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Identifying Knowledge, Skill and Competence for Nanoscience and Nanotechnology Research: A Study of Postgraduate Researchers' Experiences*

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Over the past few decades, scientific disciplines have changed significantly with the introduction of new and complex aspects of research, particularly in the area of nanoscience and nanotechnology (N&N). Efforts to develop science education programmes in N&N area to adopt these complex changes are also evident from recent literature and educational reports. However, these attempts are focused towards identification and inclusion of contextual scientific knowledge in the curricula and very little is understood about the attributes knowledge, skill and competence necessary to successfully undertake N&N research. Identification of these attributes is important so that the contextual scientific knowledge can be embedded in the curricula more effectively. Also, it is uncertain whether this growing research area requires researchers that have studied specialised undergraduate or postgraduate N&N programmes or traditional science and engineering disciplines. In other words, is N&N research multidisciplinary, interdisciplinary or will it develop into a unique discipline is not clear. To address this question, this qualitative study will examine the postgraduate researchers' experiences of researching in N&N area. Studying how the researchers understand, interpret and describe their experiences, we can achieve a new; or; at the very least a wider understanding of what N&N research is; and how the postgraduate researchers use their education and training to research in this area. This in turn will inform the curriculum development at the undergraduate and postgraduate levels and address the issues of whether we should have specialised undergraduate N&N programmes or simply different distinct science and engineering disciplines coming together.

Keywords: science curricula; phenomenology; interdisciplinary skill

1. Introduction

The area of nanoscience and nanotechnology (N&N) is considered to be one of the most important scientific research areas of the 21st century [1]. N&N research involves the manipulation, control and development of atomic and molecular level assembly which are of the size of nanometres (10^{-9} metres) and also the study of their properties and interactions for specific purpose [2]. The properties can be physical, chemical, biological, electrical or mechanical. Therefore it is not incorrect to say that N&N research encapsulates knowledge of several scientific disciplines such as physics, chemistry, biology, engineering and biotechnology; and the researchers working in this area experience novel phenomena and/or processes at nanoscale while researching in any of the above mentioned discipline/s.

N&N research has also impacted numerous important industries such as aerospace, automotive, biotechnology, ceramics, chemicals, electronics, metals, materials, renewable/sustainable energy, textiles and telecommunications [3]. The potential of N&N research to impact on these industries and thereby on the economy has attracted government and private sector funding. As a result, significant increase in the financial investments in this area has been observed in recent years [3]. Researchers are expanding their research into, or incorporating elements of N&N research in their existing research area as it is a promising research area with guaranteed funding.

Although funding agencies are supporting the N&N research area, they have also raised concerns about the shortages in the workforce in this area [4]. According to NSF (National Science Foundation) in the United States of America, more than 2 million jobs and 6 million supporting positions will be generated in N&N area by 2015 [5]. Although every new field initially experiences shortages in workforce, and it is not a new phenomenon, the accelerated growth of N&N and its potential impact on the industrial sector makes it a concern and timely challenge [4]. The nature of N&N research is complex and with the inclusion of several disciplines under one research theme [6], it makes curriculum development in this area challenging.

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Roco M. [1] argues that 'the education and training of a new generation of skilled workers in the multidisciplinary perspectives' is a key challenge for educators working on curriculum design in N&N. Schummer J. [7] have further identified some cognitive challenges when researchers from different scientific disciplines work together under a common research theme in nanoscience and nanotechnology research. It has also been reported in qualitative research reports that the industries largely depend on the educational institutes for the development of their workforce and hold a strong belief that the educational institutes have and will further reform science curriculum and training programs where necessary to develop a skilled workforce for N&N [8–9]. Although much has been written about the skill needs in N&N area and the necessity of workforce development to date, the available literature provides very little insight with respect to the actual skill needed to be a nanoscience researcher [10–12]. Although many national and international nanotechnology research programmes recommend the development and implementation of educational programmes in N&N, the level at which these programmes should be introduced still remains under debate [13]. Tinker R. [14] emphasises reconstructing the K-12 science curriculum in the United States of America to take a more interdisciplinary approach while Zeng *et al.* [15], Samet C. [16] and van Horn *et. al.* [11] have instead discussed possible reforms for undergraduate programmes in science and engineering. Prof. Besenbacher, Director of iNANO (Interdisciplinary Nanoscience Centre, Denmark), in his talk [17] in 2003, suggested that the specialised knowledge for cross-disciplinary nanotechnology research may only be needed at a late stage in a researcher's career and the undergraduate curricula should therefore focus mainly on core knowledge needed for a foundation in all specialisations.

