World Journal of Chemical Education, 2025, Vol. 13, No. 3, 40-47
Available online at http://pubs.sciepub.com/wjce/13/3/1
Published by Science and Education Publishing
DOI:10.12691/wjce-13-3-1

Structured Undergraduate Research Training in Phyto-Nanochemistry

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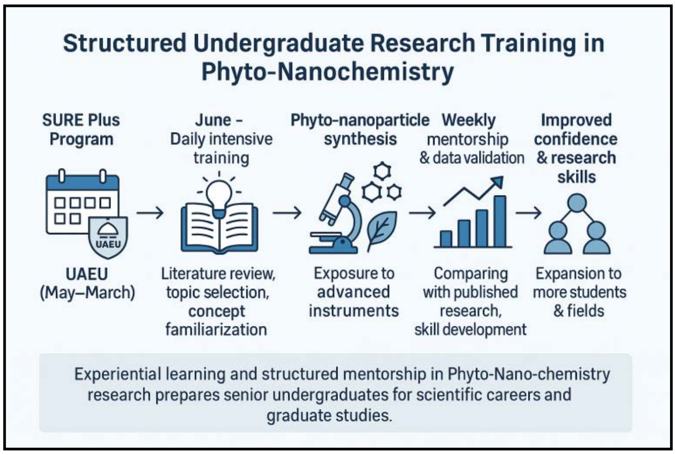
Received May 25, 2025; Revised June 27, 2025; Accepted July 04, 2025

Abstract This study explores the structured training of senior undergraduate chemistry students through the summer undergraduate research experience (SURE Plus) program funded by the United Arab Emirates University aimed at exposing students to real world research methodology. Rooted in the context of natural product extraction and nanoparticle synthesis, this project provides students with exposure to advanced instrumentation and techniques beyond the scope of typical undergraduate laboratories. The study aims to document the progression of the students' research training over a defined timeframe, emphasizing the instructional strategies and mentorship practices used at each stage. By focusing on a research area that integrates practical laboratory skills with real-world scientific inquiry, the study highlights how experiential learning and guided mentorship can effectively prepare students for graduate studies and careers in scientific research. Evidenced by a post-training survey, these findings underline the importance of structured support and skill development in helping students gain confidence and competence in independent research settings.



Keywords: *Undergraduate Research Training, Phyto-Nanochemistry, STEM Education, Green Nanoparticles, Natural products*

Cite This Article: Mohammad A. Khasawneh, and Rana Ahmed El-Fitiany, "Structured Undergraduate Research Training in Phyto-Nanochemistry." *World Journal of Chemical Education*, vol. 13, no. 3 (2025): 40-47. doi: 10.12691/wjce-13-3-1.

1. Introduction

Background & Rationale: Chemistry is mostly a practical field, and undergraduate chemistry curricula usually have many laboratory-based courses students take throughout the duration of their study programs. Most students' learning of challenging theoretical chemistry concepts is highly enhanced by working in a laboratory setting [1]. Furthermore, learning basic research skills is becoming increasingly important for several reasons including experiencing chemistry in a real-world setting, getting the excitement of discovery, preparing for future career or graduate school. However, the transition from a completely supervised laboratory-based course into an independent research setting is quite challenging for many students. Research requires a lot more than studying an experiment one day before laboratory starts. Students must learn certain essential skills to start doing research on their own. Additionally, research settings usually utilize materials and instrumentation that are more sophisticated than laboratory-based courses. Therefore, the role of mentorship in guiding students through the research process is crucial to this process [2,3].

Objectives of the Study: This study aims to document, within a defined timeframe, the process of training seven senior undergraduate students in scientific research, to highlight the instructional methods employed at each stage, and to evaluate the effectiveness of the training approach. This study is based on the extraction of plant-derived natural products and the synthesis of nanoparticles based on the active compounds found in them. This field of research requires the use of various sophisticated techniques during all the stages of the project, which provides students with a wide range of knowledge, expertise, and skills that are useful for their future careers.

2. Methodology and Context

2.1. Student Selection and Initial Assessment

2.1.1. Selection Criteria

In a typical study, 2-5 senior undergraduate students majoring in chemistry or related fields were selected randomly with minimum levels of prior research experience but with previous hands-on experience including laboratory courses taken before. GPAs for students were recorded but were not taken as a major factor in the selection criteria.

