Undergraduate Nanoscience Education Development

An Interactive Qualifying Project Report
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Abstract:

This project provided a comprehensive view of the state of undergraduate nanoscience education development efforts for the National Science Foundation: Division of Undergraduate Education (DUE). Data was gathered on current efforts in nanoscience undergraduate education by analyzing the results of two surveys, one for schools with developed curricula in undergraduate nanoscience education, and one for schools in the development phase. Recommendations were made regarding direction of focus for undergraduate nanoscience education development efforts to the NSF-DUE.

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1. Executive Summary

Nanotechnology has an enormous potential to revolutionize today's way of life. To make this possible, nanotechnology requires the growth of a workforce to nourish it. As the science behind nanotechnology, nanoscience is essential in today's undergraduate science and engineering programs.

This project provided the Division of Undergraduate Education (DUE) with a comprehensive view of the state of undergraduate nanoscience education development in the country. The project gathered data from institutions that have developed undergraduate curricula in nanoscience, as well as from institutions that are in the process of developing undergraduate nanoscience curricula. The Division of Undergraduate Education can use this information to provide help and focus in their efforts to stimulate undergraduate nanoscience education development.

Information obtained came from two different, but related, surveys. The first survey obtained data about institutions with established curricula. The second survey collected information about institutions without curricula. Participant institutions are schools that are involved in nanoscience research or education at the graduate and/or undergraduate level. The final pool of institutions included school names obtained from research journals, previous NSF awards lists, and references from NSF contacts.

The survey responses revealed commonality between institutions from a question-by-question analysis according to the frequency of common responses. The total number of surveyed institutions was 77, of which 35 had developed programs and 42 were schools in the developing stage. The response rate was 57% from our sample of institutions with undergraduate nanoscience curricula and 45% from out sample of institutions without one. The surveys returned represent a wide variety of schools in type, size and focus.

Participating institutions with developed programs display the following common highlights: 1) most institutions utilize their existing resources to support their undergraduate nanoscience education program; 2) undergraduate students receive research opportunities in nanoscience; and 3) institutions incorporate the new nanoscience topics into existing courses. Amongst all participant schools, the following are common problems in development: 1) institutions lack funding, which also affects the creation and re-allocation of facilities; 2) professors lack time to dedicate to the development of a new program; 3) there is not enough administrative support for an undergraduate nanoscience education program.

2. Introduction

Nanotechnology is a new discipline that has many applications in fields that range from biomedicine to space exploration. It is the science and engineering of manipulating properties of materials at the molecular level, or $1*10^{-9}$ meter. The ability to control individual molecules at this size level in solid substances can greatly alter their physical and chemical properties, which provides the ability to design and engineer new materials from the atomic scale all the way to the macro scale, possibly creating stronger materials and self-assembling materials as well.

Since nanotechnology is in its infancy, experts in this field are needed to pursue fundamentals research in nanotechnology to push the discipline forward. Also, a sustainable workforce is needed to help ensure its survival so that products may be made available to the public. In addition, there is a need to explore the societal impact that nanotechnology may have in the future to prepare society for the changes that may occur as a result of nanotechnology. There is interest amongst those in academia (Appendix B) and government to introduce nanotechnology throughout all levels of education.

Currently, there are limited resources available to institutions trying to develop nanotechnology courses at the undergraduate level. Our objective was to compile information about undergraduate nanotechnology education development efforts. Our research covers not only the development process of schools currently sustaining courses in nanoscience, but also development efforts from schools without courses. The Division of Undergraduate Education (DUE) can use this information to gain an understanding of undergraduate nanoscience education development efforts, so they may guide their efforts in undergraduate nanoscience education appropriately. Also, since one of the

DUE's goals is to foster unity among institutions, this study presents an excellent opportunity for them to be more involved on the frontline of undergraduate nanoscience education efforts.

