MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2023, 19(12), em2362
ISSN:1305-8223 (online)
OPEN ACCESS Review Article https://doi.org/10.29333/ejmste/13835

Science students' literacy and faculty members' perspective toward nanotechnology: Is it needed in 21st century education?

Ibrohim Ibrohim [1*], Irma Kartika Kusumaningrum [1], Erti Hamimi [1], Wira Eka Putra [1], Joko Utomo [1], Maisuna Kundariati [1], Maya Umi Hajar [1], Nik Ahmad Nizam Bin Nik Malek [2]

[1] Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, INDONESIA
[2] Ibnu Sina Institute for Scientific & Industrial Research, University of Technology Malaysia, Johor, MALAYSIA

Received 27 July 2023 ▪ Accepted 25 September 2023

Abstract
Nanotechnology has been applied in various fields of human life today. However, efforts to integrate nanotechnology into the curriculum in Indonesia are insufficient, including in higher education. The research was conducted to reveal the level of literacy of science students and faculty member at university level in Indonesia. The research method in this study is a cross-sectional survey design with a total of 63 science lectures and 388 students from 22 universities in Indonesia who are participated in this study. The literacy level of student and lecturer's perspective was analyzed from research instrument that consists of 16 questions test items in multiple choice forms. Descriptive statistics method used to analyze literacy level of science's students and descriptive analysis used to analyze faculty member perspective toward nanotechnology. This study found that the highest literacy level toward nanotechnology in student university level was chemistry students (43,789) and the lowest is biology students (29,579). It means that the understanding of nanotechnology, which is more directed to the field of biology is not widely studied by the student's in university level. Faculty members have perspective about nanotechnology are not integrated nanotechnology into classroom. They believed that nanotechnology is an important issue that must be directly available with curriculum system in education. This study contributes to primary research about nanotechnology implementation in education as a part of the need of 21st century.

Keywords: science students, faculty members' perspective, nanotechnology, 21st century education

INTRODUCTION

Nanotechnology-based nanomaterials have ushered in a new era of technology that will have an impact on all aspects of human life. Nanotechnology is the science and technology of small things (100 nm) with new chemical and physical structures, as well as increased reactivity and solubility (Malik et al., 2023). Nanotechnology refers to technological advances and developments in the molecular, atomic, and macromolecular fields (An et al., 2022) that can potentially play a decisive role in shaping a country's competitive advantage. Nanotechnology has some certain role in human life such as its potential applications in agriculture (Arora et al., 2022; Neme et al., 2021; Vijayalakshmi et al., 2017), medicine (Singh & Amiji, 2022), cosmetics (Fakhravar et al., 2016; Santos et al., 2019), health (Capurso et al., 2010; Huang et al., 2017; Li et al., 2021) and even treatment for cancer (Alrushaid et al., 2023). A dominant position in nanotechnology implies a significant window of opportunity for a developing country to move closer to the global technological-economic frontier. This is because such a system not only allows for the creation of first-mover advantages in new, potentially fast-growing sectors but

✉ ibrohim.fmipa@um.ac.id **(*Correspondence)** ✉ irma.kartika.fmipa@um.ac.id ✉ erti.hamimi.fmipa@um.ac.id
✉ wira.putra.fmipa@um.ac.id ✉ joko.utomo.fmipa@um.ac.id ✉ maisuna.kundariati.2203419@students.um.ac.id
✉ mayaumihajar@gmail.com ✉ iknizam@utm.my

Contribution to the literature

- This research provides an overview of science students' perceptions of nanotechnology and faculty members' responses to nanotechnology learning.
- The results of the research can be used as a consideration for the integration of nanotechnology in learning, especially science to empower nanomaterial literacy.
- Appropriate contribution suggestions form community communities that have good knowledge of nanomaterials.

also aids in the advancement of technology in a wide range of sectors (Niosi & Reid, 2007).

Furthermore, higher education has an important role to provide an understanding of technological advances including nanotechnology. The main subjects who play an important role are lecturers and students of science because nanotechnology is closely related to the field of science. Some countries have been integrating nanotechnology into their curriculum, such as in primary education in Greece (Mandrikas et al., 2020) and Taiwan (Yu & Jen, 2020), and undergraduate programs (Mutambuki, 2014; Shabani et al., 2011). The current literature on nanotechnology integration into school science curricula presented seven key categories of discussion: the origins of nanotechnology, challenges for educational implementation, currently available school activities, current consumer product applications, ethical issues, educational policy recommendations, and nanotechnology implications (Ghattas & Carver, 2012). Furthermore, the lack of studies in the literature on nanotechnologies in higher education is highlighted in the final critical discussion. The implications for future research as well as suggestions for nanotechnology curriculum development in Indonesia are considered.

Global public's perspective toward nanotechnology has been studied abroad. A study conducted by Yale law school's cultural cognition project assessing public perceptions of nanotechnology. The findings revealed that demographic and cultural factors influenced the public's perception of risk to the point, where destroying public trust was easier than gaining it, especially when leaders failed to accept responsibility for any negative externalities that may have occurred (Aluya, 2015). Another study specifically looked at the perceived risk of nanotechnology among a group of American students (n=102) enrolled in three nanotechnology-focused material science engineering courses. Students took a risk perception survey, and a subsample (n=21) was interviewed. It was discovered that perceptions of the risks and benefits of nanotechnology were closely related to specific groups of applications, such as common consumer products, health-related products, and advanced technological applications (Gardner et al., 2010). Also, study by Peikos et al. 2023) focus on students' perception of conceptualization or size in the context of nanoscale science and technology (NST) and explanation of the lotus effect (superhydrophobic). Meanwhile, science teacher's perception into nanoscale technology secondary learning have been studied by Laherto (2011). Sakhnini and Blonder (2015) also interviewing 82 expert on NST, which focuses on the necessary of nanotechnology content in secondary learning. The result is that respondents provide support for nanotechnology learning in secondary learning. Furthermore, no study reveals students' literacy toward nanotechnology nor faculty members' perspective toward nanotechnology-based instruction. And also, there is an increasing need to educate citizens and students about the risks, benefits, and social and ethical concerns associated with nanotechnology.

