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REVIEW PAPER

Socio-ethical Education in Nanotechnology Engineering Programmes: A Case Study in Malaysia

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Abstract The unique properties of nanotechnology have made nanotechnology education and its related subjects increasingly important not only for students but for mankind at large. This particular technology brings educators to work together to prepare and produce competent engineers and scientists for this field. One of the key challenges in nanotechnology engineering is to produce graduate students who are not only competent in technical knowledge but possess the necessary attitude and awareness toward the social and ethical issues related to nanotechnology. In this paper, a research model has been developed to assess Malaysian nanotechnology engineering students' attitudes and whether their perspectives have attained the necesary objectives of ethical education throughout their programme of study. The findings from this investigation show that socio ethical education has a strong influence on the students' knowledge, skills and attitudes pertaining to socio ethical issues related to nanotechnology.

Keywords Socio ethical education · Nanotechnology engineering · Students' attitudes · Engineering ethics

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Introduction

Nanotechnology is the study, design, creation, synthesis, manipulation and application of functional materials, devices and systems through the control of matter at a nanometer scale, which is at the atomic and molecular level. It is also the exploitation of novel phenomena and properties of matter at that scale. Nanotechnology offers a new paradigm of groundbreaking material advancement by controlling and manipulating the basic building blocks of matter at the nano scale (Uddin and Chowdhury 2001). The development of this area can be utilized to solve some of the world's most serious development issues. Nanotechnology is a fully inter-disciplinary sector that manipulates systems at the atomic and molecular levels to design and create new materials, nano-machines and nano-devices that are useful in our daily lives.

It is estimated that around 6 million nanotech workers will be needed by the year 2020. Currently, there are only about 400,000 such workers globally (IZON 2011). The United States, Europe and Japan are among the first few spearheading the initiative to embark on research and development (R&D) activities in nanotechnology. Other developing countries such as Malaysia have not been left behind in the exploration of this new technology. In 2005, the Malaysian government started an initiative focusing on nanotechnology, and hundreds of millions of dollars were allocated to develop this new sector in Malaysia (Hashim et al. 2009).

The rapid growth in nanotechnology has changed traditional practices in design, analysis and manufacturing for a wide range of engineering products and systems. This new technology encompasses multidisciplinary aspects, such as chemistry, biology, physics, engineering, manufacturing, medicine, agriculture and other disciplines. Since the nano-scale touches the very foundations of nature, socio-ethical issues need to be considered at the beginning stages of nanotechnology education. Students need to be aware of and sensitive to the benefits and risks of nanotechnology to mankind and the environment. As future engineers and scientists in this field, students need to be trained to be responsible in predicting and answering the implications of this new technological development for mankind from ethical standpoints. According to Weil (2003), students should be able to identify the issues that have already happened or are going to happen, in terms of nanotechnology consequences. At the same time, this will help to solve many socio-ethical problems stemming from nanotechnology development before they ripen into bigger problems. It is very important for students to have sufficient knowledge of how the advances in nano-science and nanotechnology might influence or affect the global environment, economics and human lives (Sweeney et al. 2003; Nikulainen and Palmberg 2010). Berne and Schummer (2005) also suggest that careful ethical consideration must be made to look into the potential benefits and risks of nanotechnology development to society and the environment.

As nanotechnology development begins to fulfill the promise of bringing benefits to society without causing any harm to mankind and the environment (Weil 2003), some efforts are necessary to instill good socio-ethical values in nanotechnology education. This is because the advances in nanotechnology will be derailed if the study of the ethical, environment and social implications of nanotechnology does not keep pace with the progress of science (Sweeney et al. 2003).

Education plays a vital role in associating socio-ethical knowledge with scientific and technological advances. It is the responsibility of every university to ensure that nanotechnology engineering programmes do not neglect socio-ethical educational aspects that are specific to the nano-science and nanotechnology areas. This is where students must be taught to be sensitive to these issues and become ethical and responsible engineers in society. Olmstead and Bassett (2009) stated that nanotechnology engineering students require exposure to the societal and ethical implications of nanotechnology development.