Furthermore, although much of the previously published literature has discussed the scientific knowledge, i.e., content focused information within N&N curricula, the knowledge, skill and competence the students are expected to develop, enhance and practise through these educational programmes are less researched and discussed.

N&N research area may not progress as fast as it can if, the knowledge, skill and competences necessary to work in this complex area are not developed in the researchers working in this area presently or in near future. Therefore, it is imperative for the education community to identify in time the necessary attributes, and then, if necessary, reform science and engineering curricula and training programs in a more targeted manner. Although very little of the research dealing with nanoscience educational reforms pay any attention to researchers' experiences, the authors believe that the researchers are active members experiencing the area in person and their experiences will inform curriculum reforms significantly. Levin B. [18] have emphasised the meaningful role of undergraduate students in defining and shaping education reforms and discussed some ways in which it can occur.

In Ireland, no specific training programme has been developed for the postgraduate researchers who are engaged in research in N&N area [19] except for the INSPIRE (Integrated nanoscience platform for Ireland) postgraduate training programme which is still under development [20]. A recent SWOT survey (strength, weakness opportunities and Survey) for nanotechnology commercialisation carried out by Lux research described the 'lack of sufficient number of qualified engineers to drive N&N research to productisation' as one of the weaknesses in Ireland's Nanotechnology commercialisation vision [20, p. 43]. This study will examine the researchers' experiences in order to get a better insight and understanding of what nanoscience and nanotechnology research is and in turn will inform curriculum development at undergraduate and postgraduate levels in science and engineering disciplines about necessary reforms to develop a skilled science and engineering workforce for N&N research.

2. Postgraduate researcher

It takes a postgraduate researcher approximately three to five years to complete their PhD programme in a typical science and engineering research framework. During this period, the researcher is expected to make a significant contribution to the field of research through independent investigations, demonstrate his/her research skill and publish papers and/or a thesis to disseminate his/her research work among the scientific community. For a postgraduate researcher, the research is a journey of generating knowledge in that area and postgraduate researchers working in the area of N&N, which is a comparatively new and complex area, are also following the same research tradition.

3. Theoretical framework and research design

Human experiences are descriptive in nature and can be illustrated qualitatively [21–25]. As this research focuses on postgraduate researchers' experiences, qualitative approaches best suit the

purpose. While following a qualitative approach, we have subscribed to Creswell's framework of qualitative research with three fundamental elements: knowledge claims or theoretical paradigms; strategies of enquires; and methods of data collection and analysis [21]. The theoretical paradigms for this research are mainly qualitative, constructive and interpretive. We have applied phenomenology as methodology or strategy of enquiry; and open ended interviews as a specific method of data collection for this research.

Dartigues A. [24] has argued that the examination of experiences or life world can provide an insight into the knowledge or underlying reasons of the human actions in their world. Van Manen describes these life or lived experiences as thoughtful and conversational in relation with the world and provide an opportunity to understand the world we live in, but further argues that these experiences are so complex that there is always an element of the ineffable to life [26]. With the examination of these lived experiences, although one can't achieve complete understanding of the world we live in, but can certainly obtain a different and broader view point of understanding it, the understanding that is obtained from experiences purely and not influenced by its taken for granted meaning [26]. This perspective of lived experiences matches well with our present research. The examination of the postgraduate researchers' lived experiences can unfold the researchers' association with their education; training; research laboratories; experimentation; meetings with supervisors; group meetings; conferences and many other (known as well as unknown) dimensions of their journey as a postgraduate researcher in the N&N area and provides an insight of how the postgraduate researchers perceive N&N area and research in this area. We are aiming to achieve a broader understanding of N&N research in postgraduate researchers' perspectives.

