple-choice format and 2 more essay type questions. To ensure content validity, the instrument was reviewed by science teachers and research advisers with experience in STEM education prior to administration. Necessary revisions were made based on their recommendations. The developed prototype utilized a laser module, optical sensors, stepper motors, a turntable mechanism, an Arduino Uno microcontroller, and visualization software. During the demonstration, the system simulated the scanning and image reconstruction processes used in Transmission Electron Microscopy through visible-light scanning and sensor-based data acquisition. Participants completed the pre-test before the instructional demonstration and the post-test immediately after the activity. Quantitative data were analyzed using descriptive statistics, including mean scores and percentage improvement. To determine whether the observed improvement between pre-test and post-test scores was statistically significant, a paired-samples t-test was conducted. Qualitative observations and participant feedback were also collected to evaluate the instructional effectiveness and operational performance of the prototype.

Presentation, Analysis, And Interpretation Of Data

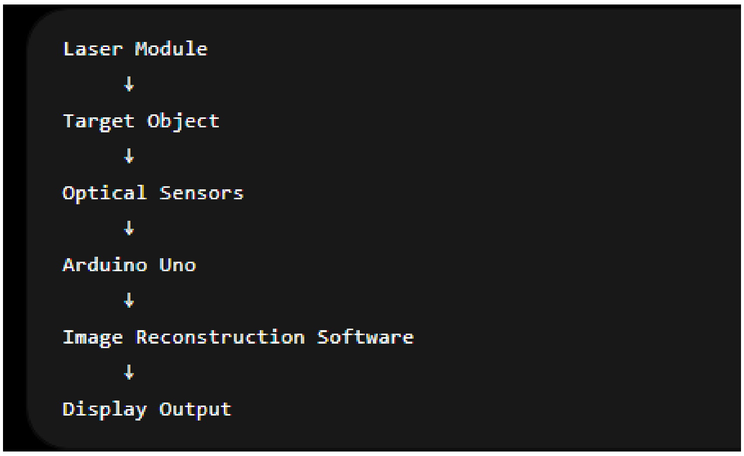
Results from the pre-test and post-test assessments indicated a substantial improvement in students' conceptual understanding of Transmission Electron Microscopy principles after exposure to the developed instructional model. The mean pre-test score was 8.20, while the mean post-test score increased to 12.40, representing a 51.22% improvement.

To determine whether this improvement was statistically significant, a paired-samples t-test was performed using the pre-test and post-test scores of the ten participating students. The analysis revealed a statistically significant increase in performance, $t(9) = 8.20$, $p < 0.001$. These findings indicate that the observed improvement was unlikely to have occurred by chance and suggest that the instructional model effectively enhanced students' understanding of TEM concepts. The results support the use of interactive and visualization-based instructional tools for teaching complex scientific concepts that are otherwise difficult to observe directly in conventional classroom settings.

The findings suggested that the interactive and observable nature of the prototype helped students better understand abstract concepts such as point-by-point scanning, signal detection, and image reconstruction. Furthermore, the study demonstrated that low-cost and locally assembled instructional materials can effectively simulate advanced scientific equipment for educational purposes, making complex STEM concepts more accessible in resource-limited learning environments (Panganiban, 2020; Umanah & Sunday, 2025).

Figure 2

Block Diagram of the Single-Point Optical Scanning Instructional System



```
Laser Module
     ↓
Target Object
     ↓
Optical Sensors
     ↓
Arduino Uno
     ↓
Image Reconstruction Software
     ↓
Display Output
```

Figure 3

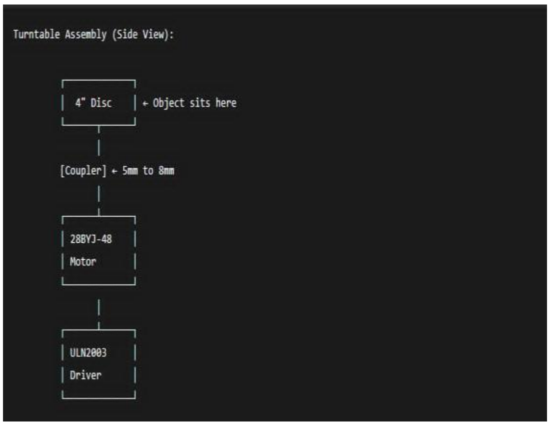
Sharp GP2Y0A51SK infrared sensor used for detecting reflected light intensity during scanning

Figure 4

Complete Z-Axis Actuator is the one responsible for stabilizing motion of the infrared sensor on the Z-axis

Figure 5

Turntable Format instruction on how to assemble the complete turntable



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Turntable Assembly (Side View):

