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Nanotechnology Education and Workforce Development through Higher Education: The Case of Malaysia

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Abstract: *This research aims to examine the main drivers of university nanotechnology programs in producing knowledge workers for the nanotechnology related job market. Three key drivers, namely multidisciplinary and complexity, hands-on training and transferability knowledge are determined in order to elicit experts' views on nanotechnology education. Ten in-depth interview sessions were conducted with middle- or high-level field experts from the various fields of nanoscience. The findings show that students stringing from an assortment of science disciplines will have an opportunity of surviving nanotechnology as the progression will be at full tilt; however, it would be challenging for management and business-oriented people to apprehend and cherish the impact of this technology. The balance between capstone experience and classroom teaching, as well as the aspects of malleability and transferability knowledge such as management and entrepreneurial skills are also important elements of university nanotechnology education. This paper ends with several key policy implications.*

Keywords: Knowledge Workers, Capstone Experience

1. Introduction

This qualitative research aims to examine drivers that lead to the transition of knowledge workers from university to job vista and issues pertaining to university nanotechnology education. While previous nanotechnology education works provide insights into the standards and curricula, pedagogy, teachers' attitudes in schools (such as Sakhnini and Blonder, 2015; Lan, 2012; Jones et al., 2013); and given that university and K-12 education are different in nature, this research extends the realm of these studies to cover university nanotechnology education. Although several studies have examined university nanotechnology education, such studies were mainly focusing on bibliometric analysis in characterizing the profile of nanotechnology research (such as Walsh and Ridge, 2012; Miyazaki and Islam, 2007), this research enrich the literature by explaining the reasoning behind those characteristics and its' implications to university nanotechnology programs. Meanwhile, numerous works have acknowledged the nature of nanotechnology as complex multiple scientific disciplines (such as Battard, 2012; Bhat, 2005) and difficulties in nanotechnology commercialization (such as Hosseini and Esmaeeli, 2010; Juanola-Feliu et al., 2012). However, studies on how nanotechnology education can be structured in order to address such issues are still limited and remains largely theoretical (Jones et al., 2013).

Malaysia has been an active constituent of the Asia Nano Forum (ANF) since May 2004. The National Nanotechnology Initiative (NNI) made its debut in the year 2006. Malaysia's NNI can be viewed upon as an avowal of the government's undertaking pledge to not only protract but to sustain nanotechnology development for an elongated period of time alongside other developing countries, until the outgrowths of its efforts can be fully embraced and relished for the betterment of the nation. The functions of NNI include, among others, coordination and planning of the research and development (R&D) and commercialization activities, develop educational resources and skilled labour, as well as provide facilities and research support services. In order to speed up the progress of home-grown nanotechnology, the National Nanotechnology Directorate (NND) was established under the Ministry of Science, Technology and Innovation (MOSTI) in 2010. In general, public universities and public research institutes are primarily carrying out nanotechnology research in Malaysia.

According to Hamdan (2014), human capital is the most crucial component to the success of nanotechnology for Malaysia. There are about 450 scientists directly involved in nanotechnology R&D. The nation required a proactive approach to encourage public universities to offer more undergraduate and postgraduate degree programmes in the various areas of nanoscience and nanotechnology. These programmes should be able to develop interdisciplinary perspective to students in order to enhance their disciplinary skills in nanotechnology. The issue of limited human capital in nanotechnology development was also highlighted by Uda et al. (2008). This was mainly due to the continued fragmentation of efforts in R&D and clustering, and linking the resources and knowledge of the local researches, industry and government in the country. In addition, Balakrishnan et al. (2013) evidenced that one of the key challenges in nanotechnology engineering, Malaysia 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. Indeed, socio-ethical education and technical education are regarded as two different entities in nanotechnology engineering programs. This resulted in the mismatch between the university graduates and workforce requirements in nanotechnology related job markets.