Phenomenology always considers the acts of 'describing' and 'interpreting' human experience as valuable for understanding the world they live in [24]. It was introduced as a philosophical approach or perspective by Husserl [21–25] and with time has undergone significant changes in its forms including development of transcendental phenomenology, hermeneutic phenomenology, existential phenomenology and different forms of analysis [26–29]. As a methodology, it has been practised successfully by many researchers to understand the policies, practises and their implementation in a wide variety of areas including education, health care and management [30–32]. In recent years, specific phenomena in education such as learning, skill development, assessment and involvement in the classroom have received much attention and have been researched by delving deeper in students', teachers' or lecturers' experiences using phenomenology as a research methodology [33–36]. After reviewing the large body of research that examined students' and teachers' experiences, we believe that, for our research of examining the postgraduate researchers' experiences in N&N area, phenomenology with its grounding and focus on rich descriptions and interpretation [24] would be appropriate research methodology.

Phenomenological methodology offers some techniques or methods to collect and examine data such as interviews and focus groups [27–28]. Bailey C. [37] has described how the informal open ended interviews stand as a conscious attempt to collect the rich life experiences. We have also adopted the open ended interviews in this research to obtain full and rich descriptions of postgraduate researchers' experiences. While examining the life experiences the researcher should bracket any presuppositions, prejudices or the understanding of the experience that exists already [30] and should focus on the individual and their interaction with the surroundings. However, bracketing prior experiences is complex, indeed identified as a next to impossible task in a phenomenological enquiry by van Manen M. [26]. We support le Vasseur's approach of selective bracketing [38] where the researcher decide how and in what way his or her understanding will be introduced in the study. In our research, the bracketing entailed setting aside our views about how the postgraduate researchers perceive the N&N research during the interviews and we entirely focused on collecting the rich descriptions of postgraduate researchers' experiences but we (particularly the interviewer) use our background of scientific research reflexively to communicate with the postgraduate researchers more effectively. While analyzing the research data, we allowed our conscious or reflections as a part of an investigation of the very nature of a phenomenon (researching in N&N area) and not an explanation for it [26].

Postgraduate researchers' life experiences can extrapolate a universal form, as they come from different institutions, work or research environment and scientific disciplines and therefore may experience researching in N&N area in different ways and settings. Although the phenomenological study does not provide the entireness of the experiences due to the limited number of participants, it definitely provides a broader, a fuller and more in depth understanding of N&N research and how the researchers carry it out. Examination of their experiences further enables the understanding of the knowledge, skills and competences necessary to work in this area allowing us to reflect on the existing science curricula.

4. Research sample, methods of data collection and analysis

It is important to justify the appropriateness of the participants' selection in qualitative research [21]. Also, the methods of data collection and analysis bring practicality to the research, therefore it is necessary to discuss how using specific methods we reliably collected the exact data and further how the analysis reliably addressed the research questions.

4.1 Research sample

There are approximately 300 researchers currently pursuing PhDs in N&N related research areas from different institutes and universities across Ireland [39]. We collected the postgraduate researchers' contact information from N&N conference abstract books, journals and proceedings published during March 2010 to the most recent. We also requested the principal investigators from different university departments and institutes involved in N&N related research projects to provide information about the postgraduate researchers working in their research groups. We then contacted the postgraduate researchers through email informing sufficient details about our research objectives and interview structure and invited them to participate in our study. We requested them to provide some basic information of their academic profile (graduation discipline, year of postgraduate research, prior research experience) and current research project (research project title and area of research) and later developed a database of this information based on their response. We also requested the postgraduate researchers to email any recent conference abstracts or publications or alternatively a short description (about 6–7 lines) of their research project which will explain the researchers work area within N&N research area.