    ┌─────────┐
    │ 4" Disc │ ← Object sits here
    └────┬────┘
         │
   [Coupler] ← 5mm to 8mm
         │
    ┌────┴────┐
    │ 28BYJ-48│
    │ Motor   │
    └─────────┘
         │
    ┌────┴────┐
    │ ULN2003 │
    │ Driver  │
    └─────────┘
```

Figure 6

Arduino UNO is the microchip responsible for software functions of the device

Table 1

Budgeting and Cost of Materials

No.	Product	Description	Quantity	Unit Price	Total Price
1	KY-008 Laser Module	Light source for scanning	1	32	32
2	28BYJ-48 Stepper Motor	Controls scanning movement	2	50	100
3	ULN2003 Microcontroller	Controls the stepper motor	1	20	20
4	Adafruit TSL2591	Light intensity sensor	1	605	605
5	Tactile Switches	Limit switch for movement	5	27	135
6	Sharp 0A51SK	Infrared sensor	1	435	435
7	Arduino UNO	Main system controller	1	605	605
8	5V Power Supply	Power source for the system	1	100	100
9	8mm Threaded Rod	Z-axis Actuator Part	1	284	284

TABLE 1: Budgeting and Cost of Materials Continuation

No.	Product	Description	Quantity	Unit Price	Total Price
10	8mm Steel Support Shaft	Z-Axis Actuator Part	1	248	248
11	2 Axis analog Joystick	Manual Controls	1	Recycled component	0
12	Breadboard	Perf Board substitute	1	Recycled	0

				component	
13	Jumper Cable	Solid Core wire Substitute	20	Recycled component	0
14	Linear Bearings	Reduces friction	2	180	360

Operation of the Single-Point Optical Scanning Instructional System

The developed instructional system was designed to simulate the fundamental imaging principles of Transmission Electron Microscopy using visible-light components and macro-scale scanning mechanisms. The system consists of a KY-008 laser module, Adafruit TSL2591 light sensor, Sharp GP2Y0A51SK infrared sensor, 28BYJ-48 stepper motors, a motorized turntable, a Z-axis actuator, an Arduino Uno microcontroller, and image visualization software. During operation, the laser module emits a focused beam of visible light toward the target object to act as a guide to show where the infrared light is being beamed at. The stepper motors and turntable control the movement of the object and scanning assembly, allowing the laser to scan the target point by point. As light interacts with the surface of the object, the sensors detect variations in reflected light intensity and position. These measurements are transmitted to the Arduino Uno, which coordinates motor movement, collects sensor data, and sends the information to the visualization software. The software processes the point cloud model and using 3D reconstruction software like Blender, the point cloud model can be processed to form a smooth 3D model. This process mimics the scanning, signal detection, and image reconstruction stages of Transmission Electron Microscopy. Although the system uses visible light rather than electrons, it enables students to observe and understand the fundamental principles of point-by-point image formation in an accessible and interactive manner.

Figure 7
Point cloud model of a roll of tape rendered in meshlab

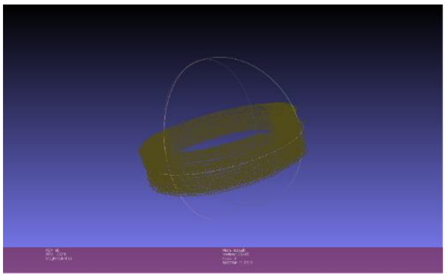

Figure 8
The same point cloud model only this time processed in blender

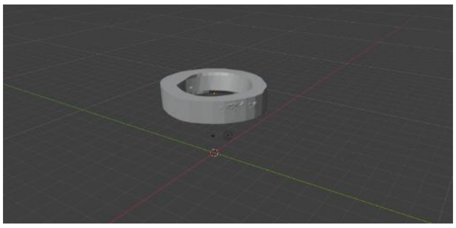

Table 2
Pre-test and Post-test Scores of Students

Students	Pre-test Scores	Post-test Scores
1	8	12
2	7	13
3	7	10
4	4	12

5	7	11
6	10	13
7	8	12
8	11	14
9	10	14
10	10	13

Table 3

Pre-Test and Post-Test Scores Mean

Participant Group	Mean Pre-test Score	Mean Post-test Score
Students	8.20	12.40

Table 4

Percentage Increase

Participant Group	Percentage Increase
Students	51. 22 %

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Study Limitations

Several limitations should be considered when interpreting the findings of this study. First, the study involved only ten (10) student participants, which limits the generalizability of the results to larger student populations. Second, the study did not include a control group, making it difficult to determine whether the observed improvements were solely attributable to the instructional model or influenced by other factors. Third, because the same participants completed both the pre-test and post-test, a learning effect may have occurred, wherein familiarity with the assessment instrument contributed to improved scores. Despite these limitations, the findings provide preliminary evidence supporting the effectiveness of the developed instructional system as a teaching tool for Transmission Electron Microscopy principles. Future studies should involve larger sample sizes, control-group comparisons, and long-term assessments of knowledge retention to strengthen the validity of the findings.

