Silver nanoparticles green synthesis: What is green and safe for science education?

Aleksi Takala, Outi Haatainen, Emmi Vuorio and Reija Pesonen

The Unit of Chemistry Teacher Education, Department of Chemistry,
Faculty of Science, University of Helsinki, Finland

Abstract: Nanoparticles are 1–100 nm in diameter and exhibit unique qualities that are different in comparison to the same elements on a larger scale. These properties make nanoparticles widely used in various industries and consumer products. However, silver nanoparticles are a cause for concern because they are biologically active and potentially toxic. In this paper, we present a safe green synthesis workshop for silver nanoparticles that aim to engage students to have discussions regarding chemistry in a safer manner based on green synthesis and green chemistry. A Likert scale questionnaire was produced and implemented, and the results (N=7) indicated positive but inconclusive results regarding interest and understanding of concepts. The revision of the workshop and the further study of the topic aims to better accomplish these tasks.

Keywords: green synthesis, chemical safety, nanochemistry, science education.

Contact: aleksi.takala@helsinki.fi

1 Background

This conference abstract presents a workshop about green synthesis of silver nanoparticles using watermelon rind extract based on a scientific publication by Ndikau, Noah, Andala, & Masika (2017) to further the authenticity of the purpose of the workshop's goals. This study aims to bring a novel way of learning nanochemistry in the context of green synthesis, and to better understand upper secondary students' attitudes towards chemical safety, green synthesis, and green chemistry with a practical introduction to silver nanoparticles and nanochemistry. The workshop was piloted in ChemistryLab Gadolin for two upper secondary student groups, and questionnaire (N=7) results are presented regarding student interest, the relevance of the learning objectives to students and understanding of the concepts.

ChemistryLab Gadolin is a versatile, active learning environment at University of Helsinki's chemistry department, and it is also part of LUMA Centre Finland. Gadolin's goal is to promote inquiry-based chemistry education, provide opportunities for hands-on work in an authentic laboratory environment, and support both students and teachers in chemistry education. ChemistryLab Gadolin also serves as a development and research environment, where new solutions, models and pedagogical innovations are produced based on research. These are closely integrated into the daily operations of Gadolin, guided by key focus areas where the main theme is sustainable chemistry and development. Research activities are conducted in extensive collaboration with chemistry researchers, teacher education, and the business sector.

1.1 Green synthesis and safety of silver nanoparticles

Green synthesis is guided by the principles of green chemistry developed by Anastas and Warner (1998). The central idea of green chemistry is thoughtful design of chemicals with minimal harm, guided by the 12 principles. These principles provide guidance for considering the entire life cycle of the product during the design process for achieving more benign and environmentally friendly outcomes (Anastas & Warner, 1998). Green chemistry is a central tool for achieving a more sustainable chemistry, while sustainable chemistry can be seen as a much wider perspective, including societal, economic, ecological, and cultural aspects (Anastas & Zimmerman, 2019).

Green chemistry approach towards synthesis is significant for the future of nanomaterials to create more safe, eco-friendly products with wide acceptance in the industry (Varma, 2012). Modern multidisciplinary research and technology in green synthesis using microbes, parasites, plants and plant extracts as reductants and stabilizing agents are also important to make green chemistry even more sustainable and are an integral part of green strategies (Gour & Jain, 2019).

Safety is paramount in nanoparticle chemistry because of the aquatic toxicity and bioaccumulation of nanoparticles (Sajid et al., 2015; Tortella et al., 2020). While toxicity can be induced at various degrees (Prabhu & Poulose, 2012), their synthesis conditions can be made safer (e.g., Banerjee, Satapathy, & Mukhopahayay, 2014; Zhang, Liu, Shen, & Gurunathan, 2016).

1.2 Science education perspective on green synthesis of silver nanoparticles

School chemistry education should promote students' competencies to become more scientifically literate, which means engaging in societal debate and questions related to the environmental impacts of chemical syntheses (Eilks & Rauch, 2012). In the designed workshop, silver nanoparticles form a colloid that exhibits a spectroscopic phenomenon called: localised surface plasmon resonance. This is a clear indication that a reaction is taking place when the colour of the liquid changes from clear to yellow or brown gradually in real time. This macroscopic and submicroscopic phenomenon is complex but could enhance the idea of the chemistry triplet, which has been linked to a better understanding of chemistry concepts and phenomena (Johnstone, 1991; Gabel, 1999). Facilitating the shifting between macroscopic level phenomenon and submicroscopic concepts with ambiguous symbolic representations and theoretical models can support the development of explanations relating the two conceptual levels (Taber, 2013). The authentic scientific publication that forms the background of this workshop (Ndikau et al., 2017) can also scaffold and support students in learning how to operate between the triplet as experts.