Following the in-depth nature of phenomenological interviews and their subsequent analysis, it was essential to limit the sample set that could give enough time to analyse the research data but at the same time the research sample size should not appear 'less credible' to policy makers who prefer numbers. Therefore, amongst the interested participants, we choose to interview 6 postgraduate researchers for the pilot and 40 postgraduate researchers for final interviews. The final sample set represented 13% of total PhD researchers in N&N area in Ireland which is credible to convince the policy makers and is still within the reach of a phenomenological interviewer's perspectives. An important consideration in research sample selection was to maintain a good variation in terms of following categories i) graduation discipline, ii) year of postgraduate research/PhD study, iii) area of research within N&N area, iv) institute/university and v) prior research experience. We choose our research sample in such a way that they represent much possible variation in each of these categories above, except for the last, where we prioritised researchers having less experience as the study is more relevant for fresh postgraduate researchers. The database with academic and research information of postgraduate researchers facilitated in the selection the participants.

The pilot study considered 6 participants which we chose on the basis of their immediate availability for the interview, however, we still ensured to maintain a good variation in all of the five categories in the pilot sample set. The pilot interviews were undertaken mainly to inform the process and research design and facilitate a better construction of final interview structure. By limiting the number of participants to 6, we could engage in what we understand by phenomenological interviewing and analysis before proceeding for the actual interviews. Understanding the research process was crucial than the research findings at this stage. The details of the participants for the pilot interviews are provided in Table 1.

4.2 Data collection

The research data were collected through semi-structured interviews. The interviews were conducted at the participants' workplace and each lasted approximately one hour. During the interviews, the participants were assured about the confidentiality of the data so as to encourage their involvement in the interview process. The interviews

Table 1. Research sample specifications

Participant	Year of postgraduate research/PhD	Graduation discipline	Research area	Prior experience (research/industry) in years
A	3rd	Engineering	electronics, nanomaterial fabrication	0
B	2nd	Chemistry	nanotoxicology	0
C	3rd	Chemistry	nanomaterial synthesis	3
D	4th	Physics	nanomaterial synthesis	1
E	1st	Chemistry, Biochemistry	ecotoxicology, nanotoxicology	2
F	2nd	Physics education, MSc Physics	Engineering	0

were audio recorded with the permission of the participants and transcribed later. The transcripts were taken back to the participants if any clarification was required.

In phenomenological interviewing, the interview questions play a significant role in encouraging the participants to delve deeper into their experiences and describe them as fully as they can. The interview questions that were put to participants were open ended and indirect which would probe their experiences about researching in N&N area. Also, the interview questions were reduced to a very small number (maximum of 5) which would provide the participant plenty of time to elaborate on their experiences. The open ended interview questions are designed to allow the data to emerge [40] but there is a danger of collecting long descriptions of mechanical actions and even opinions from the participants instead of their experiences of a particular phenomenon. Although one cannot certainly avoid the descriptions of actions completely using open ended questions; we endeavoured to use these descriptions to get closer to the experience and using probing questions encouraged them to describe their experiences fully. The end result of data collection is a rich report of postgraduate researchers' lived experiences. Encouraging the researchers to describe their life worlds which includes research laboratory, experimentation, meetings, conferences, discussions but not limited to them, we can collect rich descriptions of their lived experiences. It is these rich descriptions which describe how the postgraduate researchers make sense of their world and connect their education and training to that world and understand it.

4.3 Data analysis

We tailored the pilot interview analysis method to loosely match the methodology of thematic coding. We preferred this methodology for the pilot study following its highly flexible nature with fewer specified procedures [41]. The analysis included repetitive reading of the transcripts to get a general feel of the interview. We then identified the sentences or sections that pertained directly to the experiences of doing nanoscience research. From these selected sections, we developed codes or themes in each transcript which can be supported by quotations or dialogues within the transcripts [41–42]. With the complex nature of nanoscience and nanotechnology research, we cannot deny the possibility of the interlinking of many aspects of the research with each other [43]; therefore we allowed multiple themes from the same sections [41]. We then constructed a basic template with the derived themes and applied it to the pilot interview transcripts in order to analyse the transcripts further [41]. The basic template was revised with a few iterations of pilot interview analysis. We clustered similar themes and identified the 'core' themes [41]. The core themes obtained from pilot interviews were very broad but still provided a quick and general overview of some aspects of nanoscience and nanotechnology research. The themes further informed the interview questions which will be used to gather researchers' experiences from future interviews.