2.1.2. Initial Knowledge Assessment

Students were subjected to a pre-training survey to evaluate their background knowledge on research methodologies in the field and identification of their knowledge gaps in plant extraction and nanoparticle synthesis. The students' responses are displayed in figures 1-3. Based on the students' responses, it is evident that most of the trainee students (71.4%) have heard of natural products chemistry and possess only a superficial understanding of natural product extraction and its primary purpose (Figure 1a and 1c). In contrast, few are familiar with the commonly used extraction methods or the role of plants in the synthesis of nanoparticles (Figure 1d and 2b). A significant portion of the students (57.1%) had not conducted natural product extraction or been involved in nanoparticle synthesis prior to the training (Figure 1b and 2a). Although the majority demonstrated a general awareness of NP synthesis methods (Figure 2c), fewer than half reported high confidence in their ability to actively contribute to plant-based NP synthesis projects (Figure 3b), critically evaluate relevant scientific literature, or analyze and interpret experimental data (Figure 3c and 3d). Most students lacked familiarity with the specific processes involved in natural product extraction and the synthesis of nanoparticles (Figure 1b and 2a), and they also indicated limited exposure to scientific research methodologies (Figure 3a). Despite these gaps, the students exhibited a strong interest in expanding their knowledge and skills. They were eager to learn a range of nanoparticle characterization techniques, including spectroscopic methods such as UV-Visible (UV-Vis) spectroscopy, Fourier-transform infrared spectroscopy (FTIR), and nuclear magnetic resonance (NMR) for compound identification. They also showed interest in imaging and sizing methods such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), and dynamic light scattering (DLS). Furthermore, they expressed a clear desire to strengthen their competencies in experimental design, data analysis, and scientific writing and reporting (Table 1).

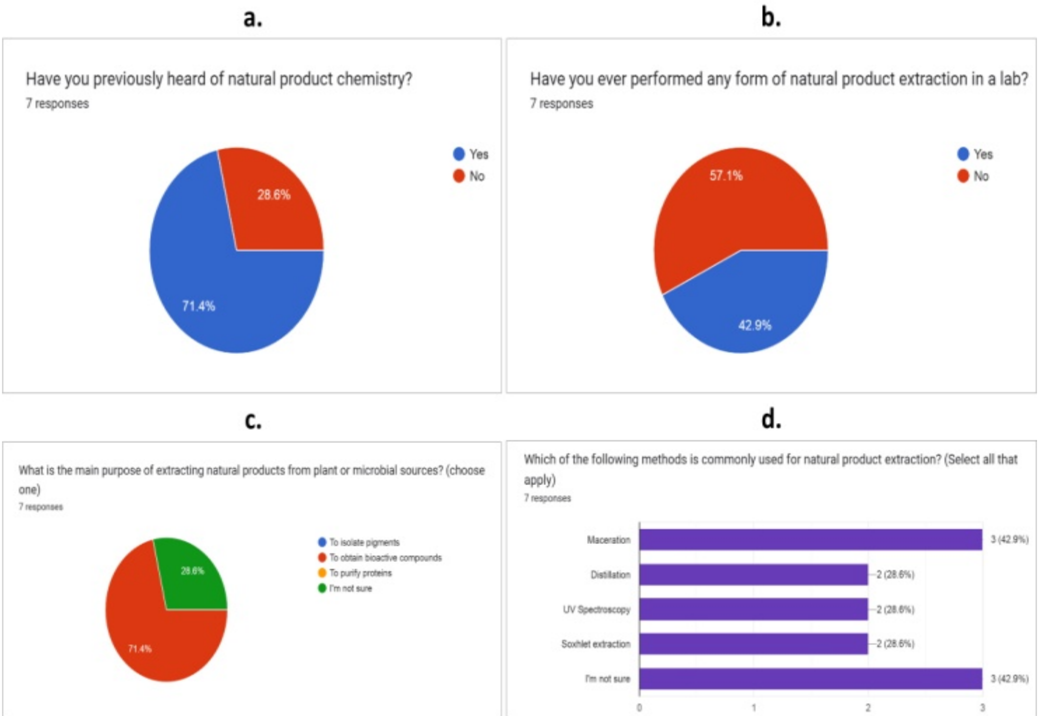


Figure 1. Distribution of the pre-training survey responses regarding the students' prior knowledge of natural product chemistry