2 Methods

In this workshop, upper secondary students synthesise silver nanoparticles using watermelon rind extract in a similar manner as Ndikau, Noah, Andala, & Masika (2017). The workshop takes 90 min in total in addition to pre-assignments and homework. The lesson plan includes lecturing about nanochemistry and the synthesis and properties of nanoparticles, and green chemistry and synthesis in addition to a discussion about the silver nanoparticles in relation to chemical safety and green chemistry. Everything is done in a fume cupboard.

The method in this synthesis begins with the extraction of polyphenols from watermelon rind by boiling 100 g of grated watermelon rind with 400 ml of deionised water. The mixture is filtered, and 50 ml of this filtered extract and 40 ml of 0,001 M silver nitrate solution are poured into 200 ml of deionised water. The solution is made strongly basic with NaOH (pH>10) and heated to +80 Celsius for 3 minutes. This method forms spherical silver nanoparticles of roughly 20 nm in diameter. The formation of silver nanoparticles can be observed when the solution exhibits a colour change from a clear solution to yellow or brown. This is due to localized surface plasmon resonance. Silver nanoparticles are treated as inorganic waste in a solution and handled with care based on their properties and the corrosive nature of the high pH solution.

Silver nanoparticle formation and optimal green synthesis conditions are studied by UV-VIS-spectroscopy based on the method and graphs provided by Ndikau et al.'s (2017) publication. The measurements and graphs are compared to make assessments. Then discussions are held about the results, optimal synthesis conditions, spectroscopic phenomena, the use of silver nanoparticles and the comparison regarding what makes the synthesis green – which leads us to consider whether the green synthesis of silver nanoparticles is green chemistry or not. Principles regarding the twelve principles, circular economy, waste treatment, human and environmental health and the wide use of silver nanoparticles are considered in the discussion.

2.1 Investigation regarding student attitudes and interests

Two upper secondary groups, with 11 (group 1) and 12 (group 2) students, were given a questionnaire in May 2022 after their workshops. Students were given the option to respond to the questionnaire at the end of the workshop, and seven responses were collected (N=7) with the use of a 5-point Likert scale: 1 = totally disagree, 2 = somewhat disagree, 3 =neither agree nor disagree, 4 = somewhat agree, and 5 = totally agree. Standard deviation, mean, standard error and margin of error were calculated based on the 5-point scale. See Table 1 for the results.

3 Results

The following results from students (N=7) to each question or statement are presented in Table 1:

Table 1. Questionnaire results from respondents (N=7)

Question or statement	Mean	SD	SEM; margin of error
How interesting was the experiment?	3.857	±0.639	0.2415; ±0.4829;
How meaningful is the green synthesis to society?	3.7142	±1.03	0.3894; ±0.7788
The experiment helped me to understand spectroscopy.	3.857	±0.83	0.3148; ±0.6296
The experiment helped me to understand green chemistry	3.571	±0.50	0.1870; ±0.374
How interesting do you find nanochemistry to be?	4.1428	±0.83	0.3148; ±0.6296
How important is it to understand the environmental and health impacts of nanoparticles?	4.2857	±0.88	0.3328; ±0.6656
I learned new things about nanochemistry and nanomaterials.	4.000	±0.76	0.2857; ±0.5714
I learned new things about chemical safety and the environment.	3.4285	±1.18	0.4452; ±0.8904
I felt the laboratory experiment was safe regarding nanoparticles and materials. (Yes[Y]/No[N])	Y =7 N = 0	-	-

The results indicate that the students felt safe working in the laboratory. The results also indicate that students were interested in nanochemistry and viewed silver nanoparticle chemical safety important for health and the environment. However, students' understanding of green chemistry and spectroscopic analysis and phenomena varied among the participants.

4 Discussion

The large SDs are attributed to the small sample size making it hard to draw clear conclusions about the data. A revised questionnaire and a larger sample size for the workshop are future goals of this project, as well as thematic interviews on green chemistry and chemical safety. The objective is to understand better (1) What interest do students have in green synthesis of silver nanoparticles? (2) What relationship do students' characteristics have with personal interests regarding green synthesis, green chemistry and chemical safety? (3) How do students perceive green synthesis to better green chemistry and chemical safety?

These research questions can help us understand how to approach chemical safety and green synthesis as part of green chemistry and the environmental impacts of chemistry in science education. The safety in the synthesis of silver nanoparticles is high because the reaction is taking place in a fume cupboard, the investigated sample is very dilute, and the risk of exposure with proper protection is very limited. This challenges the notions about nanoparticles and chemical safety in society.

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