It is essential to consider all the aspects of the individual postgraduate researcher's experiences in great depth from the future interviews to understand how each postgraduate researcher does and understands nanoscience and nanotechnology research. Further, exploring the variations in the ways in which the different aspects of nanoscience and nanotechnology research are experienced by subgroups (formed according to graduation discipline or research area) will also be useful while addressing the research questions. Therefore it is necessary to study transcripts individually and also in groups. We will be using deeper hermeneutic strategies for the analysis of future interviews and will portray the individual researcher's experiences in form of a detail phenomenological draft as well as study the transcripts in groups to understand the variations in the experiences of researchers about a particular aspect [26]. The hermeneutic approach, similar to thematic coding involves deriving qualitatively distinct themes from researchers' perceptions, assumptions and approaches, but in addition, the interpretive rigor in hermeneutics allows the researcher to construct the higher order themes using his/her own knowledge reflexively [44]. With the themes derived from interview transcripts and the higher order themes formulated by the researcher using his/her own understanding, a thicker description of the phenomenon with still maintaining faithfulness to the participants and their interpretations is achievable [44].

As this research is ongoing, we have presented only the core themes derived from the analysis of pilot interviews with sufficient examples from the interview transcripts demonstrating grounding in the data.

5. Research data analysis

It must be kept in mind that the findings are drawn from pilot interviews and subject to change with the future data set. The themes which emerged from the transcripts were i) *dominance of the instrumentation in N&N research*, ii) *research collaborations and postgraduate researcher's participation issues* iii) *research policies versus researchers' impression*, iv) *dynamics in nanoscience research and researchers' attitude and* v) *complexities in explaining N&N*

research. Presenting these primary themes, we describe how postgraduate researchers understand what N&N research is and how they connect their education and training to it.

5.1 Dominance of instrumentation in N&N research

In N&N research, the researchers use the instruments which allow them to characterise the nanoscale objects in terms of size and scale or visualise the nanoscale assembly such as deposition layers, bio/cellular interactions with nanoparticles and devices in the process of development. The interaction of researchers with colleagues or collaborative researchers is mainly about the usage of the equipments or instruments, so the instruments are the common points where researchers who may work in different disciplines meet or share the information. Even within the research cluster, the facility of using the scientific instruments amongst collaborators is supported very strongly. Darby *et al.* have already pointed out the importance of instrumentation, more specifically the nano-scale instrumentation as an important area that provides a common platform for the various N&N fields [45].

5.2 Research collaborations and postgraduate researchers' participation issues

In the researcher's frame of reference, since they are the one who actually uses these instruments for data generation (which can be used by themselves and/or shared within other collaborators) it is necessary to have good discussion about what information obtained using the instrumentation, other collaborative researchers are interested in, particularly when more than one discipline are involved in certain project. It is evident from experiences shared by two participants:

> *In our case . . . the work wasn't of sufficient standard. That is true in lot of cases and even in XXXX case also. We have sent samples to a group . . . I won't mention who for YYY measurement and they have not got into the bottom of it...bottom of the problems . . . there were too many people involved at upper stage . . . and postgrads . . . nobody cares what it is for.. a postdoc sitting there, sends an email . . . we have a new collaboration and sends the sample to do this. . . . they do the experiment and send it back . . . when we are looking at the data back here . . . none of them make sense . . . as nobody was knowing or understood what we were interested in . . . it is shear wastage of time!! (PhD researcher C)*