Base on the case context of a developing country - Malaysia, this research attempts to answer the following fundamental questions: How university nanotechnology education can be constructed to fulfil the workforce requirements? Findings from this research provides educators and policymakers with a broad strategy direction toward achieving a pool of skilled and educated workforce in order to congregate the projected demand in the future nanotechnology development. The central idea for this research is that in order to intensify science education research, assessments of innovation of nanotechnology from non-sciences perspective such as social sciences and humanities – that could enrich our understanding of existing and future nanotechnology trends – should be incorporated. Such approach, i.e. the integration of social-technical paradigm in university educations provides suggestions for improvement to nanotechnology education in general, as well as the context specifically of Malaysia.

2. Nature of University's Nanotechnology Education

With regard to university programs, even if it is not a nanotechnology specific course, Uddin and Chowdhury (2001) have recommended educators to introduce the concept of nanotechnology during the freshman and sophomore engineering courses and to continue throughout the subsequent engineering science curriculum. Adding to this proposition, Roco (2002) suggests emphasizing interdisciplinary internships in graduate programs, whereas Meyyappan (2004) proposes that these nanotechnology internships should select highly skilled high school and undergraduate students as a way for these programs to attract young students in order to stay interested in science and engineering and to pursue a career in research. The point made by Meyyappan (2004) is definitely convincing.

However, necessary advanced skills in this intensively science-based area can only be realistically developed through concentrated multidisciplinary undergraduate and postgraduate courses. Stephen et al., (2007) in their study conclude that the job market for those with skills in nanotechnology still remains small; where the largest part of the growth is centered at universities and government labs. Hullmann (2006) argues that many of these jobs will be created in small and medium firms but not exclusively. The lack of highly skilled staff would be a main difficulty for firms and start-ups in nanotechnology.

Fonash (2001) argues that the nano workforce should have an expansive understanding of principles ranging from biology, physics, chemistry and engineering; all of which combined provides the basic concepts of nanofabrication and that of which leads to an understanding of nanotechnology. It is in this context that the author prescribes a need of a ‘unified approach’ to understanding and using science and engineering. It is a field that is at a crossroads of many disciplines (Battard, 2012). Vogel & Campbell (2002) points out that education in the past has revolutionized by first laying an underpinning groundwork and then gradually building pyramids of knowledge step by step and has resulted in a highly specialized workforce. This approach has augmented departmentalization in academia; whereby each field has imprinted its unique way of thinking while allowing it to evolve its own unique languages and acronyms. The author further draws attention to the fact that an education system focusing on solitary disciplines will not provide sufficient training to graduate students. Corbett, et al., (2000) proclaims that nanotechnology can be developed realistically through intensive, multidisciplinary postgraduate courses. However, this extends to whether or not it will do good if students were to pursue a too broad an education and end up knowing little about many fields, but not enough in any one field to make a significant contribution.

Hosseini & Esmaeeli (2010) has pointed out the importance of education in commercialization process of nanotechnology. Training in the field of nanotechnology, making use of academic opportunities, studying the existing conditions and training in line with achieving ideal conditions and holding educational workshops are of great significance and can be effective in accelerating the commercialization of nanotechnology. Lo et al., (2012) predicts that nanotechnology may generate new manufacturing and service models that will necessitate forward thinking by enabling disruptive innovation into the edifice of appropriate skills and knowledge that can maximize the opportunities offered by the nanotechnology commercialization activities. However, considering that, there is neither a shorter path towards producing knowledgeable human capital required for the commercialization of nanotechnology; observantly, an emphasis has to be made here that hands on training could be acquired in a shorter time span compared to traditional classroom learning, which requires years of study. Nevertheless, whether or not the “capstone experience” can be effective single-handedly, given the fact that we need a solid number of nanotechnology workforces, is somewhat questionable and need to be examined further.

Palmberg (2008) identifies that the lack of business skills amongst university researchers are among the challenges that inhibit the active interaction between university researchers and private sector companies. The findings of Nikulainen & Palmberg (2010) revealed that one could not unearth a significant effect of university-industry interaction on the involvement of researchers in nanotechnology. However, their findings and the findings of Palmberg (2008) did disclose that in the field of nanotechnology, the most imperative and yet frequent modes of interactive interdependency between industries (firms) - universities (researchers) takes place in public R&D programs, conferences/seminars and bilateral R&D projects. However, Juanola-Feliu, E. et al., (2012) highlights that today, universities seek to cultivate "interactions and spill overs" in an attempt to bond research with "application and commercialization"; thus, the processes of the formation, attainment, dissemination and consumption of knowledge are at the nucleus of the university's functions. Therefore, when it comes to this new field of nanotechnology, the question arises as to how transferable are their skills and how quickly can they learn how to drive these new business models and whether or not, more universities professors should become affiliated with these companies that conduct nanotechnology R&D to ensure strategic partnerships to be successful.