This papers' contribution to literature is provides an overview of science students' perceptions of nanotechnology and faculty members' responses to nanotechnology learning, the results of the research can be used as a consideration for the integration of nanotechnology in learning, especially science to empower nanomaterial literacy, and appropriate contribution suggestions form community communities that have good knowledge of nanomaterials.

METHOD

Research Design

This study adopted a cross-sectional survey design (Cresswell, 2011). This cross-sectional survey design in this research was conducted in July 2019. This study aims to determine the science student literacy and faculty member perceptions in university level regarding nanotechnology. The design was chosen based on the fact that is easier for researcher to measure and observe variable at the same time.

Participants

A total of 63 science lectures and 388 students participated in this study. Participants were taken from 22 universities around Indonesia. The lectures and students who participated in this study were asked to be willing to become research subjects, then the research design and objectives were explained. The participants from lecturers are lecturers in the Faculty of Mathematics and Natural Sciences, State University of Malang, science lecturers at various universities in Indonesia, as well as doctoral students who are currently teaching at various universities in Indonesia.

Table 1. Student respondents' demography

Criteria	Groups	n	Percentage (%)
Gender	Male	53	13.66
	Female	335	86.34
Age	17-20	191	49.23
	21-23	194	50.00
	24-27	3	0.77
Department	Biology	273	70.36
	Chemistry	74	19.07
	Physic	17	4.38
	Science	15	3.87
	Pharmacy	9	2.32

The demographic data of science students are differentiated by gender, age, and department. Most respondents are women with 86.23% with an age range of 21-23 as much as 50.00%.

A total of 70, 36 respondents came from the biology department. Demographic features of the student participants' criteria can be shown in **Table 1**.

Meanwhile, the data of lecturer respondents are differentiated based on gender, degree, and teaching experience. Most respondents were female (58.27%) and hold master's degree certificates (59.73%). Most respondents have teaching experience of more than five years (36.51%). Demographic features of the faculty member participants' criteria are shown in **Table 2**.

Instruments & Data Collection

The instrument for collecting data on the level of student knowledge of nanotechnology is multiple choice questions with five choice items. This instrument consists of 16 test items was declared valid with the reliability value of Cronbach's alpha 0.588. The lecturer's perspective data instrument on learning to build nanotechnology knowledge consists of 16 question items. This instrument is multiple choice questions, which can be answered with more than one choice. This instrument is used to determine the perspective of science lecturers in Indonesia on learning to develop nanotechnology knowledge

The research instrument was created on a Google form, the link was then shared via WhatsApp. The main reason for using this tool is because lecturers and students have familiar to use this platform in their daily activities. As an ethical consideration, faculty members also have the right not to fill out the questionnaire-filling

Table 2. Faculty member respondents' demography

Criteria	Groups	n	Percentage (%)
Gender	Male	26	41.27
	Female	37	58.73
Degree	Master	44	69.84
	Doctor	9	14.29
Teaching experience	>5	23	36.51
	5-9	15	23.81
	10-19	11	17.46
	20-30	11	17.46
	>30	3	4.76

the questionnaire that was based on faculty member volunteerism. The data that has been provided was also kept confidential and anonymous.

Thus, the selection of respondents in this study was carried out using the snowball sampling technique.

Data Analysis

The data that has been obtained is initially checked, sorted, and discarded if there are two or more identities of the same lecturers and students. In addition, participant data were also excluded if they were not science lecturers. Quantitative data regarding the level of students' knowledge of nanotechnology were analyzed using descriptive statistics, while lecturer data regarding the learning perspective to build knowledge of nanotechnology were analyzed using quantitative descriptive analysis.

Data on the level of student knowledge of nanotechnology was previously tabulated to be tested for homogeneity and normality, then a different test was performed using ANOVA. Lecturer data regarding the learning perspective on nanotechnology is presented in the form of a bar that shows the percentage of lecturer responses to learning needed to develop students' knowledge of nanotechnology.

RESULTS & DISCUSSION

Data on students' knowledge of nanotechnology was then analyzed using quantitative descriptive to determine the number of samples, mean, maximum value, and minimum value (**Table 3**). Previously, data homogeneity (0.061) was carried out, and resulted as homogeneous.