CONCLUSION

The study concluded that the single-point optical scanning instructional model is an effective and affordable teaching tool for demonstrating the imaging principles of Transmission Electron Microscopy. The system successfully transformed abstract and invisible scientific processes into observable and interactive learning experiences, significantly improving students' conceptual understanding and engagement. The findings supported the hypothesis that hands-on instructional tools enhance comprehension of advanced scientific concepts while also offering a practical alternative to expensive laboratory equipment. The researchers recommended integrating similar model-based learning tools into STEM instruction, expanding future studies using larger participant groups, improving software visualization capabilities, and further developing low-cost educational technologies for teaching complex scientific systems (Lim et al., 2024; Low et al., 2025).

Recommendations

Future research should involve larger sample sizes, control-group comparisons, improved image reconstruction software, additional instructional features to further validate and enhance the educational effectiveness of the system and video documentation to provide better evidence of learning enhancements.

REFERENCES

1. Adachi, Y., Yamamoto, N., & Sannomiya, T. (2023). Focused light introduction into transmission electron microscope via parabolic mirror.. Ultramicroscopy, 251, 113759 . https://doi.org/10.1016/j.ultramic.2023.113759
2. Adi, N. H., & Azra, F. (2023). Students' difficulties in learning atomic structure. Journal of Education and Learning (EduLearn), 17(2), 267–274. https://doi.org/10.11591/edulearn.v17i2.22475
3. Alcorn, F. M., Jain, P. K., & van der Veen, R. M. (2023). Time-resolved transmission electron microscopy for nanoscale chemical dynamics. Nature Reviews Chemistry, 7(4), 256–272. https://doi.org/10.1038/s41570-023-00469-y
4. Aycan, S., Altun, E., Yerdelen, S., & Göksu, V. (2019). Students' mental models of the atom and their difficulties in learning abstract atomic concepts. Journal of Baltic Science Education, 18(1), 9–23. https://doi.org/10.33225/jbse/19.18.09
5. Benjin, X., Liu, J., & others. (2020). Developments, applications, and prospects of cryo- electron microscopy (cryo-EM). Protein Science, 29(1), 39–52. https://doi.org/10.1002/pro.3805
6. Cheng, Y. (2018). Single-particle cryo-EM—How did it get here and where will it go. Science, 361(6405), 876–880. https://doi.org/10.1126/science.aat4346
7. Dablio, A. R., Lagmay, M., Margarito, M., de Yro, P. A., & others. (2024). Philippines' success in interlaboratory comparisons of nanoparticle geometric size measurements. Measurement Sensors, 38, Article 101527. https://doi.org/10.1016/j.measen.2024.101527
8. Da Cunha, M. B., dos Santos, F. M. T., & Giordan, M. (2023). Students' use of quantum and Bohr models of the atom: A representational versus conceptual understanding. Research in Science Education, 53, 151–170. https://doi.org/10.1007/s11165-021- 10023-1
9. de Broglie, L. (1924). Recherches sur la théorie des quanta [Research on the quantum theory] (Doctoral dissertation, University of Paris). Annales de Physique, 10(3), 22–128.
10. Dongre, A., Joshi, A., & Kapadia, M. (2012). Enhancing Conceptual Understanding through Hands-on Practical Tools in Science Education. arXiv. https://arxiv.org/abs/1205.1141
11. Gabor, D. (1946). Theory of electron optics: A new approach to electron microscopy. Panganiban, R. E. (2020). The effectiveness of indigenous and low-cost teacher-made science instructional materials in selected third year students of the Balayan National High School. Instabright International Journal of Multidisciplinary Research, 2(1), 49–52. Retrieved from https://instabright.online/index.php/journal/article/view/8
12. Freed, N., et al. "An Interactive Online Electron Microscopy Platform Integrating Classroom Lectures and Lab Practice." Microscopy Today, vol. 28, 2020, pp. 46 - 51. https://doi.org/10.1017/s1551929520000656.
13. Galaz-Montoya, J. G. (2024). The advent of preventive high-resolution structural histopathology by artificial-intelligence-powered cryogenic electron tomography. Frontiers in Molecular Biosciences, 111390858. https://doi.org/10.3389/fmolb.2024.1390858