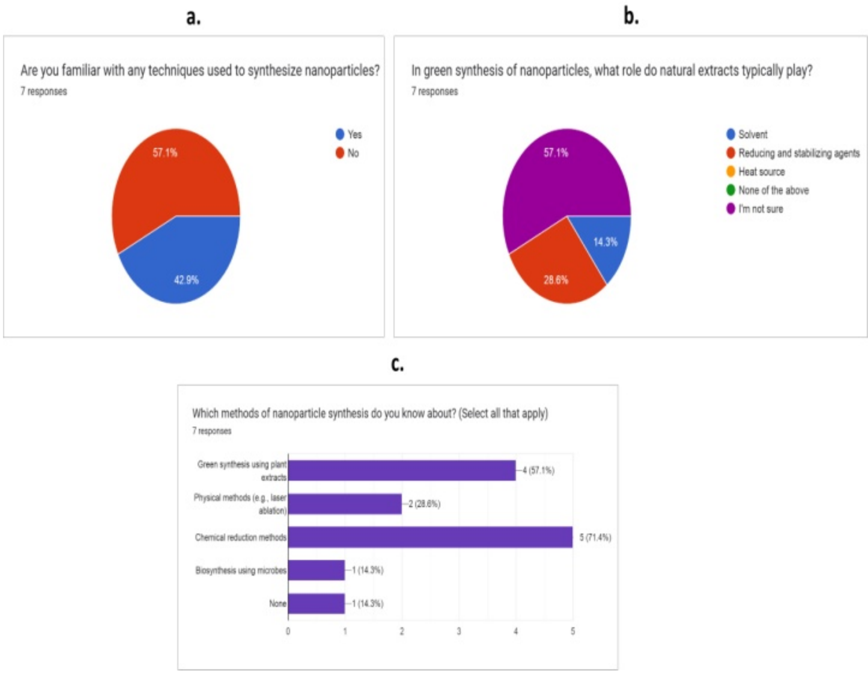


Figure 2. Pre-training assessment of participants' background knowledge of nanoparticles' synthesis techniques

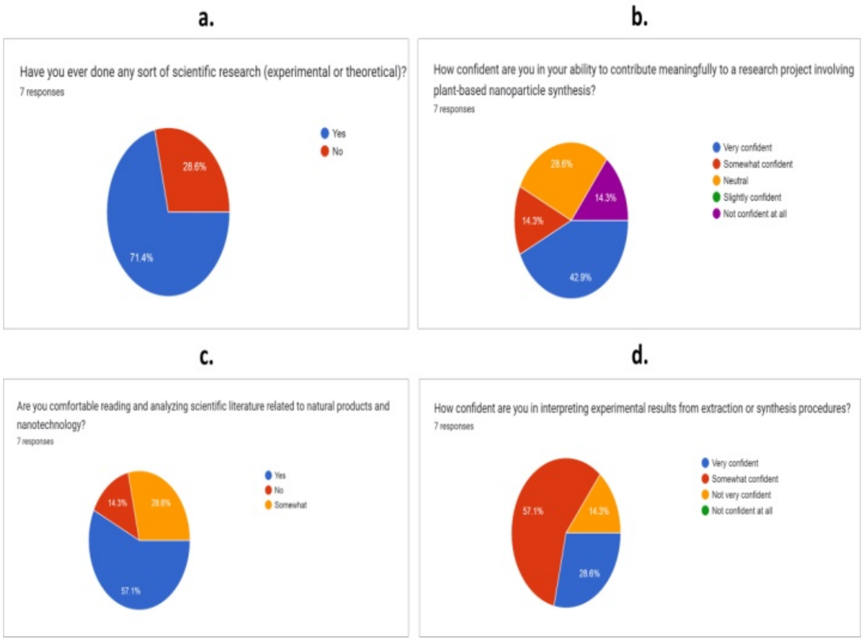


Figure 3. Insights from the pre-training survey on participants' prior involvement in scientific research

Table 1. Overview of Training Expectations Expressed by Students in The Pre-training Survey

What specific topics or skills would you like to learn more about during this training?	2 responses Lab techniques. Spectroscopic analysis (e.g., UV-Vis, FTIR, NMR for compound identification) Nanoparticle characterization (using SEM, TEM, DLS, etc.). Experimental design and data analysis 4. Scientific writing and reporting.

2.2. Structure of the Research Training Program

This program was supported by SURE plus (Summer Undergraduate Research Experience) funding program at the United Arab Emirates University (UAEU). The project usually runs over a 10-month period, including the summer semester (Phase 1, May - June), fall semester (Phase 2, August -December) and part of spring semester (phase 3, January - March). Phase 1 was condensed with the aim of building skills on the topic (5 weeks, 5 days per week, 5 hours per day. Phase 2 (one 4-hour session per week) was designed to collect all remaining results, verify the validity of results. Phase 3 was allocated for data analysis and reporting. At the end of the training period, students are expected to give a 15-minute presentation at an on-campus event. Students are allowed to take up to one course along with the training program in phase 1 but can take normal loads in phase 2 and 3. Methodology followed in this training included a blend of hands-on experiments, guided mentorship, and weekly discussions.

2.3. Stages of the Project

The project was divided into several interrelated stages starting from building basic knowledge and skills through surveying previous literature, deciding on suitable experiments to conduct, collecting, and analyzing data, and scientific writing. In the following paragraphs, we discuss all the applied stages in this study. It is worth noting that some stages were started before the preceding stages were completed to maximize the time efficiency of the project.