Since engineering education is as broad as other areas of study, the engineering education curricula should contribute to the preparation of graduates who are socially and ethically responsible in their decision-making and conduct. According to the Accreditation Board for Engineering and Technology USA (ABET) (2007) and the Engineering Accreditation Council Malaysia (2007), this would require students to be educated in professional and ethical responsibility as well as the impact of engineering solutions in a global and social context. On the other hand, though, Conlon in Zandvoort (2008) argued that there is concern that engineering education focuses overly on employability rather than producing graduates who are adequately prepared for social responsibility. Zandvoort (2008) was also concerned about the knowledge and attitudes being transferred to these future engineers for them to make decisions and act in an ethically and socially responsible way. Therefore, it is important for us to assess the extent to which universities are incorporating socio-ethical knowledge into their nanotechnology engineering curricula in preparing students to meet the engineering accreditation criteria, which are focused on ethics and social responsibility.

Thus, in this paper, we investigate nanotechnology engineering students' perspectives on attaining the objectives of socio-ethical instruction in engineering education as well as their attitudes towards socio-ethical issues related to their field of study—i.e., nanotechnology—in Malaysia. The investigation of socio-ethical issues amongst nanotechnology engineering students is not a well-researched area outside the US and EU regions. Findings from this study could provide insight and serve as a cornerstone for the enhancement of engineering ethics education in engineering programmes to produce responsible and ethical engineers in the future.

Socio Ethical Issues in Nanotechnology

The essence of nanotechnology is the ability to work at the atomic, molecular and super-molecular levels in order to create, manipulate and use materials, devices and systems with fundamentally new properties and functions because the properties of structures are expressed at a small scale (Roco 2002). Since the development of nanotechnology is occurring very rapidly, the education system that produces the experts—engineers and scientists—in this field should also move forward at such a pace as to keep abreast with this development. Berne and Schummer (2005, 459) stated that "the emerging fields of nano science and nano engineering are leading to unprecedented understanding and control over the fundamental building blocks of all physical things. This is likely to change the way that almost everything—from

vaccines to computers to automobiles and objects which have not yet been imagined—is designed and made." At the same time, Roco (2002) suggested that there must be a continuous effort to educate future engineers, scientists and the general public regarding the ongoing developments in nanoscience and nanotechnology.

Before developing an application, one must focus on the types and magnitude of risks that the development of the application could cause to the society at large. Public perceptions of the applications are very important because public perceptions and attitude towards scientific and technological creations have helped shape the direction and pace of R&D activities in numerous fields, especially in nanotechnology (Roco and Bainbridge 2005). Schuurbiers et al. (2009, 197) cited that "several nanoethicists have recently indentified the need for better ethics of emerging technologies, arguing that ethical reflection should become part and parcel of research and development process itself." Moreover, any current technology is the product of a complex interplay between its designer and the larger society in which it is developed (Sweeney et al. 2003). Nanotechnology applications revolutionize and solve the problems of human beings in this world. Some applications of nanotechnology that benefit mankind are as follows (Buentello et al. 2005):

1. Energy storage, production and conversion
2. Agriculture productivity enhancement
3. Water treatment and remediation
4. Disease diagnosis and screening
5. Drug delivery system
6. Food processing and storage
7. Air pollution and remediation
8. Construction
9. Health monitoring
10. Vector and pest detection and control

The key question here is: "How are these new technologies expected to affect all aspects of human experience?" Therefore, in many countries, massive funding has been allotted to studying the short-term, intermediate and long-term risks of nanotechnology applications to mankind and the environment (Steven et al. 2006). The outcomes of the studies showed that several advancements in nanotechnology might cause harm to society. Therefore, sufficient knowledge of the implications of nanotechnology advancement to society should be instilled amongst engineers to ensure continued public safety.

The implications of nanotechnology are now among the most important topics discussed by policymakers around the world because the development of nanotechnology causes many changes in human lives, some of which have raised public concerns. Berne and Schummer (2005, 460) stated "the unknown and potential substantial harms and benefits and the risks and opportunities it represents to social life warrants immediate and careful ethical reflection." Vanderburg, in Sweeney et al. (2003), proposed that a preventive approach to technological advancement must be developed that involves a meticulous investigation of how the latest and emerging technologies influence human lives and the environment.