2.1 National Science Foundation Background

The National Science Foundation (NSF) is an independent agency of the U.S. government established in 1950 (Appendix A) by the "National Science Foundation Act". The foundation board consists of 24 members and a director who monitors the activities and projects of the NSF. Its mission statement is,

> *"To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense."* (National Science Foundation Homepage)

We worked with the Division of Undergraduate Education (DUE). Their mission statement is more specific towards undergraduate education,

> *"To promote excellence in undergraduate science, technology, engineering, and mathematics (STEM) education for all students."*

(National Science Foundation Homepage)

The DUE has set forth goals that will help them accomplish their mission. Their goals are to:

- *Provide leadership*
- *Support curriculum and development*
- *Prepare the workforce*
- *Foster connections*

Our efforts supported the DUE's objectives and were centered on the development of undergraduate nanoscience education. Hopefully, providing education in nanoscience will inspire undergraduate students to pursue further studies in nanoscience. Then the workforce needed to sustain nanotechnology will likely develop naturally.

3. Literature Review

Four significant workshops engaged the issue of undergraduate education in nanoscience. The first, the Nanotechnology Undergraduate Education workshop, demonstrated the need for a technician-level workforce in the area of nanofabrication. The second, the Nanoscale Science and Engineering Workshop, emphasized the need for synergy in the growth of nanoscience education at the undergraduate level. The third, the International Conference on Engineering Education, introduced two theoretical nanotechnology programs for engineering students at the undergraduate level. The fourth, the Nanoscale Science, Engineering, and Technology (NSET) workshop, indicated that society must prepare itself for the changes that may occur as a result of nanotechnology.

3.1 Evaluating Education

3.1.1 Nanotechnology Undergraduate Education (NUE) Workshop

On September 11, 2002 the National Science Foundation organized a workshop to discuss the development of undergraduate nanotechnology education. According to the proceedings paper of the NUE workshop, the following items summarize the requirements for stimulation of undergraduate nanotechnology education:

- Substantial investment from NSF in infrastructure and course development.
- Training in nanofabrication of a technician level workforce.
- Multi-disciplinary and multi-institutional approach.
- Nationally unified assessment.
- Information for the public and all levels of students about nanotechnology.

These are the five basic components that will push nanotechnology studies at the undergraduate level forward (Fonash, 2002, p.2). The first panel summary of the 2002 NUE workshop report was titled "Associate Degree Education" and explains the need for both hands-on education and technician level workers skilled in the area of nanofabrication. Also, this panel's summary discussed the need for "educational programs and financial aid programs to serve existing workers, dislocated workers, and students from underrepresented groups" (Fonash, 2002, p.6).

Penn State is one of the leaders in the nation's race toward nanotechnology education development, by having the only associate's degree program in nanofabrication. Pennsylvania's community colleges use the NSF sponsored National Nanofabrication Users Network (NNUN) facilities at Penn State. Students from 15 community colleges attend an 18-credit capstone semester in nanotechnology taught by NNUN staff. Over 140 students completed their capstone semester by the date of the NUE workshop. Graduates are currently working for companies using nanotechnology while continuing their education.

According to Fonash, the only evident threats to undergraduate nanotechnology education are the "failure to provide the skilled workers and failure to provide the adequate funding and facilities for nanotechnology education programs" (Fonash, 2002, p.7). To facilitate the growth process of undergraduate nanotechnology education, state governments must become actively involved in its promotion (Fonash, 2002, p.7). The problem of high-cost training must be overcome as well. National conferences on state and regional workforces and economic development must address the inevitability of the influence nanotechnology will have on the economy. Successful programs and other efforts should be made accessible to all other organizations attempting to promote undergraduate nanotechnology education. The development of undergraduate nanotechnology education programs should be a multi-disciplinary and multi-institutional effort (Fonash, 2002, p.7).

Penn State's multi-institutional approach is unique. They offer community college students access to nanoscience facilities. Their multi-institutional model may encourage other community colleges to form partnerships with major research universities with adequate facilities. This will ensure that community college students have access to the best facilities that may train them for technician level work, and possibly inspire them to pursue higher degrees. Effective partnership and collaboration is important in ensuring the success of undergraduate nanotechnology education, as well as sustaining a future nanotechnology industry.

3.1.2 Nanoscale Science and Engineering Education Workshop

The Nanoscale Science and Engineering Education (NSEE) workshop was a three-day conference held September 28-30, 2003 at the NSF. The focus of the workshop was on nanoscience education, and ways to expand it. It was very similar to the NUE workshop, in that this conference was organized to promote synergistic growth among universities pursuing nanoscience education and research (NSF: NSEE, 2003). Workshop topics ranged from building nanotechnology research centers to expanding nanotechnology education in universities.

