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Disciplinary Identity of Nanoscience and Nanotechnology Research- A Study of Postgraduate Researchers' Experiences

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Abstract

Nanoscience and Nanotechnology research although growing at very fast rate, its disciplinary identity remains 'ill-defined'. It is often viewed as multidisciplinary; and/or interdisciplinary science or even as a unique discipline on its own way. As a consequence, whether this growing research area requires researchers that have studied specialised undergraduate or postgraduate nanoscience and nanotechnology programmes; or traditional science and engineering disciplines is still less understood. The examination of postgraduate researchers' experiences of nanoscience and nanotechnology research can provide a way of understanding nanoscience and nanotechnology research and the associated forms of disciplinarity, which in turn can address what the type of graduates are required to work in this area. In this paper, we review the different forms of disciplinarity associated with nanoscience and nanotechnology research and demonstrate that disciplinary identity of nanoscience and nanotechnology research is not yet clear. This study encouraged us to design a qualitative research framework to collect and examine postgraduate researchers' experiences of nanoscience and nanotechnology research for understanding what nanoscience and nanotechnology research is and thus operationalize disciplinarity associated with it. With this knowledge, whether the current education prepares postgraduate researchers to do PhD in nanoscience and nanotechnology research can be researched and guidelines for the curriculum development in nanoscience and nanotechnology can be suggested.

Keywords: interdisciplinary research, nanotechnology trends, nanotechnology curricula, nanoscience researchers

1. Introduction

Nanoscience and nanotechnology research encapsulates many scientific and engineering disciplines including physics, chemistry, biology, biotechnology, material science, molecular biology and medicine [1]. This research area has shown a potential of developing new materials which at nanoscale

exhibits different physical, chemical, biological, electrical and mechanical properties and therefore is referred as one of the most important technologies of 21st century [2]. With the significantly growing government and industrial investments in this area, promises of new scientific discoveries and increasing research opportunities, nanoscience and nanotechnology research has captured attention of many science and engineering research institutes, universities as well as industries and as a result workforce needs in this area has increased. To fully support the growth of this area, educational institutes and universities must understand the disciplinary identity of nanoscience and nanotechnology and provide the students with curriculum by which they learn, understand, practise and enhance the knowledge, skills and competence necessary to work in this area [3]. But with complex nature of nanoscience and nanotechnology, encapsulating several disciplines under one research theme [4], disciplinary identity of nanoscience and nanotechnology remains as an unsolved 'jigsaw puzzle' making the curriculum development in this area very challenging. In spite of this, there is an increasing trend of introducing undergraduate courses in nanoscience and nanotechnology for students from a wide range of disciplines including the natural & social science and engineering. However, whether these courses are merely developed to gain attention and interest of students; or develop the specialists to work in this area is always bypassed. Further, if such curricula will end up producing technicians with just basic knowledge of many disciplines or will be successful to develop specialist with necessary skills, competences and deeper understanding of nanoscience and nanotechnology area is not understood. A critical understanding of nanoscience and nanotechnology research and its disciplinarity is essential for any curricular reforms to support the future success of this area.