One point that differentiates nanotechnology-related ethical issues from other areas of engineering ethics is that most of the nanotechnology applications are still at the developmental stage. Some are very new, and we do not know how and where these applications and developments will affect human beings and the environment. Zandvoort (2008) stated that engineers have a collective responsibility to improve the lives of people around the world and should thus contribute toward the building of a more sustainable, stable and equitable world. Interestingly, this statement reflects the importance of engineers to the world. Future nanotechnology engineers have the ethical responsibility to ensure that the development of this field will not cause harm. Thus, students need to be exposed to and taught about nanotechnology engineering ethics at the same time. They need to be taught about sustainability development wherein social, environment and economics restructuring occur concurrently with technological restructuring.

Integration of Nanotechnology Ethics in Engineering Education

Engineering has always had a massive impact on human health and welfare (Barakat and Jiao 2011). Ethics has become an important aspect of the engineering profession's ability to guard the safety of humankind. Ethics is also necessary for the survival and continuity of the engineering profession itself because ethics leads engineers to make rational and socially responsible decisions in designing engineering products. Education on ethics and social responsibility is important in making sure that future engineers will act responsibly, where the welfare of humankind and the safety of the environment should be considered in every decision-making process and in their innovations as well.

Heikkero, in Zandvoort (2008), defines "socially responsible engineers" as those who strive for values that are in harmony with public welfare, safety and health; however, one of the main problems nowadays is the lack of importance given to socio-ethical education in engineering faculties. Pimple (2002) reported that instruction areas that touch on the social responsibility of engineers to society at large receive much less attention or are completely ignored; similarly, Rugarcia et al. (2000) stated that engineers often make decisions without feeling a need to take into consideration any social and ethical consequences, owing to the failure of the engineering education system to integrate technical and socio-ethical knowledge in engineering curricula. Therefore, engineering education must teach not only technical skills but also the concept of socio-ethical issues, through which it can build a strong awareness among students about the importance of becoming ethically responsible engineers who are technically proficient and capable of solving both social and environmental problems in ethical ways.

In the context of socio-ethical issues in nanotechnology engineering, since nanotechnology is still in its infancy and the applications of nanotechnology have just started to penetrate our daily lives, it is hard to apply the standard methods of technological assessment. It is difficult to consider issues relating to socio-ethical aspects that need to be taught in the classrooms. Faculty should equip nanotechnology

engineering students with sufficient socio-ethical knowledge and awareness of the nanotechnology to prepare them to be responsible engineers in future.

Efforts have been taken to teach engineering ethics in nanotechnology engineering programmes by using various methods. Berne and Schummer (2005) introduced science fiction stories in engineering ethics classrooms to provide nanotechnology engineering students with the ethical skills and cultural knowledge required for responsible decision-making. Hoover et al. (2009) designed a new interdisciplinary course that integrates nanotechnology and its socio-ethical implications, to improve the students' understanding of social ethical issues. As such, following the Malaysian Engineering Accreditation Engineering Council regulations, all engineering faculties that offer engineering programmes should include at least one engineering socio-ethics subject in every engineering programme regardless of the discipline involved. This socio-ethics subject should cover the societal implications, ethical considerations and economic impacts of the engineering profession as well as both the national and international contexts.

Research Model and Research Issues

The conceptual model of this research is shown in Fig. 1, which describes the variable relationships postulated in this study. This model has been developed to study the knowledge, skills and attitudes attained in ethical instruction in engineering education in order to equip future nanotechnology engineers with the capability to make decision ethically and act in ethical and socially responsible ways.

The model investigates the relationship between nanotechnology engineering students' perspective in attaining the objectives of socio-ethical instruction in engineering education and their attitude towards socio-ethical issues related to the students' major—i.e., nanotechnology.

Harris et al. as reported in Newberry (2004), thoroughly delineate the possible objectives for ethical instruction in engineering education. These objectives cover aspects of emotional engagement, intellectual engagement and particular knowledge. Emotional engagement deals with developing the students' desires, affective levels and ability to resolve of ethical issues. Intellectual engagement enhances students' understanding of socio-ethical issues. The third aspect concentrates on developing the students' knowledge about ethical codes, principles and cases of ethical standards. The objectives are well aligned with ABET and Malaysian Engineering Accreditation Council's ethical education objectives for engineering programmes including nanotechnology engineering programme.