2.3.1. Stage 1: Literature Review and Research Question Development

Students were introduced to the available online scholarly databases through the UAEU library (Scopus, Web of Science, Google Scholar, Science Direct, PubMed, and SciFinder). Students were given thorough training on the most effective search techniques used in the field by the graduate students involved in the project. They were directed to read about the medicinal folk use of the medicinal plants used in the study, in addition to their reported bioactive compounds, and biological activities. Furthermore, they were guided to review previous studies on plant-mediated nanoparticles' synthesis and to formulate research hypotheses and objectives [4,5,6]. This stage took place from day 1 to the end of week one, while the part of the literature survey extends until the end of phase 1.

2.3.2. Stage 2: Selection and Preparation of Plant Samples

Students were given comprehensive trainings on the way of selecting and preparing medicinal plants used in this study, guided by UAE ethnobotanical practices and prior research [7]. Plant sample preparation included the collection from the field, drying of plant material, authentication of the plant specimen and grinding into fine powder for extraction. This stage spanned from day 3 to the end of week 2.

2.3.3. Stage 3: Extraction of Natural Products

Students were made aware of the several methods for extraction of natural products from plants including solvent extraction (methanol, ethanol, water-based), Soxhlet, decoction, maceration, and other green extraction techniques (e.g., ultrasound-assisted, and microwave-assisted, using green solvents) [8]. In this project, decoction, and maceration extraction methods, using water and ethanol, were chosen, respectively. This stage was scheduled to occur in week 3.

2.3.4. Stage 4: Synthesis and Characterization of Nanoparticles

In this project, green synthesis of zinc and iron metal nanoparticles using UAE-plant extracts as reducing, stabilizing, and capping agents was favored over the energy intensive and environmentally polluting chemical synthesis. Reaction conditions were carefully identified including (pH, concentrations, temperature, and reaction time). Characterization of the fabricated nanoparticles was conducted using several techniques, including Fourier Transform Infrared Spectroscopy (FT-IR) for functional groups analysis, ultraviolet-visible spectroscopy (UV-Vis) for plasmon resonance confirmation, X-Ray diffraction (XRD) for crystallinity determination, Scanning Electron Microscope equipped with Energy-Dispersive X-ray Spectroscopy (SEM/EDX) for morphology and elemental analyses, and Dynamic Light Scattering (DLS) for particle size and zetapotential distribution investigation [5,9,10,11]. Some of these instruments can be easily used by the students and need minimum training, while others are very sensitive and can be used by well trained personnel. Therefore, the students were accompanied by a technician and a senior graduate student during the experiments. Beginning on week 3, this stage continues until the close of week 4.

2.3.5. Stage 5: Chemical and biological Investigations of the Plant extracts and Their Nanoparticles

The total phenolic content (TPC) and the total flavonoid content (TFC) of the plant extracts and their corresponding nanoparticles were evaluated by applying Folin-Ciocalteu and aluminum chloride colorimetric assays [12]. Also, the antioxidant effects of the above-mentioned samples were examined through conducting DPPH and ABTS assays [13,14,15]. Students were then trained to run these techniques that involve precise solution preparation and time-sensitive spectral measurements. These techniques equip the students with a great set of valuable and life-long skills in data collection, analysis, and interpretation. Examples of figures and tables produced in this stage were of high quality and were included in a publication produced from one of these types of projects [16]. The implementation of this stage occurred in week 5.

2.3.6. Stage 6: Data Analysis and Interpretation

Analysis and interpretation started as soon as data were collected from all stages of the project. High quality tables, figures and graphs were generated in this stage. Several software like Origin, Excel and other statistical analysis platforms were used. Students were also asked to check existing literature to use a guide for data analysis and interpretation. This stage helps students develop critical skills in judging the significance, reliability, and quality of their outcomes. These skills are essential to be used later in the publication stage and are indispensable for their future careers as researchers. During this period, discussions were held on the experimental findings and their associated limitations.

2.3.7. Stage 7: Scientific Writing and Communication

This stage was started during the fall semester based on one laboratory session per week. Write ups, graphs, figures, and tables produced from all previously discussed stages were then used to prepare a scientific paper to be submitted for publication. For example, stages 1 and 2 were used to write the introduction, stages 3-5 were used to write the methods, and stage 6 was used to prepare the results and discussion. The abstract and conclusions were then written at the end. Each student was given one part to focus on, with some tasks being assigned to a team of 2 students. Citation management software was used including Mendeley or EndNote. In this stage, the students were trained on recent AI tools to create scientific graphical abstracts, presentations, posters, and figures like Biorender, and Canva. On a parallel effort, research posters and PowerPoint presentations were then prepared for conferences on campus and nationwide.