Table 3. Literacy levels of students in science major toward nanotechnology

	n	Mean	Standard deviation	Standard error	95% Confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
1=Biology	273	29.579	10.9009	.6598	28.280	30.878	6.3	68.8
2=Chemistry	74	40.146	12.6629	1.4720	37.212	43.080	6.3	62.5
3=Physics	17	31.276	11.6860	2.8343	25.268	37.285	12.5	50.0
4=Science	15	34.200	16.1683	4.1746	25.246	43.154	6.3	56.3
5=Pharmacy	9	43.789	5.3983	1.7994	39.639	47.938	31.3	50.0
Total	388	32.177	12.2354	.6212	30.956	33.398	6.3	68.8

Table 4. Summary of students' literacy levels in science major toward nanotechnology significance

	SS	df	MS	F	Sig.
Between groups	7,830.991	4	1,957.748	14.965	.000
Within groups	50,104.960	383	130.822		
Total	57,935.951	387			

Note. SS: Sum of squares & MS: Mean squares

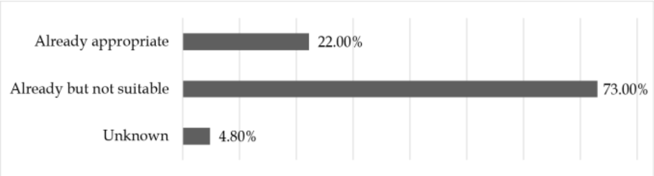

Figure 1. Have you considered the demands of 21st century life skills? (Source: Survey result)

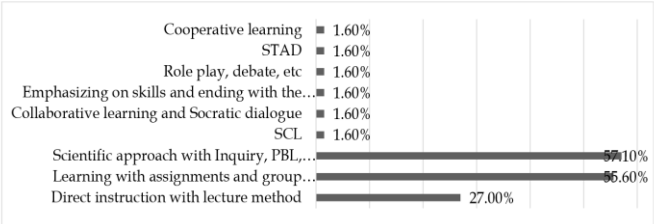

Figure 2. What approaches and learning methods are chosen to design and implement learning? (Source: Survey result)

Next, the analysis using the parametric statistical ANOVA test was performed to differentiate the knowledge levels (**Table 4**).

Faculty Members' Perspective Toward Nanotechnology

A total of 63 science lecturers from 22 universities in Indonesia were given a questionnaire to determine their knowledge of nanotechnology. The data obtained were then analyzed descriptively. The results of the study are presented, as follows.

Fulfilling demands of 21st century skills in learning & learning methods

Figure 1 shows the results for the question: "*Have you considered the demands of 21st century life skills?*"

Figure 2 shows the results for the question: "*What approaches and learning methods are chosen to design and implement learning?*"

Utilization of information & communications technologies in learning

Figure 3 shows the results for the question: "*Is the learning in the courses you are capable of integrating information & communications technologies (ICT)?*"

Figure 4 shows the results for the question: "*What is the form of integrating ICT in learning?*"

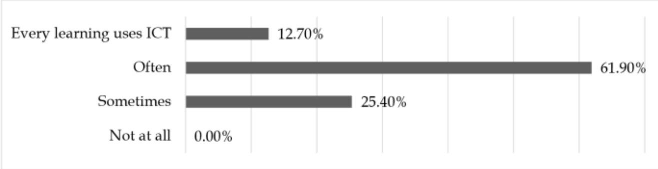

Figure 3. Is the learning in the courses you are capable of integrating ICT? (Source: Survey result)

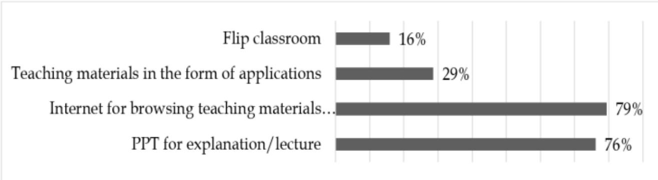

Figure 4. What is the form of integrating ICT in learning? (Source: Survey result)

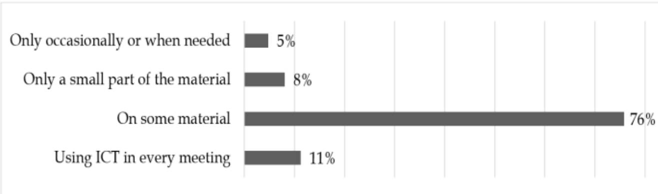

Figure 5. How often is the use of ICT applied to support the learning process? (Source: Survey result)

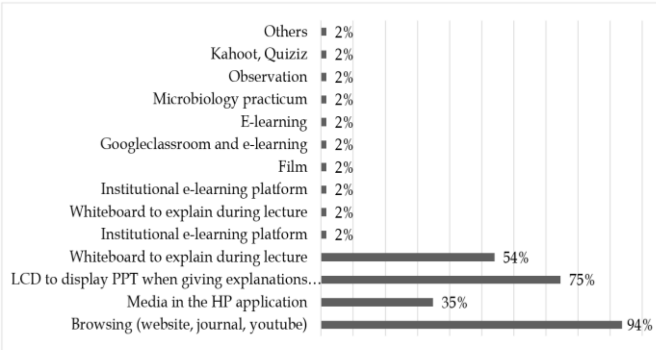

Figure 6. What kind of activities do you do in class? (Source: Survey result)

Frequency of information & communications technologies use in learning

Figure 5 shows the results for the question: "*How often is the use of ICT applied to support the learning process?*"

Figure 6 shows the results for the question: "*What kind of activities do you do in class?*"

Activities in class

Figure 7 shows the results for the question: "*Does it need to be given the material on nanotechnology in your learning*?"