2. Scientific discipline, multi- and interdisciplinary of scientific disciplines

Before discussing the features of disciplinarity associated with nanoscience and

nanotechnology research, it is important to explain the concept of scientific discipline, interdisciplinarity and multidisciplinary. Scientific discipline is a body of knowledge that is taught in a certain school of education and is learnt, practised and modified through scientific research by the students while strictly obeying the rules of that school [5]. According to Khun, production of knowledge is deeply embedded with its disciplinary values and methods and even the students' perceptions also are influenced by their disciplinary values [6]. Van den Daele and Weingart discuss three aspects namely cognitive, institutional and social [also referred as political or external in some papers] that play major role in the formation of scientific discipline and differentiating it from other scientific disciplines [7]. Cognitive aspects specify how knowledge is produced in that discipline and involves epistemic practises such as the activities students engage in to develop their understanding. In institutional aspects, scientific discipline is considered as a social system and therefore emphasis is given on processes such as communication, interpersonal relationship, career and networking. While social or political aspects consider how scientific discipline is driven or controlled by social/ political or external factors. Both 'multidisciplinarity' and 'interdisciplinarity' features of a discipline are based on the input of two or more disciplines to the body of knowledge, research activities and teaching to that research area as well as their integration in terms of institutional and external aspects. In multidisciplinary research, the same research objective is approached from different angles using different disciplinary perspectives but neither the perspective nor the research findings are integrated in the end. Whereas, in the interdisciplinary research, different disciplines are integrated in such a way that the overlap creates its own theoretical, conceptual and methodological identity, reflecting strong disciplinary coherence [8]. In very lucid terms, multidisciplinary feature represents a loose or preliminary relation between the disciplines involved whereas interdisciplinarity represents strong overlap or integration.

3. Disciplinarity of nanoscience and nanotechnology research

Schummer [1] has contributed significantly in the investigation of disciplinarity in current nanoscience and nanotechnology research through Scientometrics studies and reported that nanoscience and nanotechnology research as a whole is neither particularly multidisciplinary nor interdisciplinary. He describes that

nanoscience and nanotechnology research includes different areas such as 'nano-chemistry', 'nano-physics' or 'nano-electrical engineering' which are not much related to each other and collaborate simply as the traditional disciplines does while describing disciplinary identity of science. Therefore the multidisciplinary feature of nanoscience and nanotechnology research stands as trivial as in the case of whole science and engineering in general. About interdisciplinarity, he suggests two patterns fitting nanoscience and nanotechnology research. In first, several auxiliary disciplines are strongly associated with one major or also identified as a 'mother' discipline and researchers working in auxiliary disciplines make tremendous efforts to contribute to the major discipline. Such pattern however draws boundaries between scientific disciplines and limits the social infrastructure such as research institutes, curricula, research journals and carrier opportunities to that major discipline. Nanoscience and nanotechnology represents cluster of such auxiliary disciplines deeply integrated with major disciplines. In the second pattern however, many different disciplines of equal ranking have strong connections between each other. This pattern would require reorganising a new research landscape around nanoscience and nanotechnology for interdisciplinary research and most importantly overcome cognitive barriers to interdisciplinary nanoscience and nanotechnology research.

When one thinks of cognitive barriers in interdisciplinary science is obviously interested to analyse where the different major disciplines meet. A common link between different disciplines involved in nanoscience and nanotechnology research is 'objects'- objects of nano (1-100 nm) size [5]. The researchers using similar objects may have some idea of sharing common objects but the understanding of the shared object is different in each discipline. For instance, gold nanoparticles, physicists will be familiar with size and spatial structure whereas chemist will be interested in solubility, catalytic properties and dynamics; engineers may be aware of electrical properties and biologist will be familiar with biological functionality and will be interested in applications such as carriers for drug and gene delivery. Although alteration of size - and thereby surface - changes electrical, mechanical or catalytic properties and thus properties of the objects in different disciplines can be interlinked, but what is important that the researchers understanding of the object matter itself is different in each discipline and even similar size objects are viewed as just another research object with strong disciplinary perspectives by researchers. Therefore what we

understand as 'shared object' is different in each discipline and is understood separately in the cognitive, instrumental and problem perspective of those disciplines and limit the knowledge construction in interdisciplinary science. Such disciplines when brought together in nanoscience and nanotechnology research, the researchers may not have to be constructivist but rather have to understand the potential of other discipline and trust the body of knowledge and practices of these disciplines. Therefore 'research objects' although falsely understood as but may not be a common ground for integration of scientific disciplines but it surely impacts disciplinarity identity of nanoscience and nanotechnology research to some extent.