3. Methodology of Research

Framework and Scope of the Research

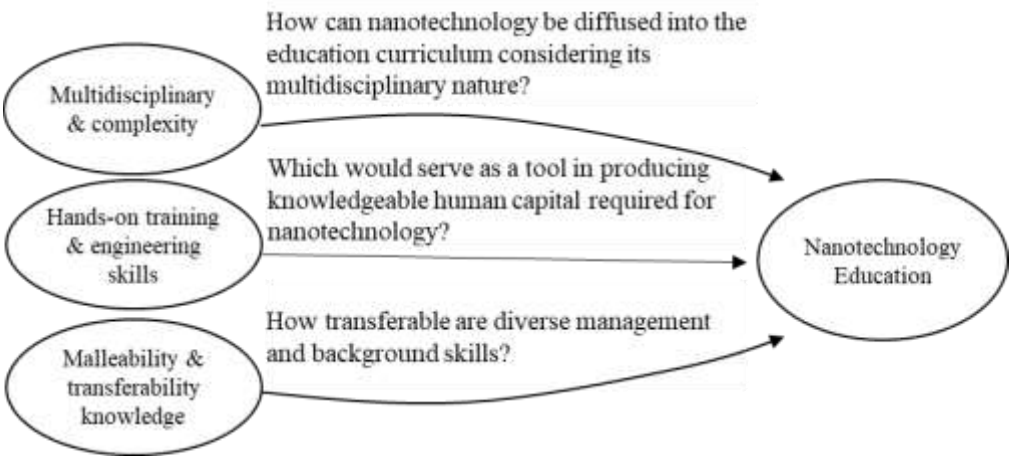

Figure 1: Research framework

Figure 1 presents the research framework and the broad exploratory questions employed in this paper. It draws upon the three specific drivers of nanotechnology education synthesized from the abovementioned literatures, namely (a) Multidisciplinary and complexity that address the fundamental yet comprehensive arrays of engineering and science education; (b) Hands-on training and engineering skills that address traditional classroom learning and "capstone experience"; and (c) Malleability and transferability knowledge base that address nature of transferability of skills and learning to drive new business models. Nevertheless, this research does not touch upon the elements of environmental, legal, ethical and precautionary principles of nanotechnology; for which these elements branches out from a new study known as nano-ethics. Table 1 lists the specific exploratory questions used during the interviews.

Table 1: Key specific exploratory questions

Drivers	Key specific exploratory questions
Multidisciplinary and complexity	• What good will it do when students pursue a too broad an education and end up knowing little about many fields, but not enough in any one field to make a significant contribution? • Are comprehensive learners mostly required as opposed to non-comprehensive learners? • What approach can be taken in the delivery of nanotechnology and how it should be addressed within the tertiaries of university education? • What are the problems/challenges that would lead to the difficulties in constructing a standalone nanotechnology program?

Hands-on training and engineering skills	• Which would serve as a quicker tool in producing human capital required for nanotechnology? • In the field of nanotechnology, which requires high levels of training: the technical worker or the knowledge worker? • What about the expertise of using microscopes and the expertise of maintaining microscopes, which are widely used in the field of nanotechnology?
Malleability and transferability knowledge base	• How transferable are other diverse management and background skills and how quickly can they learn how to drive these new business models? • In the area of nanotechnology management: Which is more crucial? Is it the understanding of technology expertise or the impact of technology towards its target consumer market? • Would be a matter of great importance to incorporate the management of technology into the nanotechnology curriculum?