3. Results & Discussion

3.1. Outcomes

Thanks to the persistence and commitment from the students' side, combined with the close follow-up and support from the faculty and PhD student, the training was productive, resulting in outcomes such as increased confidence in research skills. This is evident from the students' responses in the post-training surveys as discussed above, along with the successful synthesis and characterization of bioactive and sustainable nanoparticles. The ultimate outcome of the training is evident from the successful publication of a paper in top ranked and peer-reviewed journal [16], in addition to two poster presentations in the International Workshop On Advanced Materials at Ras Al-Khaimah city in the United Arab Emirates [17,18].

3.2. Challenges and Solutions

Several challenges were encountered during the training related to experimental aspects (difficulty in understanding extraction techniques, optimization of nanoparticle synthesis parameters, experimental failures and troubleshooting issues). Other challenges were related to personal differences between students. As expected, some students showed greater interest in the project than others. Solutions to these issues included several approaches. Learning thrives when students actively engage in the process, and a constructivist approach naturally fosters this. By centering learning around their own interests and questions, students are empowered to build upon their existing knowledge, reconstruct new information, and ultimately develop their own unique understanding. To achieve this, all the necessary conditions to sustain inclusive and constructivist learning styles were provided. For instance, collaborative and interactive classroom environment was maintained through weekly lab discussions, group activities, field visits, brain storming, and problem-solving sessions, beside encouraging teamwork, with the close supervision and individualized mentorship to keep students actively engaged in the training. Moreover, to ensure that the training effectively reaches the widest possible range of students with diverse backgrounds, inclusive pedagogy is essential. It acknowledges that everyone possesses unique potential that is best unlocked through learning experiences that recognize and value their varied ways of knowing and demonstrating knowledge. Consequently, we proactively prioritize the creation of accessible and equitable course materials that are inclusive of all students' diverse backgrounds, encompassing activities and assessments, to cater to the diverse needs of all students. Furthermore, we adapt these materials to the specific requirements of each cohort. This is accomplished by developing instructional resources and plans that integrate multiple means of assessment (e.g., written, verbal, in-class, digital, collaborative, and individual tasks) and diverse teaching techniques (e.g., visuals, texts, videos, interactive elements). To empower students to successfully unlock their full potential and cultivate efficient work habits, our instructional materials and methods are designed to motivate and engage. This is why our proposed program emphasizes in-depth exploration over broad coverage. For example, we favor the thorough synthesis of one nanoparticle using a single plant rather than superficially exploring the synthesis of numerous nanoparticle types with multiple plants. This focused approach allows the students to concentrate on the training's core objectives, maximizing their acquisition of the essential and relevant skills and knowledge. Furthermore, incorporating up-to-date and cutting-edge content that reflects the latest advancements is crucial to achieving this goal. Cultivating respectful and friendly relationships with each student is another crucial approach. This fosters a supportive environment that dismantles barriers, boosts trainee engagement, and cultivates a strong sense of belonging to the program and the wider university community, particularly for less actively involved students. A final key element is to encourage students to voice their questions without fear of judgment, no matter how inconsequential they might seem. This builds a positive learning culture that activates and strengthens their confidence and critical thinking skills.

3.3. Evaluation of Training Effectiveness

The effectiveness of the training was assessed by post-training surveys completed by the students. The results of the post-training surveys are presented in figures 4-7. It can be concluded that students have reported a substantial improvement in their basic knowledge of natural products (Figure 4a), plant extraction, green nanoparticles, research data analysis and interpretation, scientific reporting (Figure 4b and 5b), technical skills (Figure 5), and future interest in research careers regardless of the topic (Figure 6). A percentage of 57.1 of the participated students demonstrated confidence on performing nanoparticles' synthesis, followed by 28.6% who expressed their comfortability to conduct characterization techniques of the nanoparticles (Figure 5a). All the participants reported that hands-on lab work was the most helpful learning method during the training, followed by group discussions and feedback on the work (85.7%) (Figure 5c). The majority of the students (85.7%) expressed their interest to join further research projects related to phytonanochemistry (Figure 6a and 6c). Also, 57.1% demonstrated their openness to join projects on other chemistry fields (Figure 6b). Furthermore, the students found the experience of joining research competitions like the UAEU innovation competition and presenting their posters at the International Workshop on Advanced Materials to be highly rewarding 17,18. In addition to their interest in expanding their technical skills, the students also expressed enthusiasm for participating in further training programs and attending additional related scientific conferences (Table 2). Ultimately, the participants showed strong support for the program, expressing their willingness to recommend this training program to their colleagues (Figure 7a).