14. Haider, M., Uhlemann, S., Schwan, E., Rose, H., Kabius, B., & Urban, K. (1998). Electron microscopy image enhanced. Nature, 392(6678), 768–769. https://doi.org/10.1038/33823
    a. https://doi.org/10.1119/1.18165
15. Koguchi, M., Tsunekawa, Y., Tsunoyama, K., & Banerjee, I. A. (2015). Electron tomography: A three-dimensional analytic tool for hard and soft materials research. Advanced Materials, 27(38), 5638–5663. https://doi.org/10.1002/adma.201501015
16. Kumar, A., Sharma, P., & Singh, R. (2022). The Role of Virtual Microscopy in Science Education: Benefits and Challenges. Computers & Education, 180, 104458. https://www.sciencedirect.com/science/article/pii/S0377123722000181
17. Lam, Matilynn, et al. "An Introduction to Scanning Electron Microscopy and Science Communication

Skills for Undergraduate Chemistry Students." Journal of Chemical Education, 2023. https://doi.org/10.1021/acs.jchemed.3c00076.

18. Lim, Sin Ting, et al. "An Educational CT Scanner Prototype Using Optical Scanning." 2024 Multimedia University Engineering Conference (MECON), 2024, pp. 1-5. https://doi.org/10.1109/mecon62796.2024.10776174.
19. Liu, X., & Lesniak, K. M. (2016). Progression in students' understanding of the matter concept from elementary to high school. Journal of Research in Science Teaching, 53(5), 683– 708. https://doi.org/10.1002/tea.21312
20. Liu, Zhongwei. "Design and Implementation of an Integrated Teaching Approach for Transmission Electron Microscopy Laboratory Education." International Journal of Multidisciplinary Research and Growth Evaluation, 2025. https://doi.org/10.54660/.ijmrge.2025.6.6.1103-1106.
21. Low, Darren Yi Sern, et al. "Improving Student Motivation and Learning in Chemical Engineering Education: A Case of Scanning Electron Microscopy with Virtual 3D Technology." Education for Chemical Engineers, 2025. https://doi.org/10.1016/j.ece.2025.100498.
22. Magnani, L., Rossi, M., & Bianchi, F. (2025). Accessibility Challenges in Microscopy Education: A Review of Low-Cost Alternatives. Journal of Microscopy Education, 12(1), 45–59. https://pubmed.ncbi.nlm.nih.gov/39611369/
23. Nguyen, K. X., Yuan, R., Brown, H. G., Chen, M., Sunku, S. S., & Ercius, P. (2024). Achieving sub-0.5-angstrom–resolution ptychography in an uncorrected scanning transmission electron microscope. Science, 384(6694), 522–527. https://doi.org/10.1126/science.adl2029
24. Padilla, Hurtado, and Juan Pablo. "Electron microscopes as educational tools: The use of a Scanning Electron Microscope to develop 3D models for educational programs." Microscopy and Microanalysis, vol. 26, 2020, pp. 65 - 66. https://doi.org/10.1017/s1431927620000562.
25. Pennycook, S. J., Lupini, A. R., Varela, M., & Hetherington, C. J. D. (2003). Sub-Ångstrom resolution through aberration-corrected STEM. Microscopy and Microanalysis, 9(S02), 926–927. https://doi.org/10.1017/S1431927603444632
26. Prameela, Suhas Eswarappa, et al. "Looking at education through the microscope." Nature Reviews. Materials, vol. 5, 2020, pp. 865 - 867. https://doi.org/10.1038/s41578-020-00246-z.
27. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 197(1051), 454–467. https://doi.org/10.1098/rspa.1949.0005
28. Ruska, E. (1987). The development of the electron microscope and of electron microscopy. Reviews of Modern Physics, 59(3), 627–638. https://doi.org/10.1103/RevModPhys.59.627
29. Ullah, N., Qazi, R. A., Ullah, S., & Khan, S. (2022). Application and importance of scanning and transmission electron microscopes in science and technology. Contributions, Section of Natural, Mathematical and Biotechnical Sciences, 43(1–2), 27–37. https://doi.org/10.20903/masa/nmbsci.2022.43.13
30. Waheed, Malaika, et al. "Design and development of a portable compound microscope for interactive bioscience learning." , vol. 13024, 2024, pp. 130240Q - 130240Q-6. https://doi.org/10.1117/12.3022127.
31. Wolf, Vanessa, et al. "Utilization of Remote Access Electron Microscopes to Enhance Technology Education and Foster STEM Interest in Preteen Students." Research in Science Education, vol. 52, 2020, pp. 617 - 634. https://doi.org/10.1007/s11165-020-09964-4.
32. Zhang, Chengyi, et al. "Integrating Laser-scanning Technology into a Construction Engineering and Management Curriculum." 2021 ASEE Virtual Annual Conference Content Access Proceedings, 2024. https://doi.org/10.18260/1-2--37361.
33. ZEISS Microscopy Education. (2024). Teaching Microscopy in Resource-Limited Settings. Carl Zeiss Microscopy. https://www.zeiss.com/microscopy/en/applications/education-teaching.html