> *This girl PPPP, I was in touch with her through email. . . . She provided the MMMM for my project. She also gave me the information about the electrochemistry of molecules and the solvent she used while characterizing the molecules . . .But you know what, they don't know what we are using MMMM for . . . But I am pretty sure that she didn't understood what it was for anyways!! In this collaboration, we are not particularly totally dependent on each other or independent, but the outcome of our work or their work won't be completely go wrong, if something goes wrong in any of the side. . . (PhD researcher A)*

The postgraduate researchers consider themselves at the bottom of the research cluster and are more often ordered to exchange the experimental results or products within collaboration, without having much scope for exchange of the knowledge or information of, what the particular product/data is being used for? From a postgraduate researcher's perspective, they feel it is important to involve themselves in every step of knowledge exchange in a collaborative project, which could avoid delays and accelerate their research work in a right direction.

While building up the dialogue between the researchers, the researchers felt that, it was also important that they understand how their research data can be used in other disciplines. Every scientific discipline has its own set way of thinking and practises [46] and researchers' activities are guided by these practises [40]. Developing a trust on the thinking and practises of other different disciplines is possible when these intertwine at certain stages in the research journey, which is possible predominantly at the stage of instrument usage as stated earlier. Therefore during the training session for N&N related instruments, the researchers could be encouraged to discuss how the data obtained from the instruments will be used for their projects. The researchers also expressed the need of common vocabulary, with which concepts can be explained and ideas can be shared across the disciplines at ease. Thus the postgraduate researchers can be aware of the potential of other disciplines and make a request for correct information from co-researchers. A stronger research network is also possible through this common vocabulary. Nanotechnology, being a broad research area, brings together researchers of various scientific disciplines (in the laboratory or at conferences). A common vocabulary can achieve more interactive discussions. Postgraduate researchers in such interactions treat researchers of other discipline as a 'non-specialist' audience and try to communicate their work or idea in a simplified form. Building this aptitude in communication not only encourages constructive discussions between researchers of different disciplines but also bring ease while communicating with specialist audience from same discipline. Postgraduate researcher (E) shared his experience at a conference during poster presentation:

> *Even sometimes . . . here people are like, oh 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 . . . (PhD researcher E)

5.3 Research policies versus researchers' impression

The 'commercialisation' of N&N research is identified as one of the main interests of the stake holders [20] and as a consequence the research policies are structured to contribute to it by the research cluster approach. A postgraduate researcher, although an integral part of the research cluster, sometimes finds it difficult or struggles to pursue their research interest and can feel under pressure. From their perspectives, the 'goal posts tend to shift' due to the commercialisation activities and this affects their personal interest in their research:

I was there for a day in MMM conference but it was total waste!! It was nothing to do with research. It was more for commercialization and I think they were trying to drag the students for . . . (PhD researcher D)

It is terrible when you are doing something and the other people who are powerful would cut your funding . . . and then the people in the research cluster quickly gather a plan which is pretty poor . . . it is very annoying subject...we had lots of ideas but . . . there were a strong influential personalities in the research cluster that wanted to direct it towards a particular application for DDD . . . which has been done a lot and to be honest with you, personally, I have no interest in it unfortunately. . .honestly, I will ignore it . . . it will affect the research cluster but will not affect me because initially a vast amount of time was wasted as it always jumped from topic to topic . . . it was purely bureaucratic nonsense . . . I mean people fighting . . . it happen . . . it is the person in the bottom of the chain who always suffers!! . . . (PhD researcher D)

Postgraduate researchers can be made aware of the big picture of current trends of research policy developments and perspectives; commercial enterprise perspectives; social aspects of research and significance of researchers' contribution in overall research development, probably through training and curricula, which could minimise the tension.

5.4 Dynamics in nanoscience research and researchers' attitude; and complexities in explaining N&N research

N&N research is further experienced as 'dynamic', 'complex' and yet 'ill-defined' by postgraduate researchers. The researchers carry an impression that physical and chemical properties at nanoscale are very difficult to predict and explain. The researchers' background knowledge of the core subject and awareness is mainly implemented in designing the experiments. The researchers appear to put most effort into the experimentation work and think that complex phenomenon at nanoscale can only be understood through the experimental observations. Learning how to use an instrument or technique dedicated for characterizing or processing nano-sized materials are understood as 'specialized skills' by postgraduate researchers. N&N research for the postgraduate researchers is a process in which they integrate the specialized skills with the developed subject knowledge and their prior experience. Postgraduate researcher (B) shared her experience during the interview.