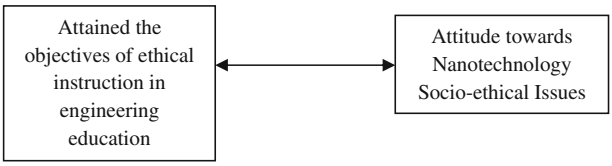

Fig. 1 Research model

The objectives are as follows:

1. Stimulate the ethical imagination of students
2. Help students recognize ethical issues
3. Help students analyze key ethical concepts and principles
4. Help students deal with ambiguity
5. Encourage students to take ethics seriously
6. Increase student sensitivity to ethical issues
7. Increase student knowledge of relevant standards
8. Improve ethical judgment
9. Increase ethical will power

In Malaysia, engineering programmes have only one subject where the ethical issues, principles and concepts are the focus. It covers only the surface level of the abovementioned nine possible objectives for ethical education. In Malaysia, generally speaking, no strong emphasis is placed on embedding socio-ethical issues into technical subjects; instead, socio-ethical education and technical education are regarded as two different entities.

Attitude is an important element driving students to recognize the importance of particular knowledge and skills. Lathem et al. (2011) pointed out that while the engineering educators concentrate more on the importance of engineering knowledge and skills in undergraduate education, students' attitudes have also been shown to be equally important because it is proved that attitude influences how an engineer's knowledge and skills can be directed. It shows that socio-ethical knowledge and having a good attitude towards it are very crucial to producing socially responsible and ethical engineers. Thus, it is vital to assess students' attitude towards socio-ethical issues related to nanotechnology in order to get a better picture of how engineering ethics education could prepare students for dealing with socio-ethic issues related to their field (Vanasupa et al. 2006; Hayden et al. 2010).

It is important to study the relationship between these two aspects because attitudes towards nanotechnology socio-ethical issues among the students are developed in the process of learning throughout their studies in undergraduate engineering education (Lathem et al. 2011); also, it is vital to explore the interrelationship between those aspects to indentify the fundamental problems of socio-ethical instruction in order to realize the full potential of improved socio-ethical instruction (Newberry 2004).

Extrapolating from the findings, we tested a few research issues in this study. These issues are as follows:

(a) Nanotechnology engineering students' perspectives on attaining the nine possible objectives of socio-ethical instruction in engineering education;
(b) Nanotechnology engineering students' attitudes towards socio-ethical issues of nanotechnology; and
(c) The relationship between nanotechnology engineering students' achievements and the attaining of the possible objectives of socio-ethical instruction in engineering education and their attitudes towards socio-ethical issues of nanotechnology.

Methodology

In this study, we focused on the students' attitude and beliefs on socio-ethical issues of engineering generally, and on nanotechnology specifically, rather than the content of the subject related socio-ethical education.

The evaluation was administered to 30 nanotechnology engineering final-year students from Multimedia University (MMU), Malaysia. All participants were in their final semesters before graduation. The respondents also went through a compulsory engineering ethics subject—Engineers in Society—which covers socio-ethical issues, environment impacts and economic implications of the engineering profession. The objective of the subject is to expose students to the history of science and technology, issues of the impact of technology on economical development and environment, issues of engineering in the Malaysian context, the engineering profession, the code of ethics, and professionalism. The teachers for this subject are engineering graduates who have limited knowledge and experience of socio-ethical issues, principles and concepts—not experts in socio-ethics education.

The students were surveyed via a questionnaire containing statements related to the research issues being investigated. In the questionnaire, a 5-point Likert-type scale (5 for Strongly Agree and 1 for Strongly Disagree) was used to rank the level of agreement and disagreement with the statements (See Appendix; Parts 1 and 2).

For the first research issue, the statements measure the participants' perception as to attaining the nine objectives of ethical instruction in engineering education, which was proposed in Newberry (2004). The first part of the questionnaire was not just limited to students' perception of the engineering ethics subject taught in the classroom—Engineers in Society—but also covered the overall programme of study such that the outcome of this study could indicate the university's effort in incorporating socio-ethical knowledge in their nanotechnology engineering curricula overall, unrestricted to the engineering ethics subject.

For the second research issue, the statements were designed to assess students' attitudes towards socio-ethical issues in nanotechnology, which was adopted from Lathem et al.'s (2011) study, and the statements were modified here according to this study's needs. The third research issue was to evaluate the connection between socio-ethical knowledge attained by the students in their engineering programme and their attitude towards the socio-ethical issues in nanotechnology such that the outcome of this study could reflect the effectiveness of nanotechnology engineering programmes in preparing students to be ethically and socially responsible engineers in the future.