Instrument, Procedures and the Researchers' Role

Purposive sampling was employed due to its flexibility in terms of selecting interviewees according to the broad exploratory questions. This purposive data sampling technique was determined based on theoretical saturation. The selection of the interviewees was determined based on the following criterion: area of specialization, position held in the organization to demonstrate the authority of given information, consisting the fine blend of both industry and academia or purely from academia, and the level of active participation in the area of nanotechnology.

Ten middle-level or high-level personnel who consisted of professors, researchers and directors from universities, research institutes, ministries and industry in Malaysia were interview. Ten face-to-face interviews were conducted in which one of the interviewees has been visited twice. Table 2 provides the coding system of interviewees used in this study. The interviewees had expertise from various fields of sciences such as nano-materials, nano-advanced materials, micro-engineering, nano-electronics, catalysis, nanotechnology and combinatorial chemistry, mechanical engineering and nano-structured materials. Four of the interviewees were chosen for their fine blend of both industry and academia put together; whereas six of the interviewees were purely from academia. This combination of interviewees provides a good representative to address the main exploratory questions posted in this paper. The interviewees were contacted via email explaining to him or her the purpose of the research. They were interviewed one to one separately at his or her own affiliated premises. The time taken for each interview averaged between 70 and 90 minutes.

This qualitative method was conducted using an “open ended” approach whereby the questions were not worded in exactly the same way with each of the interviewees. The interviewees were open to respond in their own words that which paved way to a more complex and multifarious form of responses that went beyond than a mere “yes” or “no” type of fixed responses. They were given opportunities to give their convoluted and detailed views on the subject in question. The researchers had the opportunity to respond and probe immediately to what the interviewees had to say by constructing subsequent questions to information the interviewees had provided. Interview questions were never given to the interviewees in advance in which the interviews were conducted using an *impromptu* technique in order to evoke spontaneous and unanticipated results rather than rehearsed responses.

Table 2: Alphabetical code representation of interviewees

Interview No.	Respondent's code	AREA
1	AA	A/I
2	AB	A
3	AC	A/I
4	AD	A
5	AE	A
6	AQ	A
7	AG	A/I
8	AX	A
9	AI	A/I
10	AU	A

Legend for Area: A = academia; A/I = academia & industry

Data Analysis

Considerable amount of time was taken to transcribe the recordings of each of the interviewees in order to capture the essence of their insights in their own words. Interim analysis (ongoing and iterative) was carried out until the subject matter had been greatly understood and sufficient data had been gathered to provide evidence to satisfy the research questions. Investigator triangulation approach was used to check the conclusions from one data source to another and to unearth the complexity and of finding different views. The contradictions and differences within the data collected went through further analysis and investigation until a clear cumulative effect of the findings could be established.

To put it succinctly, the approach used to perform triangulation for this research was distinctively carried out during the interview process and not at the end of data anthology. For instance, important aspects of findings from Interviewee [AA] needed to be posed again, through the same and different level of questioning to Interviewee [AB], in order to increase data precision. This was not only increased the level of confidence in the findings for this research along the way, but also displayed consistent data flow towards attaining the right answers to the research questions. The process continued through the development of different lines of questioning (same question subject but in a different angle) from one interviewee to another based on finding aspects that required additional authentication.

4. Results of Research

Multidisciplinary and Complexity

The interviewees were asked "*How would students address something as wide and comprehensive as nanotechnology in university*?" and "*Will the lack of proficiency in other scientific discipline hampers the study of nanotechnology in university?"* The main concern is whether students will end up knowing little about many fields when they pursue a broad education. The interviewees shared the similar concern here.

AA: In schools, students are already exposed to science subjects. However, when these students enter university, for instance, a student enters into the Department of Physics to study Physics; and clearly, the student can't enter all three departments such as Biology, Chemistry, and Physics simultaneously which would be downright unmanageable and impossible.

AB: If person A [in university] were to know the subject of Chemistry and lack the proficiency in the subject of Physics, whereas person B were to know the subject of Physics and lack the proficiency of electronic engineering, there will be a void. Hence, in the effort to expunge the existence of this void, balancing will need to conquest.