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 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 . . . (PhD researcher B)

The postgraduate researchers think N&N is 'very expensive science' and feel responsible due to large amount of financial investment in the research. The expensive nature of research, fast pace of the developments in the area and competitive environment have built a lot of mental pressure on the researchers. Postgraduate researchers are well aware of the competition due to strong networking between research groups by virtue of research collaborations, conferences, meetings, seminars, and research publications etc. The researchers in spite of experiencing mental pressure try to be more disciplined and organised in their research; keep themselves alert and accelerate their research work to survive in the competition.

Although it is so expensive and complex venture, we know that there are few groups which have capabilities that we have in our lab and it makes WWWW so much competitive . . . I have worked for HHHH for last few months and just before drafting . . . I saw that PPPP have recently published it . . . I have to work fast . . . I am still undergoing through . . . (PhD researcher F)

6. Conclusion

The pilot interviews introduced us to postgraduate researchers' different perceptions of about N&N research. Although the themes derived are preliminary, they can be examined further from future interviews. Also, it is important to understand that one should not generalise these experiences to all

postgraduate researchers but one can extrapolate a broader understanding of N&N research from postgraduate researchers' point of view.

For two researchers (A and C) discussion or interaction amongst research collaborators at the level of postgraduate students was important and would have saved their research time effectively and/ or would have brought more healthy research outputs. Also, at certain times it appeared that postgraduate researchers' (A and D) ways of judging 1) research collaborations' and 2) research policies support activities for processes such as commercialization; were contradictory to that of research collaborators' beliefs or policies' agenda. Two recommendations can be made in this context. 1) Researchers understanding and engagement with ethical, social and commercial issues related to nanoscience and nanotechnology research could be encouraged in their training/ academic curricula. 2) If postgraduate researchers initiate, lead and interact with other senior researchers in planning and executing the research, it can change postgraduate researchers' attitude towards looking at research collaborations and could uplift their participation in research collaboration and bring more healthy research outputs. Following that more attention can be paid towards enhancement of professional skills in postgraduate students. Further, it was reflected that while planning research work and experimentation in the laboratory, postgraduate researchers (B, F) exhibit their alertness, creative thinking and ability to integrate the contextual knowledge with specialized skill in order to explore different ideas or processes in N&N research. Furthermore, one postgraduate researcher (E) felt successful in communicating her results to non-specialized audience in a multidisciplinary conference. Further research is necessary to analyse more details about how the specialized skill, ability of integrating specialized skill with subject knowledge and competences were developed.

Finally, the implementation of the pilot interviews and thematic analysis served the purpose of exploring the research process and proved to be essential in reconstructing the interview questions. During pilot interviews, we (the interviewer) used our scientific research background reflexively in data gathering process and occasionally requested for more detailed descriptions of experimentation to understand how the researchers deal with some aspects of N&N research that are of our particular interest, for example 'disciplinarity'. With pilot interview analysis, we have identified some themes that will facilitate in bringing the postgraduate researchers close to their experiences in future interviews. We therefore reconstructed our interview questions around the identified core themes and used them as a starting point in the semi-structured interviews in future studies. These questions lead to what aspects of the research question the interviewee will address in the interview and therefore assure that postgraduate researchers delve deeper into their experiences to unfold that particular aspect of N&N research and share them during interview process. But of course the interviews will remain open ended encouraging the participants' to describe all possible experiences of researching in the N&N area. Combining pilot study and future interviews we continue to develop a deeper understanding of N&N area from postgraduate researchers' perspectives and study how they approach N&N research with their education and training. The future investigations will further identify if the existing curricula prepares the postgraduate researchers for a PhD in the N&N area.

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