Technological paradigms are also referred to as another cognitive barrier in the interdisciplinarity of nanoscience and nanotechnology research [5]. The technological paradigms are deeply rooted within the scientific discipline and are formulated on the past successful attempts in research of that discipline. The technological paradigms of one discipline although are applied to solve issues in other discipline under technological vision, often encounters with paradigms guided by the opposite view. For example, Schummer has explained how the development in the mechanical engineering has facilitated the control of atomic and molecular level assembly with high end, precise instrumentation which can potentially be used for the artificial and controlled development of new chemical compositions but at the same time it encounters the technological paradigm of chemistry discipline which is deeply embedded around the concept of 'self assembly'. Although nanotechnology vision brings together these two research approaches guided by two very opposing views, how they merge in interdisciplinarity is quite less understood to date.

Considering institutional and external aspects, Schummer further reports that research infrastructure, research papers, networking between disciplines is rapidly growing under the umbrella of nanoscience and nanotechnology research. Furthermore, social sciences, ethics and humanities are becoming integral part of this research which altogether reflects the growing inclination of the research community towards the second pattern of interdisciplinarity, but is again less understood by research community. He also comments that with such a wide perspective about nanoscience and nanotechnology research, research community is trying to portray the future of nanoscience and nanotechnology as a super-interdisciplinary structure of the whole of science, including technology, social sciences and the humanities

which will need a crucial understanding of 'interdisciplinarity in nanoscience and nanotechnology research' for its success in future. Roco M. C. proposes a term 'convergence' of disciplines to explain the connection between different disciplines contributing in nanoscience and nanotechnology research [9]. He argues that nanoscience and nanotechnology has been multidisciplinary for many years however the interdisciplinary connections between different scientific disciplines need to be promoted by identifying the factors that hinder and promote interdisciplinarity in nanoscience and nanotechnology research. He also argues that the researchers, being taught in traditional disciplines very often, understand the connections between different disciplines only in the late stage of their PhDs. With interdisciplinary perspective, he envisions 'a learning pyramid' for undergraduate education which starts with specific techniques and formalisms taught in the first year and with gradual introduction of its potential in different disciplines at higher levels leading to a coherent understanding of physical; chemical and biological features as the output of the learning pyramid [2]. He further emphasizes on reorganizing the entire research framework around nanoscience and nanotechnology with more interdisciplinary perspective. Sweeny *et. al.* [10] further explains that with the convergence of nanoscience and nanotechnology research with many disciplines like biotechnology, information technology and engineering in one hand it promises tremendous growth of nanotechnology research but inevitably accompany emerging social and ethical issues which should be considered addresses seriously. Therefore subjectivity of nanoscience and nanotechnology research provides another dimension to the disciplinarity in nanoscience and nanotechnology research. Porter *et. al.* [11] have reviewed interdisciplinarity of nanoscience and nanotechnology research using 'science overlay maps' with a focus on three elements firstly the research areas included in nanoscience and nanotechnology research, secondly the connection between the research publications with their citations and third the extent of integration of the contributing disciplines within nanoscience and nanotechnology research. In the mapping of nanoscience research activities, they noticed a dominance or prime linkage of material science with many disciplines including physics; chemistry; condensed matter physics and electrical engineering within the framework of nanoscience and nanotechnology research. Material science could also show linkage with

disciplines such as clinical medicine, mathematics and biomedical science which altogether indicated that within nanoscience and nanotechnology research framework, many disciplines cluster around materials sciences and around this discipline the knowledge exchange is taking place. Similar observations have reported by Battard *et al.* [12] in case of the material science and even molecular biology. They refer to these disciplines as crossroads where the boundaries between different scientific disciplines meet in nanoscience and nanotechnology research. Porter *et al.* [13] further could also observe through science mapping that nanoscience and nanotechnology research draw knowledge from disciplinarily diverse knowledge sources which however are connected under a common broad research theme. They also indicated that the 'interdisciplinarity' factor in empirical results of bibliometric studies is high as a virtue of researchers' tendency to sight work in neighbouring field more than the work in more distant fields [13]. Therefore they described nanoscience and nanotechnology research as a loose amalgamation of many scientific disciplines and interdisciplinarity in nanoscience and nanotechnology is obvious in the same way as science as a whole is multidisciplinary.