Figure 8 shows the results for the question: "*Is the course that you are fostering include a subject/topic about nanotechnology?*"

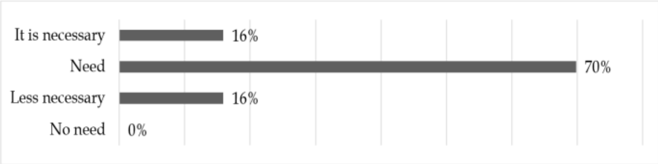

Figure 7. Does it need to be given the material on nanotechnology in your learning? (Source: Survey result)

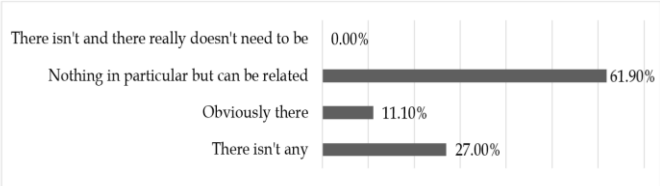

Figure 8. Is the course that you are fostering include a subject/topic about nanotechnology? (Source: Survey result)

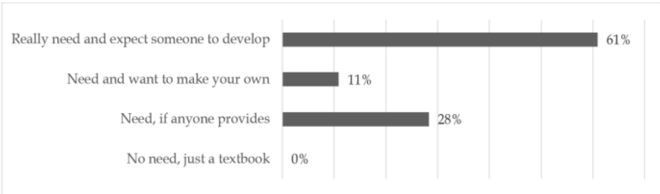

Figure 9. Do you expect that learning materials or media in the form of interactive content will be available on the mobile application? (Source: Survey result)

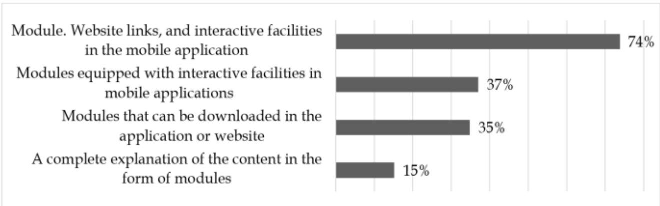

Figure 10. What form of teaching materials or media do you expect? (Source: Survey result)

Urgency of developing teaching materials on nanotechnology

Figure 9 shows the results for the question: *"Do you expect that learning materials or media in the form of interactive content will be available on the mobile application?"*

Figure 10 shows the results for the question: *"What form of teaching materials or media do you expect?"*

Figure 11 shows the results for the question: *"What are the detailed forms of nanotechnology learning media that you hope to illustrate the nanotechnology process?"*

Perspectives on nanotechnology video & animation in mobile phones

Figure 12 shows the results for the question: *"What do you think about the use of video and animation in nanotechnology learning media that are applied to mobile phones?"*

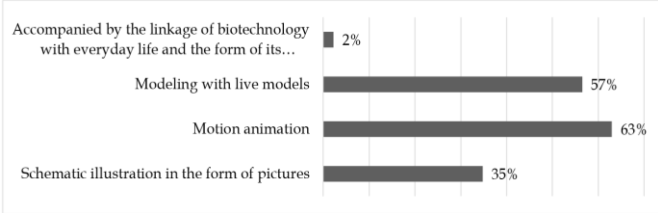

Figure 11. What are the detailed forms of nanotechnology learning media that you hope to illustrate the nanotechnology process? (Source: Survey result)

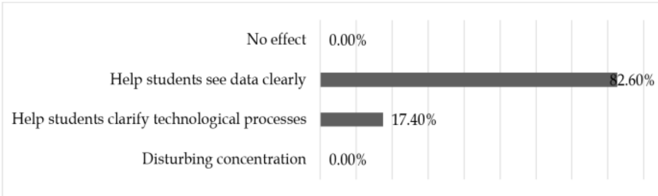

Figure 12. What do you think about the use of video and animation in nanotechnology learning media that are applied to mobile phones? (Source: Survey result)

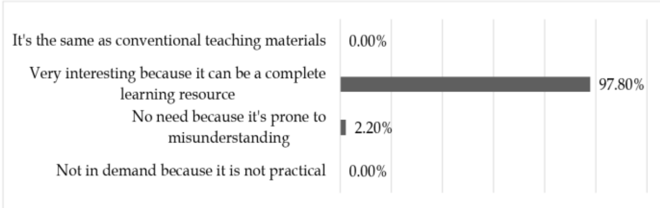

Figure 13. What do you think if there is a module equipped with access to online learning resources? (Source: Survey result)

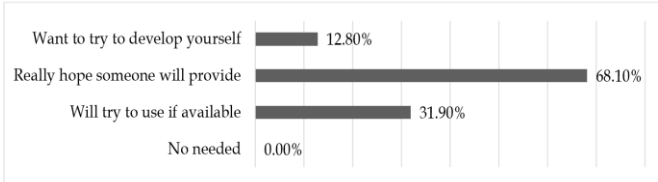

Figure 14. What is your opinion regarding the use of online nanotechnology learning materials and media that are applied to mobile phones? (Source: Survey result)

Figure 13 shows the results for the question: *"What do you think if there is a module equipped with access to online learning resources?"*

Figure 14 shows the results for the question: *"What is your opinion regarding the use of online nanotechnology learning materials and media that are applied to mobile phones?"*

Figure 15 shows the results for the question: *"If there are parties who develop nanotechnology learning materials and media in the health sector, what are your comments?"*

Figure 16 shows the results for the question: *"What are your comments regarding the costs of developing and using a mobile application in the health nanotechnology field?"*

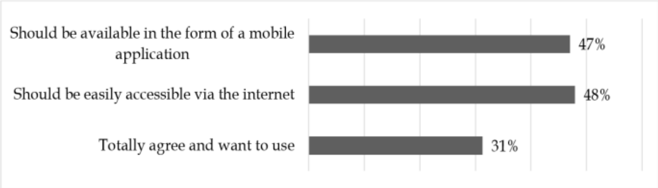

Figure 15. If there are parties who develop nanotechnology learning materials and media in the health sector, what are your comments? (Source: Survey result)

Figure 16. What are your comments regarding the costs of developing and using a mobile application in the health nanotechnology field? (Source: Survey result)

Faculty Members' Suggestions for Further Development

Accordingly, the lecturer suggested to develop mobile or computer applications containing nanotechnology that are easily accessible. The development of learning media for biological materials has been widely developed (Nurafifah et al., 2017; Widiansyah et al., 2018), and nanotechnology is one of the priorities going forward. As the pointed out,

> "Made in an easily accessible application" (faculty member 1).