The complexity nature of nanotechnology that demands for a hybrid expertise of workforce was highlighted:

AG: If a student were to learn the subject of Chemistry for example, let’s say in the first three years of secondary education, they learn that if they add a certain chemical particle, the colour will change from white to blue to green. The first level is through observation and later they connect that observation to a simple deduction. The same thing is repetitive in the fourth year of secondary education whereby the students begin to look into the complexity of the chemical particle or substance. For instance, when copper is neighbouring with sulphate, it will give a certain colour. If copper is neighbouring with nitrate, it will give a different colour. Therefore, this is “complexation chemistry”.

The interviewee provided a detail account on how university nanotechnology education could be different from school.

AG: If a student was to go to university, the same topic is repeated but a different approach toward learning nanotechnology is absorbed. This time they will look from the perspective of quantum and hybridization…This means that the smooth progression from one education level to the next leads to the deeper reasoning of what nanotechnology really is.

The science-based individuals need to communicate with the engineering-based individuals. For instance, in the design of the semiconductor light source – which is the Light Emitting Diode (LED):

AG*:* If a researcher were to understand the liking of the optical but do not understand the physical, he or she will not be able to engineer the device. In the case of designing a LED for example, a student will want to know how and why ‘light’ is achievable, and for that, he or she needs to study quantum mechanics. Then, the student may have to go into Physics and study the behaviour of electrons. Later, they need to venture into Chemistry and study the bonding behaviours, which take a lot of understanding of various sciences.

Training and Skills: Hands-on and Scientific Training

The interview sessions attempt to determine “*Which would a serve as a quicker tool in producing knowledgeable human capital required for nanotechnology?”* This is based on general perception that hands on training can be acquired in a shorter time span compared to traditional classroom learning which requires years of study. In addition, this research seeks to examine “*Can the capstone experience be effective single-handedly given the fact that we need a solid number of nanotechnology workforce?*”

AB: Experience cannot simply replace classroom learning and this is true not only for the field of nanotechnology. Hands on training minus knowledge accumulated from traditional classroom learning will take the field of nanotechnology nowhere.

An academician suggests that those who wish to take their research to greater heights; they will require a deeper knowledge about assorted aspects of nanotechnology. Only if they meet these conditions, they would be able to execute hands-on or else they will replicate, duplicate and reiterate what other people have previously done, or else the phenomena will produce a whole line of technical workers rather than knowledge workers. This finding has been established from the facet of microscope utilization.

AE: If it's a simple optical (light) microscope; for example, an introductory biological compound microscope - then any student from elementary school will be proficient enough to use it. Thus, when it comes to the field of nanotechnology, one will require the use of electron microscopes such as Scanning Electron Microscopes (SEM) and Transmission Electron Microscopes (TEM). For the use of SEM, it will require the basic background because you need to apply and interpret the results whereby a bachelor's degree will do.

For the use of TEM however, a researcher will require higher levels of training to interpret the results generated from it. In this context, a Master's degree will be preferred. This finding clearly declares that postgraduate training and experience is paramount for the use of the TEM.

AQ: However, one cannot produce a person who has just learnt the use of a TEM from school to be an expert in TEM microscopy, because to understand the use of a TEM, a student needs in depth knowledge of Chemistry, Physics, Electronics and Mathematics. Therefore, it is improbable to produce a student who just finished school learning - to use microscopes.

The interviews also seek to examine the requirement for the element of engineering and scientific skills in nanotechnology education. We framed our questions to stimulate discussions on "*What about the expertise of using microscopes and the expertise of maintaining microscopes, which are widely used in the field of nanotechnology?*" because microscopy skill for data interpretation is important. Although microscopy skill does not really require a specific knowledge in nanotechnology, in certain cases, it would be a best option to have a PhD holder instead - a scientist who is an expert in the use of microscopes. Among the physicists and biologists, although they use the same microscopes but the preparation techniques are seemed different. For materials, they will require an electron microscope that is of high specification. On the other hand, for biologists, they will not need a high specification microscope. They will need a lower end microscope.

AC: Ideally, they should come from the Physics background. The good thing about physicist is that they understand the knickknacks of the principles of microscopes. That is why, it would even be better if one has a PhD in the field of microscopy.