Eto H. carried out bibliometric analysis of journals, citations and authorship patterns to analyse the disciplinary factor in case of Japanese sponsored nanoscience and nanotechnology projects [14]. He observed multidisciplinary in nanotechnology research with chemistry discipline at center and extending to physics and material sciences and, to a lesser extent, biology and instrument technology. Horn C.V. presents a field study aimed at identifying the workforce skill requirement in industries associated with nanoscience and nanotechnology research and brings to attention the difficulties in nanoscience and nanotechnology research caused due to the inability of scientists from the two different disciplines to effectively communicate [15].

4. Reorganising disciplinary identity of disciplines involved in nanoscience and nanotechnology research

Nanoscience and nanotechnology research being very broad and with boundaries not defined specifically allow many disciplines contributing to it to reform their own disciplinary identities. These reformations indeed affect disciplinary identities of nanoscience and nanotechnology research. Porter *et al.* [11] and Schummer J. [5] have reviewed these reforms for two main scientific disciplines physics and

chemistry whereas considering comparatively newer disciplines, Kuruth *et al.* discuss how the entry of toxicology into nanoscience and nanotechnology research has impacted the formation of disciplinary identities of toxicology [7]. The discipline of Toxicology is dedicated to examining the potentially harmful effects of chemical or physical agents on biological systems and environment. He used qualitative interviews with particle toxicologists and demonstrated that with the entry of toxicology in nanoscience and nanotechnology research, it not simply remains as auxiliary discipline but takes a definitive role in the formation of cognitive, institutional and social framing of nanoscience and nanotechnology. In cognitive aspects, toxicology in nanoscience and nanotechnology research brings much of its well established body of knowledge, practices and approaches used to study physical or chemical particles of micro (10^{-6} m) or ultrafine dimensions for studying the health effects of particles of nanoscale. But at the same time it provides a room for new research focusing the analysis of the potential impacts of engineered and new nano-scale particles. In institutional aspects, after emergence of the word 'nano', the funding application strategies of the institutions are changing and are getting inclined to involve 'nano' in comparison with 'ultrafine' with more chances of success with this 'buzz' word. Although there is some disagreement about inclusion of ultrafine particles under 'nanoparticle' tag, the inclusion enables research to profit from the considerable research funds available to the nanoscience and nanotechnology research to use it for the study of ultrafine dimensions. With the increasing growth of nanoscience and nanotechnology research in many scientific disciplines the demand of toxicology for risk assessment is increasing, in fact many scientific disciplines are involving toxicology research groups within them so as to accompany the technological developments in that discipline with toxicological research. Besides that, toxicology research although benefiting society by constructing a large body of knowledge about potential hazards of nanoscale particles, it is ill-reputed as a critic and the research community are often viewed as the bearers of the bad news. Toxicology research community prefers the role of productive partner than critic and desire for more appreciation from the scientific society and the public. Considering external factors affecting the disciplinary identity of toxicology, purpose driven toxicology research plays important role in reshaping disciplinary identity. Part of toxicology research in nanoscience and nanotechnology area has oriented the body of knowledge towards other auxiliary disciplines such as therapeutic science

where the same body of knowledge can be used for the production of nano scale particles for health applications.

While many of the studies described earlier express concerns cognitive barriers of interdisciplinarity a small body of literature also indicate the migration of concepts within different disciplines. Grodal and Thoma [16] has investigated how nanoscience and nanotechnology, and biotechnology has exhibited the migration of concepts of biotechnology to nanotechnology and has given rise to a 'nanobiotechnology' as a new research area within nanoscience and nanotechnology research. Battard N. has reported thorough a qualitative study that even in a strong multidisciplinary research framework of nanoscience and nanotechnology, the research collaborations are possible by trust and legitimacy of scientific instruments. He comments that the researchers from different disciplines have to make some adaptation in terms of vocabulary and experimental details in order to explicit knowledge which are normally taken-for-granted in other scientific disciplines [12]. It could be argued that it is not important whether we call nanoscience and nanotechnology research as 'multidisciplinary' or 'interdisciplinary' or a unique discipline on its own way, indeed the important factor is to identify the knowledge, skills and competences necessary to successfully work in this area.