Application content is also a highlight, as educators expect applications developed to be easy to understand, learn, and teach students.

> "Can represent concepts in nanotechnology in detail. Coherent explanations from easy to difficult, are arranged schematically. It's easy to access and free, or if it costs you try not to burden it" (faculty member 2).

Another educator responds that learning about nanotechnology is expected to develop 21st century skills. According to Organization for Economic Co-operation & Development (OECD), there are four main 21st century skills, namely, critical thinking and problem solving, creativity and innovation, communication, and collaboration (OECD, 2019; P21, 2015).

> "It needs to be developed so that it can help lecturers and students in lectures and can develop 21st century learning skills" (faculty member 3).

Other educators expect training related to the utilization and use of nanotechnology applications. As she/he stated,

> "In the dissemination process, training or training on how to manufacture and use it involves all stakeholders after the product is successfully made" (faculty member 4).

DISCUSSION

We separate the discussion into two sub-themes, the first is students' knowledge of nanotechnology and the second is the lecturer's view of the urgency of teaching nanotechnology materials in learning systems.

Students' Literacy Levels Toward Nanotechnology

Based on the results of data analysis, it was found that the highest level of student understanding of nanotechnology was chemistry students (43,789). Meanwhile, biology students have a low understanding (29,579). Whereas biology is closely related to nanotechnology (Reisner et al., 2014). Advances in nanotechnology in the scope of biology are the main capital for the development of nanomedicine (Wong et al., 2013), molecular biology (Jain, 2003; Mohanty et al., 2009; Santos et al., 2019), genetic engineering (Mirón-Barroso et al., 2021), DNA expression, and cellular signaling (Reisner et al., 2014). Nanotechnology provides technological tools and platforms for the investigation and transformation of biological and biological systems offering inspiring models and biologically assembled components in nanotechnology (Roco, 2003). For example, nanotechnology is used to characterize single molecules or cells and the study of the use of nanoscale pores that can be distinguished between molecules based on their size and biochemical characteristics. (Wong et al., 2013). Moreover, the advancement of nanotechnology can be seen in the rapid changing of genetic molecular research, such as CRISPR Cas-9 (Ahmar et al., 2021; Demirer et al., 2021).

Furthermore, there are arguments emphasizing the significance of students achieving nanotechnology literacy. The basic idea is that all citizens will require some level of "nano literacy" to get information and be responsible opinions on issues arising from nanotechnology advancements that affect their daily lives. For example, in a purpose to end the COVID-19 pandemic, people were asked about their decision to get vaccinated or not. A typical example was the modern mRNA vaccines that were based on nanoparticles and were developed due to the advancements in nanotechnology (Rangayasami et al., 2021), leading to public misconceptions. It is evident in public dialogue, that misunderstandings are exposed and spread quickly on social media. For example, some people claim that this vaccine can cause changes in the recipient's genome through the injected RNA (Löffler, 2021).

Additional arguments emphasize pedagogical benefits, which are linked to student interest in science. Nanotechnology is close to everyday phenomena making a great opportunity for learning more interesting and meaningful (Spyrtou et al., 2021). For example, when students go to the beach, they study sunscreens that contain nanoparticles (Nasir et al., 2014; Osmond & Mccall, 2016). Or in a laboratory context, when they study plant breeding through genetic engineering (Demirer et al., 2021). The introduction of nanotechnology applications in the classroom, combined with the underlying scientific principles, can guide students to interpret the modern technological world and can also increase their interest in science.

So far, science learning has been separated from everyday life (Kähkönen et al., 2011). Furthermore, it is important to integrate nanotechnology content into the curriculum in schools (Ghattas & Carver, 2012; Mutambuki, 2014). Education is considered to be the main way of bridging the gap between the needs of the workforce and the field of research. Moreover, as NST has attracted wide public interest and media attention, discussing these topics in schools can also contribute to science and technology literacy indirectly by motivating young people to study related disciplines in general (Laherto, 2010).

Faculty Members' Perspective Toward Nanotechnology

The main finding of this study is that educators have not integrated nanotechnology into classroom learning. This is following the finding Ipek et al. (2020), which state that nanotechnology is not yet available directly in the school curriculum system in Turkey. Nanotechnology-related issues are mentioned and asked spontaneously in class. In addition, these faculty members make a personal effort to teach topics relevant to nanotechnology as needed.

Also, respondents gave positive support for the development of nanotechnology mobile apps. Mobile learning apps containing nanotechnology materials are needed to develop students' understanding of nanotechnology. The use of mobile learning apps can improve understanding and academic achievement (Demir & Akpinar, 2018; Mergany et al., 2021; Mohammad et al., 2016). This situation is considered natural by researchers because young people are called "digital natives" (Wishart & Thomas, 2015). Quick access to information, anywhere and anytime learning, interacting with friends, and facilitating learning are observed as important key points of mobile learning (Demir & Akpinar, 2018) and make students more interested and motivated and interested in the material. The mobile learning application enhances the learning effect and enhances the learning process (Huang et al., 2014; Wishart & Thomas, 2015). Students emphasized that they wanted further mobile learning experiences such as doing homework on a mobile device, more activities on a tablet computer, and developing animation on a tablet computer. Also, nanotechnology is an abstract and invisible object of study that needs to be visualized in the form of mobile learning apps.