AG: This means to say that, for medical scientist or biologists for example, the sample preparation is very different compared to the materials scientists, physicists or engineers. For samples that are inorganic, which are utilised mainly in physics, chemistry, mechanical engineering – these areas of sciences will carry out different techniques.

Malleability and Transferability Knowledge

When it comes to human capital in nanotechnology, it is crucial to know that "*How transferable are their skills and how quickly can they learn how to drive these new business models?*" We examine this area of nanotechnology management by asking, *"Would be a matter of great importance to incorporate the management of technology into the nanotechnology curriculum?"*

AX: Many fall through to cognise that nanotechnology is dissimilar from other technologies. In the field of nanotechnology, the technicality of the subject matter grows into a central issue since the market is not fully mature and above all, the awareness has not fully reached its "saturation point". The top management and the boardroom must fully apprehend what this technology is all about.

If the electronically inclined people were engaged and positioned, it could help provide valuable substance towards the product of focus if it is electronics related. At that juncture, they will be capable of interfacing between the different electronically driven products as to whether it is nano embedded or not.

AE: They will be able to articulate. Another aspect that needs scrutiny is the amount of appreciation a person needs to have towards the product in focus. As long as the individual is adept in identifying and valuing the product in focus, they will be able to sell. One does not need to understand the technology expertise.

However, what the individual needs to understand is the impact of the technology towards its target consumer market. Appreciation, in this context, refers to the full understanding of the impact of nanotechnology.

AQ: If companies were to bring an intellect from the university who is proficient in the area of Physics and Chemistry, but who has never been exposed to the area of nanotechnology – the progression will still be swift. Nevertheless, if that person is not a scientist and if the company were to bring them into the organisation to work on nano, then, they will not be capable of producing valuable results. Like a relay, they need to walk one-step more, and another step more. There will be a degree of overlapping, whereby some can cross, and some cannot cross.

The other extreme will be when the technologist, may own the knowledge and competency of nanotechnology, but they may lack the realization of market penetration, since nanotechnologists also need to be realistic in terms of its future financial impact to the firm. Technologists need to recognize and understand that the market willingness must be there. Therefore, this is viewed as a challenge to technologists who must thrive to understand the industry mind-set.

AC: For instance, if the firm wants to go for market minus, same quality or better quality but same price; or to make something better with the same cost or to make the same product but at a lower cost in order for both public and industry to benefit, then the onus lies on the research community.

Base on the main findings presented above, Figure 2 illustrates the main elements and its' main contents of university nanotechnology educations.