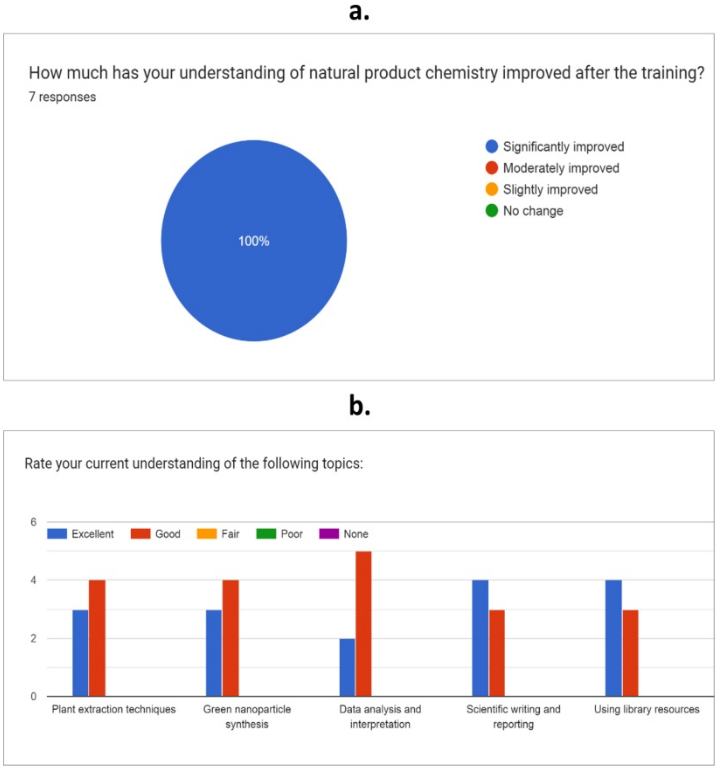


Figure 4. Post-training survey ratings of participants' understanding across core research-related topics and the perceived improvement in key scientific skills and techniques following the training

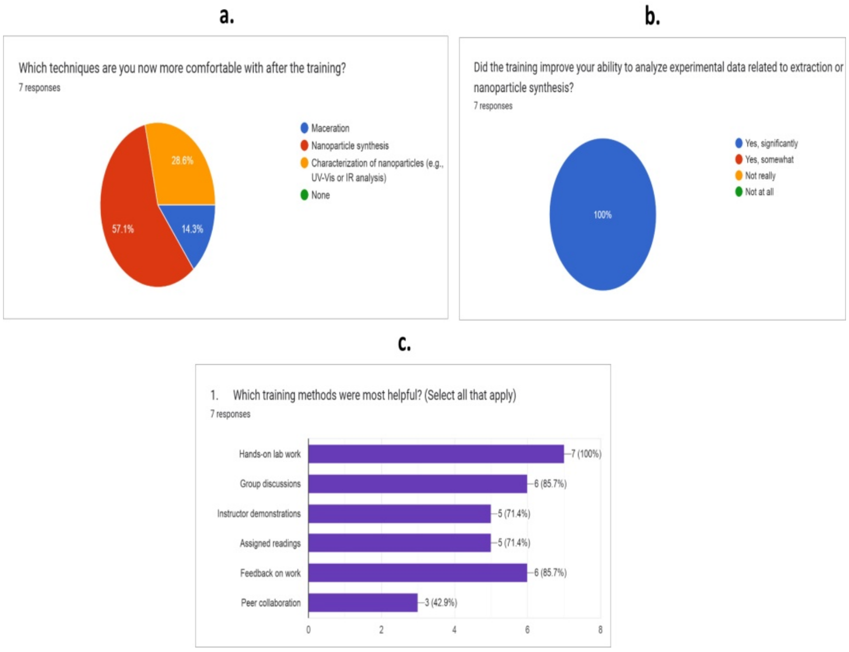


Figure 5. Participants' post-training reflections on techniques participants felt more confident using after the training, data analysis skills, and preferred learning methods

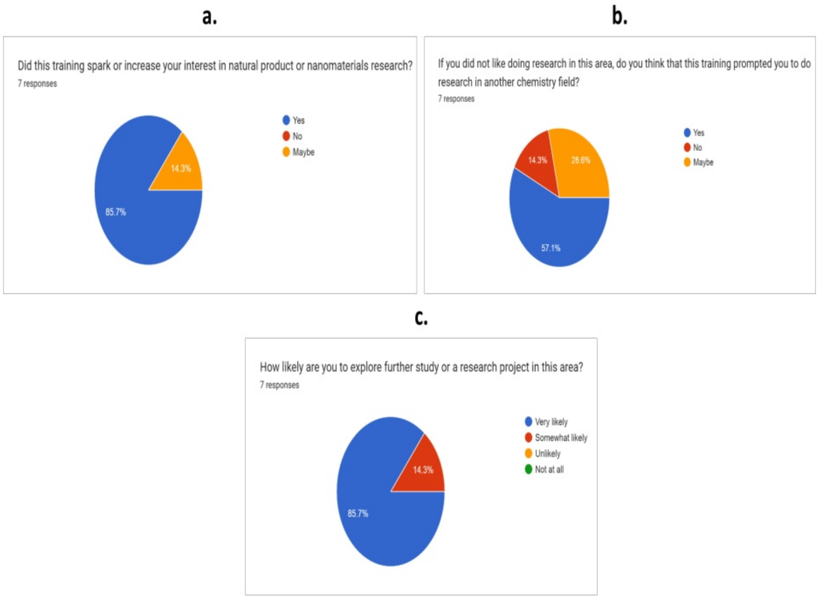


Figure 6. Participants' post-training interest in natural product and nanomaterials research, and likelihood of pursuing further research in related or alternative chemistry fields