5. Research plan and emerging themes

The entire discussion above provides different perspectives in which disciplinarity associated with nanoscience and nanotechnology research is viewed and represents no consensual agreement. It also emphasize that attention should be paid to critically understand the disciplinarity associated with nanoscience and nanotechnology research which will facilitate in the development of necessary framework for nanoscience and nanotechnology research that includes its body of knowledge, research laboratories, collaborations, networking, career and most importantly overcome cognitive barriers for the future success of nanoscience and nanotechnology research. Interestingly most of the studies aimed to identify the disciplinarity in nanoscience and nanotechnology have used bibliometric methods. Although the methods indicated good success in exploring the forms of disciplinarity associated with nanoscience and nanotechnology research, it primly focus on the institutional, social and external aspects and disciplinarity in cognitive aspects and the knowledge construction in interdisciplinary

disciplines are less addressed to date. On the other hand, the qualitative methods appear promising for understanding the disciplinary identity of nanoscience and nanotechnology research in both cognitive as well as external aspects [12], [15].

In spite of the disciplinary confusion in nanoscience and nanotechnology, there exist small body of literature which have already discussed the scientific knowledge, i.e., content focussed information within nanoscience and nanotechnology curricula [17], [18], but indeed how these curricula will be successful to overcome the cognitive barriers introduced with the complex nature of nanoscience and nanotechnology research and associated disciplinary structure is not much understood. Further the knowledge, skills and competences the students are expected to develop, enhance and practise through these curricula are less researched. Within this frame, we ask the following research questions:

- Is nanoscience and nanotechnology research 'interdisciplinary', 'multidisciplinary' or unique discipline in its own way?
- Does the current education prepare the students for a PhD in nanoscience and nanotechnology research?
- What knowledge, skills and competences are necessary to work in this area successfully?

Although very little of the research dealing with nanoscience educational reforms pays any attention to researchers' experiences, we believe that the researchers are members experiencing this research area closely. Therefore we seek the answers of the research questions in researchers' experiences of nanoscience and nanotechnology research- the experiences they live in. Bailey [19] has described how the informal interviews stand as a conscious attempt to collect the rich life experiences. We developed a research framework with postgraduate researchers (n=4) working in the area of nanoscience and nanotechnology research as our research participants and qualitative interviews as the data collection method. The interview participants represented a good variation in terms of their undergraduate disciplines, research experience and area of research within N&N area. During the interview process, we encouraged them to describe their research experiences within nanoscience and nanotechnology area as fully as they can. We used seven interview questions listed below for the qualitative interviews with a careful attempt of rearranging the sequence of

questions based on descriptions of experiences narrated by the postgraduate researchers.

- Can you please describe your research project in depth?
- What you see as the most interesting parts of your research project? Why?
- Can you describe good and bad parts of your project? How you get on with the bad parts?
- Does any part of your education was helpful in your current research? In what way?
- Have you had an experience where you struggled with use of particular instrument/s or technique/s? How you dealt with it?
- Can you tell me about with whom you discuss your work regularly and through meetings/conferences or any other places? What are the conversations like?
- Would you call your research successful? What efforts you took for that?