Although learning nanotechnology is not the main goal of education, this topic is very worrying. Learning that aims to improve the literacy skills of students in Indonesia (i.e., digital literacy, environmental literacy, and science literacy) has been wide range studied, as well as nano literacy should. Integrating nanotechnology in science curricula has been done by some countries, especially in primary, as well they are in basic education.

For example, primary faculty members trained in NST focus to make faculty members able to define the nanoscale by its size range, the landmark objects that include, the tools that render the objects visible, acknowledge that electron microscopes can be used for viewing nanoscale objects, understand that models represent properties of macroscale, microscale, and nanoscale objects; realize that models can be used to obtain information about inaccessible targets (Spyrtou et al., 2021). Meanwhile, the training conducted for secondary education educators focuses on understanding the basics of nanophotonic. The course also concluded with a presentation on nanotechnology's future visions (Laherto, 2011).

CONCLUSIONS & RECOMMENDATIONS

Nanotechnology has certain role in many sectors of human life. Therefore, nanotechnology literacy should be an important part of educational goals. This is so that people can wisely utilize and manage products that use nanomaterials. This study found that the highest literacy level toward nanotechnology in student university level was chemistry students (43,789) and the lowest is biology students (29,579). It means that the understanding of nanotechnology, which is more directed to the field of biology is not widely studied by the student's in university level. Science learning at universities does not integrate nanotechnology materials explicitly, so their understanding is still lacking. Only some science materials intersect with nanomaterials, especially chemistry programs.

Meanwhile, based on the survey to 63 faculty members shows they were concerning about nanotechnology learning. Most of them stated that they had implemented the nanotechnology learning but did not use appropriate teaching materials, therefore they expected and suggested the development of ICT-based learning media on the topic of nanotechnology. Also, efforts to develop students' understanding of nanomaterials and nano literacy should be encouraged. Therefore, an effort is needed to integrate nanotechnology into the education curriculum, especially higher education. Based on this study, educational units and educators need to develop and provide nanotechnology learning media that are effective, innovative, and able to develop students' understanding of nanotechnology and 21st century skills.

Since this study only reveals the level of nano-literacy and the perspective of faculty members toward nanotechnology, we cannot provide an overview of effective learning strategies for teaching nanotechnology. Therefore, the implementation of nanotechnology learning is still questioned. Also, we suggest that it's crucial to is the conduct of research and development of teaching materials and nanotechnology learning media that utilize ICT.

As the empirical studies suggest, ICT-based learning could improve students' motivation, effective in use, and can be assessed anywhere and every time students need it. Through this study, it is hoped that people's understanding and literacy toward nanotechnology and nanomaterials will be increase and have a good impact on human life.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: This study was supported by Universitas Negeri Malang & Universiti Teknologi Malaysia through grants Q.J130000.3009.03M46 & R.J130000.7309.4B684, respectively.

Acknowledgements: The authors would like to thank Universitas Negeri Malang & Universiti Teknologi Malaysia for matching grants & all parties who had involved in this study.

Ethical statement: The authors stated that the study was approved by the Committee of Research & Public Services Universitas Negeri Malang. Furthermore, the authors ensured that there are no conflicts of ethics during this study. Written informed consents were obtained from the participants.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Ahmar, S., Mahmood, T., Fiaz, S., Mora-Poblete, F., Shafique, M. S., Chattha, M. S., Jung, K., Schiemann, J. H., Kühn-institut, J., & Mora-poblete, F. (2021). Advantage of nanotechnology-based genome editing system and its application in crop improvement. *Frontiers in Plant Science, 12*, 663849. https://doi.org/10.3389/fpls.2021.663849

Alrushaid, N., Khan, F. A., Al-Suhaimi, E. A., & Elaissari, A. (2023). Nanotechnology in cancer diagnosis and treatment. *Pharmaceutics, 15*(3), 1025. https://doi.org/10.3390/pharmaceutics15031025

Aluya, J. (2015). Nanotechnology implications and global leadership perspectives. *Energy Sources, Part B: Economics, Planning and Policy, 10*(1), 31-37. https://doi.org/10.1080/15567249.2010.506472

An, C., Sun, C., Li, N., Huang, B., Jiang, J., Shen, Y., Wang, C., Zhao, X., Cui, B., Wang, C., Li, X., Zhan, S., Gao, F., Zeng, Z., Cui, H., & Wang, Y. (2022). Nanomaterials and nanotechnology for the delivery of agrochemicals: Strategies towards sustainable agriculture. *Journal of Nanobiotechnology 20*, 11. https://doi.org/10.1186/s12951-021-01214-7

Arora, S., Murmu, G., Mukherjee, K., Saha, S., & Maity, D. (2022). A comprehensive overview of nanotechnology in sustainable agriculture. *Journal of Biotechnology, 355*, 21-41. https://doi.org/10.1016/j.jbiotec.2022.06.007

Capurso, N. A., Look, M., Jeanbart, L., Nowyhed, H., Abraham, C., Craft, J., & Fahmy, T. M. (2010). Development of a nanoparticulate formulation of retinoic acid that suppresses Th17 cells and upregulates regulatory T cells. *Self/Nonself, 1*(4), 335-340. https://doi.org/10.4161/self.1.4.13946

Cresswell, J. W. (2011). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Pearson.