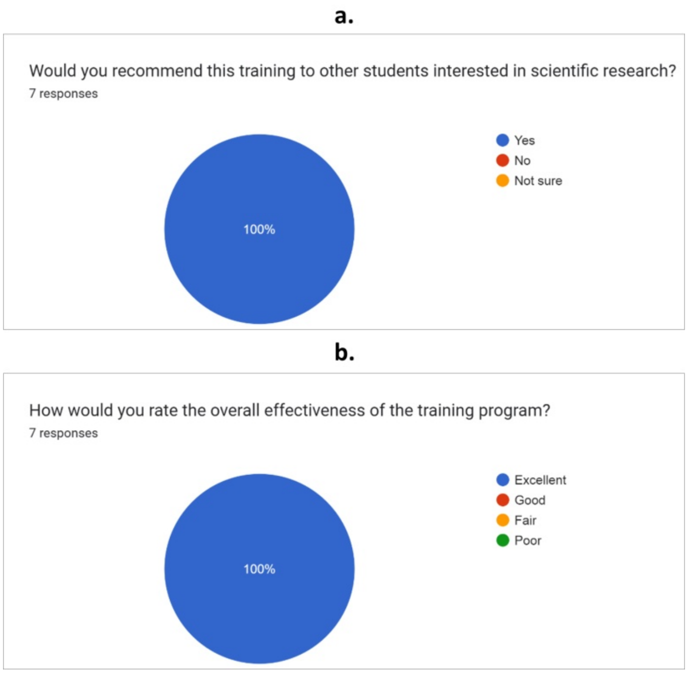


Figure 7. Participants' overall satisfaction with the effectiveness of the training program and their likelihood of recommending the program to their peers

Table 2. Students' Reflections on the Most Valuable Learning Outcomes from the Training

What was the most valuable thing you learned from this training?	7 responses This training significantly improved my ability to write a scientific paper and taught me new skills related to my subject of interest. It also provided valuable opportunities, such as experiencing my first-ever conference and winning an important research competition. I want to express my sincere gratitude for these experiences. Understanding how natural compounds can be sustainably used for nanoparticle synthesis, offering a greener, safer alternative to traditional chemical methods. How to apply the different lab techniques to get accurate results. Applying what I had learn from my study, working in the lab and understanding the work process step by step. By working from the beginning to the end of the same project. My experience with the FTIR and the UV Vis Spectrophotometer. How to read the graphs. Teamwork, research, and presenting skills.
What challenges did you face during the training, if any?	4 responses Initially, reading a scientific paper was the most challenging aspect, but with guidance from our PhD instructor and professor, we were able to overcome these obstacles.

	Nothing. None. Lab techniques are complicated to work with.
Do you have any suggestions to improve this training in the future?	4 responses None, thank you. Not at all it was very perfect, excellent training. More of these training. To participate in more conferences.

4. Conclusion and Recommendations

Research resembles an important part in modern undergraduate education. This project was designed to train senior chemistry undergraduate students to start doing independent research in the field of Phyto Nano-chemistry with the focus at synthesizing nanoparticles using plant extracts. This project ran from May to March of the UAEU academic year and was funded by the UAEU research office through the SURE plus funding program. In the beginning of the project (during June), undergraduate students were given intensive daily training on the project (literature search, reading and preparing summary on different research points) followed by starting to do further steps of the project. After each stage, thorough data analysis and interpretations were performed with the aim of training the students and validating the results in comparison with previously published research. After the condensed training period, students were asked to come to the laboratory on a once-a-week basis to finalize the remaining tasks. Students reported a great enhancement towards research after the end of the program. The program will be further pursued in the coming years involving larger number of students and other fields.

Statement of Competing Interests

There are no conflicts to declare.

ACKNOWLEDGEMENT

The graphical abstract was created with the assistance of OpenAI's ChatGPT, utilizing AI-based image generation tools to visually summarize the research workflow.

Funding

This work was financially supported by the United Arab Emirates University Research Office; Grants' Codes: G00004361, G00003977, and G00004965.

References

[1] American Chemical Society, Undergraduate Research in Chemistry, https:// www.acs.org/ education/ students/ college/research.html (accessed May 3, 2025).