A total of 15 students were selected by stratified random sampling for interviews to get their point of view on the engineering ethics education and their opinions on their roles and responsibilities as future nanotechnology engineers; the students' interviews were used to support and ascertain the findings of the research issues of this study (See Appendix; Part 3).

Results and Discussion

The data was analyzed using the Statistical Package for Social Science (SPSS). The reliability value for the collected data was (Cronbach's Alpha) $\alpha = 0.817$ for the first part—students' perspective on attaining the nine objectives of ethical instruction in engineering education—while for the second part, assessing students' attitude towards nanotechnology socio-ethical issues, the reliability value α was 0.725. Both Cronbach's alpha values indicate that the data collected for this study is reliable and acceptable. The data collected was normally distributed; therefore, we carried out a parametric test for research issue (c).

The first research issue discussed students' perception on attaining the objectives of ethical instruction in engineering education, which focused on the overall programme of study. In Table 1, mean values for statements A1–A9 range from 2.31 to 3.04 with the standard deviation ranging from 0.152 to 0.397 where the values had low mean rank scores for statements A1–A9 in the questionnaire part (a). This indicated that ethical education in nanotechnology engineering programme in the university brings low awareness and engagement levels among the students although all the respondents went through the ethics subject offered in the nanotechnology engineering programme. As such, this is clearly not sufficient to enable students to meet the objectives of ethical instruction at a satisfactory level. From the interviews, the majority of interviewees said that they had taken Engineers in Society without realizing the importance of socio-ethical issues in the engineering profession; at the same time, there was a lack of socio-ethical-related activities conducted throughout their programme of study. The students also commented on the lack of expertise amongst lecturers in teaching engineering ethics especially pertaining to socio-ethical issues in the nanotechnology field. This indicates that the faculty/university should give greater attention to the learning outcomes and teaching methodologies in order to achieve the engineering accreditation criteria focusing on ethics and social responsibility. At the same time, students should be instilled with sufficient knowledge, attitudes and skills related to socio-ethics. More socio-ethical activities related to the students' field of study need to be offered, such as service learning which could develop and improve the students' sense of social responsibility.

For the second research issue, we assessed students' attitudes towards socio-ethical issues related to nanotechnology. Table 2 shows mean values ranging from 2.06 to 3.07 with a standard deviation from 0.187 to 0.358. The mean rank scores indicated that the respondents had low mean scores in response to statement B1 through B8 in the questionnaire part (b). Statement B8 had the lowest mean score of 2.06 in part (b) of the questionnaire; this mean score pointed out that awareness and knowledge about sustainability development in nanotechnology engineering has not been well emphasized in the engineering curriculum of the university investigated. Sustainable development is a critical element and should be considered an essential element in engineering subjects for the advancement and enhancement of the quality of life. In interviews, students raised concerns about the integration of socio-ethical issues in technical subjects, which is currently not in practice in the programme. Therefore, a topic/chapter on socio-ethical implications and possible

Table 1 Mean and standard deviation (SD) for each statement for research issue (a)

PART 1

Please indicate on a scale of 1 to 5: (1—strongly disagree, 2—disagree, 3—neutral, 4—agree, 5—strongly disagree);

Your perspective on attaining the ethical instruction objectives below in your programme of study; *From my point of view, my programme of study was able to…*

Items	Mean	SD
A1: Stimulate the ethical imagination	2.69	0.355
A2: Help me to recognize ethical issues	2.31	0.265
A3: Help me to analyze key ethical concepts and principles	2.48	0.152
A4: Help me to deal with ambiguity	2.50	0.369
A5: Encourage me to take ethics seriously	2.78	0.198
A6: Increase my sensitivity to ethical issues	2.68	0.254
A7: Increase my knowledge of relevant standards	3.04	0.335
A8: Improve my ethical judgment	2.67	0.214
A9: Increase my ethical will power	2.98	0.397

Table 2 Mean and standard deviation (SD) for each statement for the research issue (b)

PART 2

(1—strongly disagree, 2—disagree, 3—neutral, 4—agree, 5—strongly disagree)