Demir, K., & Akpinar, E. (2018). The effect of mobile learning applications on students' academic achievement and attitudes toward mobile learning. *Malaysian Online Journal of Educational Technology, 6*(4), 40-52. https://doi.org/10.17220/mojet.2018.04.004

Demirer, G. S., Silva, T. N., Jackson, C. T., Thomas, J. B., W. Ehrhardt, D., Rhee, S. Y., Mortimer, J. C., & Landry, M. P. (2021). Nanotechnology to advance CRISPR–Cas genetic engineering of plants. *Nature Nanotechnology, 16*(3), 243-250. https://doi.org/10.1038/s41565-021-00854-y

Fakhravar, Z., Ebrahimnejad, P., Daraee, H., & Akbarzadeh, A. (2016). Nanoliposomes: Synthesis methods and applications in cosmetics. *Journal of Cosmetic and Laser Therapy, 18*(3), 174-181. https://doi.org/10.3109/14764172.2015.1039040

Gardner, G., Jones, G., Taylor, A., Forrester, J., & Robertson, L. (2010). Students' risk perceptions of nanotechnology applications: Implications for science education. *International Journal of Science Education, 32*(14), 1951-1969. https://doi.org/10.1080/09500690903331035

Ghattas, N. I., & Carver, J. S. (2012). Integrating nanotechnology into school education: A review of the literature. *Research in Science & Technological Education, 30*(3), 271-284. https://doi.org/10.1080/02635143.2012.732058

Huang, C., Li, N. M., Gao, P., Yang, S., Ning, Q., Huang, W., Li, Z. P., Ye, P. J., Xiang, L., He, D. X., Tan, X. W., & Yu, C. Y. (2017). In vitro and in vivo evaluation of macromolecular Prodrug GC-FUA based nanoparticle for hepatocellular carcinoma chemotherapy. *Drug Delivery, 24*(1), 459-466. https://doi.org/10.1080/10717544.2016.1264499

Huang, Y.-M., Liao, Y.-W., Huang, S.-H., & Chen, H.-C. (2014). International forum of educational technology & society jigsaw-based cooperative learning approach to improve learning outcomes for mobile situated learning. *Source: Journal of Educational Technology & Society, 17*(1), 128-140.

Ipek, Z., Atik, A. D., Tan, S., & Erkoc, F. (2020). Opinions of biology teachers about nanoscience and nanotechnology education in Turkey. *International Journal of Progressive Education, 16*(1), 205-222. https://doi.org/10.29329/ijpe.2020.228.15

Jain, K. K. (2003). Nanodiagnostics: Application of nanotechnology in molecular diagnostics. *Expert Review of Molecular Diagnostics, 3*(2), 153-161. https://doi.org/10.1586/14737159.3.2.153

Kähkönen, A., Laherto, A., & Lindell, A. (2011). Intrinsic and extrinsic barriers to teaching nanoscale science: Finnish teachers' perspectives. *Journal of Nanoeducation, 3*(1-2), 1-12. https://doi.org/10.1166/jne.2011.1017

Laherto, A. (2010). An analysis of the educational significance of nanoscience and nanotechnology in scientific and technological literacy. *Science Education International, 21*(3), 160-175.

Laherto, A. (2011). Incorporating nanoscale science and technology into secondary school curriculum: Views of nano-trained science teachers. *Nordina, 7*(2), 126-139. https://doi.org/10.5617/nordina.234

Lan, Y. L. (2012). Development of an attitude scale to assess K-12 teachers' attitudes toward nanotechnology. *International Journal of Science Education, 34*(8), 1189-1210. https://doi.org/10.1080/09500693.2011.651657

Li, A., Zhao, Y., Li, Y., Jiang, L., Gu, Y., & Liu, J. (2021). Cell-derived biomimetic nanocarriers for targeted cancer therapy: Cell membranes and extracellular vesicles. *Drug Delivery, 28*(1), 1237-1255. https://doi.org/10.1080/10717544.2021.1938757

Löffler, P. (2021). Review: Vaccine myth-buster-cleaning up with prejudices and dangerous misinformation. *Frontiers in Immunology, 12*, 663280. https://doi.org/10.3389/fimmu.2021.663280

Malik, S., Muhammad, K., & Waheed, Y. (2023). Nanotechnology: A revolution in modern industry. *Molecules, 28*(2), 661. https://doi.org/10.3390/molecules28020661

Mandrikas, A., Michailidi, E., & Stavrou, D. (2020). Teaching nanotechnology in primary education. *Research in Science & Technological Education, 38*(4), 377-395. https://doi.org/10.1080/02635143.2019.1631783

Mergany, N. N., Dafalla, A. E., & Awooda, E. (2021). Effect of mobile learning on academic achievement and attitude of Sudanese dental students: A preliminary study. *BMC Medical Education, 21*, 121. https://doi.org/10.1186/s12909-021-02509-x

Mirón-Barroso, S., Domènech, E. B., & & Trigueros, S. (2021). Nanotechnology-based strategies to overcome current barriers in gene delivery. *International Journal of Molecular Sciences, 22*(16), 8537. https://doi.org/10.3390/ijms22168537

Mohammad, H., Fuad, A., & Hourani, M. (2016). Using mobile technologies for enhancing student academic experience: University of Jordan case study. *International Journal of Interactive Mobile Technologies, 10*(1), 13-18. https://doi.org/10.3991/ijim.v10i1.4809

Mohanty, C., Arya, G., Verma, R. S., & Sahoo, S. K. (2009). Nanobiotechnology: Application of nanotechnology in therapeutics and diagnosis. *International Journal of Green Nanotechnology: Biomedicine, 1*(1), B24-B38. https://doi.org/10.1080/19430850902908522

Mutambuki, J. M. (2014). *Integrating nanotechnology into the undergraduate chemistry curriculum: The impact on students' affective domain* [PhD thesis, Western Michigan University].