[2] A. Hunter, S.L. Laursen, E. Seymour, Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development, *Sci Educ* 91 (2007) 36–74.

[3] D. Lopatto, Undergraduate Research Experiences Support Science Career Decisions and Active Learning, *CBE—Life Sciences Education* 6 (2007) 297–306.

[4] D. Kumar, P.K. Sharma, Traditional Use, Phytochemicals and Pharmacological Activity of Salvadora persica: A Review, *Curr Nutr Food Sci* 17 (2021) 302–309.

[5] H. Ashraf, B. Meer, J. Iqbal, J.S. Ali, A. Andleeb, H. Butt, M. Zia, A. Mehmood, M. Nadeem, S. Drouet, Comparative evaluation of chemically and green synthesized zinc oxide nanoparticles: their in vitro antioxidant, antimicrobial, cytotoxic and anticancer potential towards HepG2 cell line, *J Nanostructure Chem* (2022) 1–19.

[6] A.S. Borade, B.N. Kale, R. V Shete, A phytopharmacological review on Lawsonia inermis (Linn.), *Int J Pharm Life Sci* 2 (2011) 536–541.

[7] A R Western, The flora of the United Arab Emirates, United Arab Emirates University, United Arab Emirates, 1989.

[8] F.F.Y. Stéphane, B.K.J. Jules, G.E.-S. Batiha, I. Ali, L.N. Bruno, Extraction of Bioactive Compounds from Medicinal Plants and Herbs, (2021).

[9] Q. Zhan, J. Han, L. Sheng, Iron nanoparticles green-formulated by Coriandrum sativum leaf aqueous extract: investigation of its anti-liver-cancer effects, *Archives of Medical Science* (2022).

[10] S. Mourdikoudis, R.M. Pallares, N.T.K. Thanh, Characterization techniques for nanoparticles: comparison and complementarity upon studying nanoparticle properties, *Nanoscale* 10 (2018) 12871–12934.

[11] S. Gates-Rector, T. Blanton, The Powder Diffraction File: a quality materials characterization database, *Powder Diffr* 34 (2019) 352–360.

[12] S. Saboo, R. Tapadiya, S. Khadabadi, U. Deokate, In vitro antioxidant activity and total phenolic, flavonoid contents of the crude extracts of Pterospermum acerifolium wild leaves (Sterculiaceae), *J Chem Pharm Res* 2 (2010) 417–423.

[13] E.A. El-Hawary, A. Zayed, A. Laub, L. V Modolo, L. Wessjohann, M.A. Farag, How Does LC/MS Compare to UV in Coffee Authentication and Determination of Antioxidant Effects? Brazilian and Middle Eastern Coffee as Case Studies, *Antioxidants* 11 (2022) 131.

[14] E. Üstün, S.C. Önbaş, S.K. Çelik, M.Ç. Ayvaz, N. Şahin, Green synthesis of iron oxide nanoparticles by using Ficus carica leaf extract and its antioxidant activity, *Biointerface Res Appl Chem* 2021 (2022) 2108–2116.

[15] M.J. Kim, D.H. Kim, H.S. Kwak, I.-S. Yu, M.Y. Um, Protective Effect of Chrysanthemum boreale Flower Extracts against A2E-Induced Retinal Damage in ARPE-19 Cell, *Antioxidants* 11 (2022) 669.

[16] R.A. El-Fitiany, R. El Nahas, S. Al Balkhi, S. Aljaeedi, A. Alblooshi, F.M. Hassan, A. Khaleel, A. Samadi, M.A. Khasawneh, Alchemy in Nature: The Role of *Lawsonia inermis* Extract Choice in Crafting Potent Anticancer Metal Nanoparticles, ACS *Appl Mater Interfaces* 17 (2025) 4637–4661.

[17] Rana Ahmed El-Fitiany, Riham El Nahas, Seba Al Balkhi, Fathy M. Hassan, Abbas Khaleel, and Mohammad A. Khasawneh, Physicochemical study of green synthesized metal nanoparticles using Emirati Lawsonia inermis, *International Workshop On Advanced Materials* (2023). https:// drive.google.com/file/ d/ 1Y6qhw 2fCLP4BHv1cTxqWuWfOoDRFU3yD/view (accessed May 4, 2025).

[18] Rana Ahmed El-Fitiany, Ahlam Barhumi, Aisha Aldhaheri, Raya Almazrouei, Shaikha Alameri, Shama Albloushi, and Mohammad A. Khasawneh, Assessment of physicochemical and biological properties of metal nanoparticles produced via green synthesis utilizing extracts from Salvadora persica, *International Workshop On Advanced Materials* (2024). https:// drive.google.com/ file/ d/ 151Sau2V5 VfChfDs0BtmG13JSish2_oA8/view (accessed May 4, 2025).