Statement	Mean	SD
B1: I am confident to solve nanotechnology engineering problems ethically	2.87	0.358
B2: I am aware of the role of nanotechnology engineers in today's society	3.07	0.187
B3: I am aware of the impact of nanotechnology engineering on economic issues	2.34	0.256
B4: I am aware of the impact of nanotechnology engineering on the environment	2.73	0.352
B5: I am aware of the impact of nanotechnology engineering on humankind	3.05	0.285
B6: I believe in the importance of ethics in every decision making process	2.68	0.339
B7: I believe in the importance of being sensitive to the public's views in nanotechnology engineering design/projects	2.68	0.335
B8: I believe in the importance of sustainability issues in nanotechnology engineering design/projects	2.06	0.305

risks to humankind from the scientific/technological development of the subject matter should be included in technical subjects in order to produce future engineers who are socially, economically and environmentally aware of their roles and responsibilities as engineers. Such students would also be able to anticipate any risks to humankind before they occur due to nanotechnology advancements.

On the final research issue, Table 3 shows that the respondents' perception on attaining the objectives of ethical instruction has a strong (statistically significant) correlation with students' attitude towards socio-ethical issues related to nanotechnology where the Person co-efficient values are more than 0.730 ($p < 0.05$, two-tailed). This outcome indicates that engineering ethical education has a strong and positive impact on students' attitudes toward socio-ethical issues related to

Table 3 Pearson correlation values for research issues (a) and (b)

Statement	B1	B2	B3	B4	B5	B6	B7	B8
A1	0.817	0.752	0.740	0.812	0.785	0.852	0.753	0.768
A2	0.814	0.825	0.816	0.835	0.764	0.869	0.867	0.755
A3	0.822	0.832	0.834	0.764	0.832	0.907	0.887	0.801
A4	0.805	0.765	0.879	0.749	0.815	0.854	0.794	0.834
A5	0.836	0.852	0.899	0.751	0.825	0.896	0.758	0.753
A6	0.798	0.867	0.865	0.759	0.877	0.835	0.769	0.779
A7	0.809	0.768	0.752	0.763	0.897	0.842	0.760	0.811
A8	0.828	0.779	0.749	0.809	0.859	0.874	0.736	0.809
A9	0.877	0.815	0.767	0.811	0.867	0.839	0.816	0.824

$p < 0.05$ for all values

nanotechnology. In interviews, most interviewees commented on the lack of engineering ethics knowledge and exposure to socio-ethical issues related to their field of study. It is vital to equip students with sufficient socio-ethical knowledge and the necessary skills to understand the impact of engineering solutions from a global and societal context.

The overall analysis of the collected data and interview findings showed that socio-ethical education has a strong influence on the students' view and knowledge of socio-ethical issues. Respondents were unaware of the importance of the role of responsible engineers to society and the environment due to the lack of emphasis placed on socio-ethical education in their engineering curricula. The students were also unable to identify the societal impacts, economic impacts and ethical considerations of nanotechnology. As such, some strategies and methods are needed to improve engineering socio-ethical education.

Improving Socio-ethical Education in Nanotechnology Engineering Programmes

The main objective of socio-ethical education in engineering programmes is to transfer knowledge, skills and attitudes to students so that future engineers will be sufficiently prepared to make decisions and act in an ethical and socially responsible way. In the study, we found that the socio-ethical education in the nanotechnology engineering programmes was not effective enough to achieve its objectives. As such, the primary concern now is how socio-ethical education should be taught in classrooms more effectively.

The following is a list of strategies that could be considered when teaching socio-ethical concerns in nanotechnology engineering programmes:

1. Socio ethical topics should be integrated into nanotechnology engineering subjects where ethical considerations and societal impacts related to the subject matter will be included in the subject. This is crucial because, from the findings of this study, students have raised concerns about the integration of socio-

ethical issues in engineering subjects, which is currently not in practice. In this way, the socio-ethical issues related to the field can be addressed effectively amongst the students (Barakat and Jiao 2010). Students educated in this way also become capable of anticipating possible short- and long-term risks that could affect society due to developments. At the same time, the students have sufficient knowledge and skills to face such situations and are able to make the right decisions to overcome the problems.