Nasir, A., Wang, S., & Friedman, A. (2014). The emerging role of nanotechnology in sunscreens: An update. *Expert Review of Dermatology, 9872*, 3-6. https://doi.org/10.1586/edm.11.49

Neme, K., Nafady, A., Uddin, S., & Tola, Y. B. (2021). Application of nanotechnology in agriculture, postharvest loss reduction and food processing: Food security implication and challenges. *Heliyon, 7*(12), e08539. https://doi.org/10.1016/j.heliyon.2021.e08539

Niosi, J., & Reid, S. E. (2007). Biotechnology and nanotechnology: Science-based enabling technologies as windows of opportunity for LDCs? *World Development, 35*(3), 426-438. https://doi.org/10.1016/j.worlddev.2006.11.004

Nurafifah, A., Budi, A. S., & Siahaan, B. Z. (2017). Developing wave encyclopedia based on scientific approach. *Journal of Physics: Conference Series, 895*, 012018. https://doi.org/10.1088/1742-6596/895/1/012018

OECD. (2019). *PISA 2018 assessment and analytical framework*. OECD Publishing.

Osmond, M. J., & Mccall, M. J. (2016). Zinc oxide nanoparticles in modern sunscreens: An analysis of potential exposure and hazard. *Nanotoxicology, 4*(1), 15-41. https://doi.org/10.3109/17435390903502028

P21. (2015). P21 framework definitions. *P21*. http://www.p21.org/our-work/p21-framework

Peikos, G., Spyrtou, A., Pnevmatikos, D., & Papadopoulou, P. (2023). Nanoscale science and technology education: Primary school students' preconceptions of the lotus effect and the concept of size. *Research in Science & Technological Education, 41*(1), 89-106. https://doi.org/10.1080/02635143.2020.1841149

Rangayasami, A., Kannan, K., Murugesan, S., Radhika, D., Kumar, K., Raghava, K., & Raghu, A. V. (2021). Influence of nanotechnology to combat against COVID-19 for global health emergency: A review. *Sensors International, 2*, 100079. https://doi.org/10.1016/j.sintl.2020.100079

Reisner, D. E., Brauer, S., Zheng, W., Vulpe, C., Bawa, R., Alvelo, J., & Gericke, M. (2014). Bionanotechnology. In *Nanotechnology: Concepts, methodologies, tools, and applications* (pp. 31-86). IGI Global. https://doi.org/10.4018/978-1-4666-5125-8.ch003

Roco, M. C. (2003). Nanotechnology: Convergence with modern biology and medicine. *Current Opinion in Biotechnology, 14*(3), 337-346. https://doi.org/10.1016/S0958-1669(03)00068-5

Sakhnini, S., & Blonder, R. (2015). Essential concepts of nanoscale science and technology for high school students based on a Delphi study by the expert community. *International Journal of Science Education, 37*(11), 1699-1738. https://doi.org/10.1080/09500693.2015.1035687

Santos, A. C., Morais, F., Simões, A., Pereira, I., Sequeira, J. A. D., Pereira-Silva, M., Veiga, F., & Ribeiro, A. (2019). Nanotechnology for the development of new cosmetic formulations. *Expert Opinion on Drug Delivery, 16*(4), 313-330. https://doi.org/10.1080/17425247.2019.1585426

Shabani, R., Massi, L., Zhai, L., Seal, S., & Cho, H. J. (2011). Classroom modules for nanotechnology undergraduate education: Development, implementation and evaluation. *European Journal of Engineering Education, 36*(2), 199-210. https://doi.org/10.1080/03043797.2011.573536

Singh, A., & Amiji, M. M. (2022). Application of nanotechnology in medical diagnosis and imaging. *Current Opinion in Biotechnology, 74*, 241-246. https://doi.org/10.1016/j.copbio.2021.12.011

Spyrtou, A., Manou, L., & Peikos, G. (2021). Educational significance of nanoscience-nanotechnology: Primary school teachers' and students' voices after a training program. *Education Sciences, 11*(11), 724. https://doi.org/10.3390/educsci11110724

Vijayalakshmi, S., Sachin, C., & Kirtan, T. (2017). Nanotechnology: A growing need for agriculture and food sectors. *Integrated Ferroelectrics, 185*(1), 73-81. https://doi.org/10.1080/10584587.2017.1370341

Widiansyah, A. T., Indriwati, S. E., Munzil, M., & Fauzi, A. (2018). I-invertebrata as an android-based learning media for molluscs, arthropods, and echinoderms identification and its influence on students' motivation. *Jurnal Pendidikan Biologi Indonesia* [*Indonesian Journal of Biology Education*], *4*(1), 43. https://doi.org/10.22219/jpbi.v4i1.5476

Wishart, J., & Thomas, M. (2015). Introducing e-research in educational contexts, digital methods and issues arising. *International Journal of Research and Method in Education, 38*(3), 223-229. https://doi.org/10.1080/1743727X.2015.1036852

Wong, I. Y., Bhatia, S. N., & Toner, M. (2013). Nanotechnology: Emerging tools for biology and medicine. *Genes and Development, 27*(22), 2397-2408. https://doi.org/10.1101/gad.226837.113

Yu, H. P., & Jen, E. (2020). Integrating nanotechnology in the science curriculum for elementary high-ability students in Taiwan: Evidenced-based lessons. *Roeper Review, 42*(1), 38-48. https://doi.org/10.1080/02783193.2019.1690078

https://www.ejmste.com