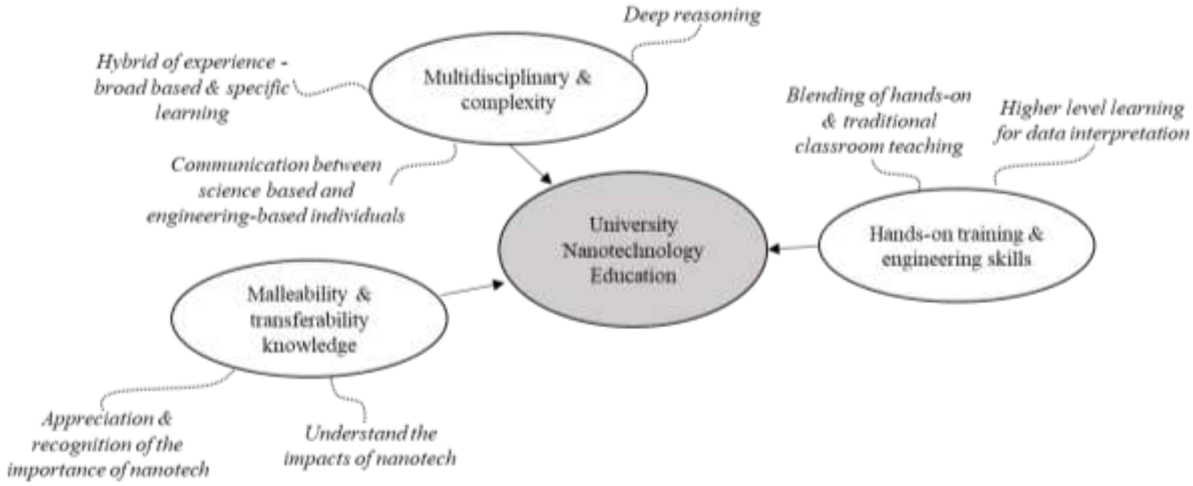

Figure 2: Main contents of university nanotechnology education

5. Discussion

Comprehensive and multidisciplinary nature

For Fonash (2001), colleges and universities must create an engineering and technical nanofabrication workforce with the broad science and technology background, and students must be exposed to state-of-the-art nanotechnology facilities. Such claim is valid given the wide and comprehensive nature of nanotechnology as discussed in previous study on the profile and characterizing nanotechnology research (see Miyazaki and Islam, 2007). Nonetheless, this paper evidences that this is possible only if students were to have the strong fundamentals related to the field of nanotechnology. Without the fundamentals, one would not be able to relate to this very complexed field of technology. However, students are not encouraged to know nanotechnology in a wider and comprehensive sense from the very beginning, as it will disable the student from contributing to a specific topic later on. In other words, in order to contribute to nanotechnology in a specific topic, student will need to have robust fundamental background in relative sciences; and not an advanced background in all relative sciences.

From the literature, nanotechnology education and training programs are seemed to be structured in a “formulaic” way (e.g. Jones et al., 2013; Meyyappan, 2004). For university nanotechnology education, scientists cum academicians will need to educate their students in relative sciences in a strong way while at the same time keeping them abreast of the possibilities of not only using his or her absorbed knowledge, but also enabling the expansion to a higher extent. Nonetheless, in this aspect, rigidity should be greatly circumvented to avoid dread and trepidation from creeping in within the subject matter. Nevertheless, when it comes to the delivery of nanotechnology as a subject, the approach will be rather different for all three levels whether it is for undergraduate, Masters or PhD studies. For PhD, it is more focused, whereby students only dwell into a small area of study. Nevertheless, for the undergraduate degree, it is considerably different whereby a student will not be able to “cover everything under the sun”. Therefore, the curriculum should cover specific mainstream subjects like Biology, Chemistry and Physics and offer a minor in nanotechnology.

Nevertheless, a student can enter into the Department of Physics and major in nanotechnology from a Physics perspective or if a student enters into the Department of Biology, he or she can major in nanotechnology from a Biology perspective. At a Masters level, a student can learn about quantum mechanics and atomic bonding; but ultimately only at a very certain depth. However, if a student were to enter into the field of nanotechnology, he or she cannot absorb the entire syllabus of advanced Physics and Chemistry. This is highly improbable. Therefore, this is the time, whereby the student will be necessitated to focus on a specialization since it is highly plausible for a student to undertake a subject like nano-chemistry or nano-mechanics. That is why nanotechnology cannot be regarded as a standalone discipline. It is merely an extension of all the other existing disciplines. Keeping this in mind, this proclamation cannot be taken as absolute since the field of nanotechnology remains a frontier yet to be experimented and its educational possibilities have yet to be explored.

Balancing capstone experience and classroom teaching

The balance between capstone experience and classroom teaching is crucial in university education. The findings indicate that hands-on learning cannot replace classroom knowledge learning and that the former must be anchored based on the latter. At the outlook, a complimentary relationship that links these two methods will ultimately churn out a productive group of nanotechnology knowledge workforce. As for engineering and scientific skills, as opposed to their biology counterparts who experiment with cells and live materials – their techniques are also very different. In certain good laboratories, universities have in place microscopes that cater for both groups of people: One is the engineering, chemistry, physics; and the other one is biology. Management who is prepared to make a higher investment should provide separate microscopes for separate fields of expertise. It is perceptible that the cost of setting up a state-of-the-art laboratory for nanotechnology is dependent on multiple factors such as type of field, type of microscopes required, the specification and functionality of each microscope, processing material, processing technique, the amount of utilization and level of skill required to use the high end/low end microscopes. In the attempt towards identifying these factors, findings directly demonstrate signs of the gigantic importance of university researchers and students in becoming the knowledge bearing assets required during the invention/discovery stage and prototyping/testing stage from R&D right up to commercialization of nanotechnology.