2. Participation by professionals who are engaged in the nanotechnology industry to educate or share their knowledge and experiences with the students on socio-ethical issues is very important because they can provide expertise in the discussion of professional standards and socio-ethical values since the lecturers who are currently teaching have limited knowledge and experience in the subject matter. Practicing engineers can share information on how they confront socio-ethical issues in their daily working situations and how they would resolve ethical dilemmas in their profession as guest lecturers. Olmstead and Bassett (2009) have cited that the use of guest lecturers has distinct advantages for lecturers who teach the subject and the students both. Thus, it could help the students to deal with socio-ethical issues in the future.
3. Interactive discussion amongst educators and students on specific cases related to nanotechnology engineering is one effective ways to convey socio-ethical knowledge. Graber and Pionke (2006) found that interactive discussion can improve critical thinking skills among the students. Engineering educators can design engineering problems and discuss ways to solve such problems ethically and in a socially responsible manner, which could help students to gain knowledge and decision-making skills in areas such as material selection and resource preservation, which can be used in actual applications for sustainable development.
4. Activities that could develop students' sense of responsibility, such as service learning, should be introduced where the students can fulfill their duty as citizens and also as engineers in the nanotechnology field. Lathem et al. (2011) stated that service learning positively influences students' attitude and understanding of the roles and responsibilities of engineers in global society. Activities focusing on community service will help students to build an attitude towards the engineer's role and responsibilities to humankind and the environment.

Conclusion

Responses to the student survey showed that the attainment of the objectives of ethical instruction among the students is low and not sufficient to raise awareness among the students about their roles and responsibilities as engineers who can make decisions ethically. The findings of this study also showed that the students' attitudes towards socio-ethical issues related to nanotechnology are low due to less emphasis being placed by faculty on the socio-ethical issues related to nanotechnology in the undergraduate engineering programme. We have noticed from students' responses that the nanotechnology engineering programme's emphasis

was less on the sustainable development issues where the faculty members need to incorporate modules that focus on sustainability in technical subjects related to nanotechnology. From the findings of this investigation, it can be said that socio-ethical education has a strong influence on students' knowledge, skills and attitudes regarding socio-ethical issues related to nanotechnology; however, students in this study were found to be unaware of the engineer's role and responsibilities to society at large. This is due to socio-ethical education that is not effective enough in building the students' knowledge, skills and attitudes regarding socio ethics.

Some strategies and methods for teaching socio-ethical education are proposed in order to produce competent and holistic engineers who are capable of handling both technical and societal issues diligently. It is worthwhile for every university to look into the implementation of socio-ethical education in the current nanotechnology engineering education setup as well as the assessment of students' attitudes towards socio-ethical issues. Failure to focus on this aspect can delay or even prevent the benefits of nanotechnology development from being reaped for the sake of the national economy, societal wellbeing, and environmental sustainability.

Appendix

PART 1

Please indicate on a scale of 1–5: (1—strongly disagree, 2—disagree, 3—neutral, 4—agree, 5—strongly disagree);

Your perspective on attaining the ethical instruction objectives below in your programme of study; *From my point of view, my programme of study was able to…*

Statement:

A1: Stimulate the ethical imagination

A2: Help me to recognize ethical issues

A3: Help me to analyze key ethical concepts and principles

A4: Help me to deal with ambiguity

A5: Encourage me to take ethics seriously

A6: Increase my sensitivity to ethical issues

A7: Increase my knowledge of relevant standards

A8: Improve my ethical judgment

A9: Increase my ethical will power

PART 2

Please indicate on a scale of 1 to 5: (1—strongly disagree, 2—disagree, 3—neutral, 4—agree, 5—strongly disagree);

Your perspective on attaining the ethical instruction objectives below in your programme of study; *From my point of view, my programme of study was able to…*

Statement

B1: I am confident to solve nanotechnology engineering problems ethically.

B2: I am aware of the role of nanotechnology engineers in today's society.

Appendix continued

B3: I am aware of the impact of nanotechnology engineering on economic issues.

B4: I am aware of the impact of nanotechnology engineering on the environment.

B5: I am aware of the impact of nanotechnology engineering on humankind.

B6: I in believe the importance of ethics in every decision making process.

B7: I believe in the importance of being sensitive to the public's views in nanotechnology engineering design/projects.

B8: I believe in the importance of sustainability issues in nanotechnology engineering design/projects,

PART 3: Interview

Questions:

Q1: How do you feel about the socio-ethical education in your engineering programme?

Q2: Please give any comments you have about socio-ethical instruction in your class.

Q3: What you think about your roles and responsibilities as a nanotechnology engineer?

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