We sometimes used probing questions to clarify their experiences more in depth. With these interview questions, we encouraged postgraduate researchers to describe their experiences of researching in nanoscience and nanotechnology area which eventually describe different elements of their association with nanoscience and nanotechnology research such as theoretical body of knowledge, research laboratory, experimentation, meetings, conferences and discussions but may not be limited to that. The interviews were audio recorded and transcribed later for further analysis. The rich descriptions of experiences inform us about how the postgraduate researchers make sense of their world and connect their education and training to that world and understand it. Examining the postgraduate researchers' experiences we identify if the researchers have experienced any intersection of different disciplines in nanoscience and nanotechnology research and if yes how they deal with it? We provide herewith two examples selected from a pilot interview transcript as an indicative of our research data. In first, postgraduate researcher from chemistry discipline describes her experiences of working with nanoparticles in toxicology research and how she used the knowledge body of toxicology methods and chemistry disciplines to evaluate the toxicity of nanoparticles. In second, she describes her experience in a general nanoscience and nanotechnology symposium.

"I am interested to examine whether the nanoparticles are toxic to the aquatic species and if yes to what extent...I had some

background in that. Toxicology was kind of the main part of my degree (in chemistry) in college. So I was kind of new about many tests and how to do that.... We used to test how much toxic the chemical pollutant are especially for the aquatic species. I didn't use the nanoparticles before so was new for me....In my project, I am using two different types of carbon nanoparticles and I need to measure size and surface area of them.... there are always new ways coming up of producing them (nanoparticles) and measuring these parameters. It is kind of new instruments are coming up every year....Also it is difficult to work with nanoparticles... the nanoparticles are not easily soluble...you need to sonicate them.... So it is kind of hard to get them into the system but then you have to mimic natural conditions so you can't sonicate them much"

"Even sometimes... here people are like, Ohh that is ecotoxicology....that is bit different... I don't know anything about that... But then I just try to explain them still that we are measuring how toxic these MMMM are...basically I just give the idea of what are these tests are and why I am doing it.... I know what are their limitations due to their backgrounds, so.... I kind of describe them using a general terminology which everybody understands, no matter which background they have...and then they are interested in testing it for their QQQQ"

The themes emerged from researchers' experiences in the pilot interview were 'dominance of the instrumentation in nanoscience and nanotechnology research'; 'research collaborations and postgraduate researcher's participation'; 'research policies and researchers' impression'; 'locus of interaction: instruments, meetings and conferences'; 'need of common vocabulary at workplace'; 'dynamics in nanoscience research and researchers' attitude' and 'complexities in explaining N&N research'. Our interest in the pilot interview analysis at this stage is just delivering the themes emerging from the examination of researchers experiences. These experiences when examined further describe the detail structure of disciplinarity in nanoscience and nanotechnology research; to present the analysis is however beyond the scope of the paper and explained elsewhere [20].

7. Conclusion

With no clearly defined disciplinary boundaries and tremendous potential for new research, not surprisingly, nanoscience and nanotechnology research entered and influenced research activities of various scientific and engineering

disciplines with tremendous speed, indeed with its great research potential, nanoscience and nanotechnology has pulled these science and engineering disciplines within it and claims to have its own emerged identity. However, the integration being so complex, the research community still debate on disciplinary identity of nanoscience and nanotechnology research. Our emphasis in this paper at the first place is, to bring into attention the range of diverse views about the disciplinarity in nanoscience and nanotechnology research, and demonstrate that disciplinary identity of nanoscience and nanotechnology research is not yet clear. Bibliometric analysis has proven successful in researching the institutional and external aspects associated with disciplinarity of nanoscience and nanotechnology research but a lot more work is required to understand how the researchers perceive, understand and construct knowledge in nanoscience and nanotechnology area. Qualitative methods has an upper hand in illustrating human experiences that reveals how the human beings make sense of their world they are situated in, which in this case is postgraduate researchers, researching in nanoscience research area. We propose a research design to examine postgraduate researchers' experiences of researching in nanoscience and nanotechnology research area. The themes derived from the pilot interviews analysis indicated the success of our attempts to reach close to these experiences through the interview questions and structure and ensured that further examination will provide broader understanding of disciplinarity of nanoscience and nanotechnology as a whole.

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