Managerial skills

For malleability and transferability knowledge, particularly regard to management skills, Hang et al., (2009) decrees that managers in the past have progressively taken up more than just project charter roles while becoming assiduous for market development, new product development, intellectual property (IP) management and even basic technological innovation processes. Largely, the success of the businesses run by companies in the field of nanotechnology relies on one: the management of resources especially financial resources. However, Hang et al., (2009) admits that there have been many graduates to date, who have occupied places in R&D and technology intensive industries in the public and private sectors. No matter how convincing this view may seem, it is very rare that you encounter proficiently technical people monopolizing the company boardrooms. Thursdy et al., (2009) have accentuated that innovation requires the expertise of (a) scientists or engineers engaged in invention and; (b) technology business experts who evaluate and develop business models for commercialization; and (b) attorneys involved in IP protection. This research postulates that what is required is a fusion of two very important elements: entrepreneurs and the technologists. If it is possible to combine to form a technopreneur, that would be exceptional. However, this is rare and not often found. For this to envision into a reality, the technologist will need to be more aware of the commercialization factors whereas the entrepreneur will need to educate themselves on the technical aspects of nanotechnology. However, it is improbable to turn a businessperson into a scientist. The phenomena should allow the scientist to be a scientist and allow the businessperson to be a businessperson.

An unimaginable amount of knowledge and expertise recites in the university. There is actually a bank of human capital stored within the solitude of the university; however, the research community should not be working in silo. The research community should be communicating more with the market or nanotechnology industry. There should be an amalgamation of roles placed in the field of nanotechnology. Furthermore, the management of nanotechnology is as imperative as the technical know-hows of this field. However, it would be a great asset, if the specific knowledge of the former were to be incorporated into the nanotechnology curriculum.

6. Conclusion and Implications

It is essentially pertinent for technology-management education to integrate the fusion of various scientific disciplines to cater for the needs of nanotechnologists and to yield a hybrid formation of both technologists and entrepreneurs. It also should be emphasized here that the predicaments associated to nanotechnology education can inform our thinking about education that prepare knowledge workers in terms of creativity and innovativeness. On top of all this, university researchers and students are undeniably the knowledge bearing assets required during the invention/discovery stage and prototyping/testing stage within the R&D and commercialization processes of nanotechnology. There is a positive need for a skilled and educated workforce trained at an array of levels affiliated to this field of nanotechnology in order to congregate the projected demand in the future.

It has been evidently proved that nanotechnology can be viewed as a fundamentally interesting case of the growing importance of interdisciplinary/multidisciplinary education for current work, as well as a quandary more than it is a likely frustration for companies who look to educational institutions to prepare future employees. It must be emphasized that this research does not in any way imply of narrowly “scientizing or modernizing” the entire education system by embedding the concept of nanotechnology but provides evidence that justifies the importance of entrenching the education of nanotechnology as a fraction of the existing science and management education, which we have today.

In terms of setting up a nanotechnology curriculum during the undergraduate program, this paper suggests that the focus of the undergraduate nanotechnology program should be to entrench a strong nanotechnology foundation. The undergraduate nanotechnology program should avoid focusing on a broad program whereby students end up knowing little about every science discipline but not enough in any field to make a significant contribution. Also, the completion of one’s Master’s education in a single field of science will provide the ability to adapt to other sciences and transcend into the pure concentration of nanotechnology. On the contrary, a standalone nanotechnology program, which amalgamates the various sciences, has more prospects of being developed as a doctorate program rather than the undergraduate or Master’s program. In addition, university PhD and MSc students coming from science backgrounds should be instructed to study the maintenance manual of the necessary equipment so that in lieu of suppliers, graduates will able to conduct the maintenance on the equipment as part of their practical training or hands on training experience. This will ensure that these postgraduates will understand first hand of the ins and outs of the functionalities of microscopy equipment used for nanotechnology.

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