Course Content:

A group led by Dr. Wendy Crone from the University of Wisconsin – Madison demonstrated the integration of nanoscience modules into the undergraduate engineering curriculum. The team chose six courses for modification, ranging from introductory engineering courses all the way to senior level materials science and mechanics courses.

Most of the modifications eliminated outdated course content and replaced it with updated content pertaining to nanotechnology (Crone, 2003). This is a wise first step in a program creation process, for it introduces certain topics in nanoscience to students thereby raising awareness and piquing student curiosity. Student interest is vital if an institution wants to make nanoscience courses at the undergraduate level available.

The University of Central Florida (UCF) has successfully designed a nanoscience program for undergraduates. The nano-related classes cover the disciplines of Engineering, Chemistry, and Physics. UCF has courses in "Nanomaterials Processing and Engineering" which is important for mechanical and chemical engineers. They offer two other courses pertaining to nanomaterials, under the Mechanical Engineering Department. The Physics Department offers courses in nanophysics, as well as nanophotonics. The Biology Department offers a course called "Nanobiotechnology" as well (Seal, 2003). However, the UCF group failed to outline a method of assessing the effectiveness of their nanoscience program.

Lab Approaches:

For courses with a laboratory component, a thorough revision of laboratory experiments had to be done to make time available for nanoscience laboratory experiments. Most of the new topics were chosen from current nanotechnology research, and modification of experimental procedures had to be done to obtain reproducible results. Dr. Wendy Crone and her group implemented a survey to judge student satisfaction with the nanoscience experiments. Based on the feedback, most students responded positively to the labs (Crone, 2003). One student reported her appreciation of the relevance of her lab experience to cutting edge research.

Faculty Recruitment:

Also, the UCF group discussed how their nanoscience research and education program affected their hiring decisions. Within the Mechanical Engineering department, the chief strengths lie in Processing and Characterization. To gain broader expertise in nanoscience, they hired new professors whose specialty ranged from carbon nanotubes to nanomaterials (Seal, 2003).

3.1.3 International Conference on Engineering Education

Under the sponsorship of the International Network for Engineering Education and Research (INEER), the National Science Foundation, and the supervision of numerous committees, the ICEE is held annually to discuss the advancement of engineering education. Since 2001, papers have been submitted to the conference that outline undergraduate nanoscience course discussion topics/syllabi, student progress assessments, laboratory experience, and integration of nanoscience topics into chemistry, physics, biology, and engineering.

Laboratory experience and integration of nano-modules in other courses have been greatly emphasized. In nanoscience education papers such as the NUE, NSET, NSEE, and the National Nanotechnology Initiative (Appendix C), the integration of theory and practice has been discussed in with nanoscience laboratory modules in lecture courses to add a dimension of reality to the topics discussed in lecture. By adding nanoscience topics to science and engineering courses, exposure to nano-topics can begin before students take nano-specific courses.

Some topics were not approached by these papers, such as pre-implementation development. Although information about intended nanoscience courses can be useful to schools, those still developing courses may not be at a point where this information is helpful yet. Such topics included motivation, development highlights, student interest, and other pre-implementation steps.

3.1.4 Nanoscale Science, Engineering, and Technology (NSET) Workshop

The subcommittee of the National Science and Technology Council (NSTC) on Nanoscale Science, Engineering, and Technology (NSET) organized this workshop held on September 28-29, 2000. The purpose of this workshop was to discuss the societal implications of nanoscience and nanotechnology.

Job Transition:

Preparing for the change in society is one of the major issues with nanotechnology and this workshop makes some important points on the societal transformation awareness that is needed for nanotechnology. One concern is the extreme effects of nanotechnology that may boost the economy and change everyday life. What the NSET wants to stress is the need to create a cohesive technological growth process. This process can be initiated by fostering communication between schools, so they can monitor growth and they can understand the effects that nanotechnology may have (Roco, 2001).

Preparation of Students:

Dr. Fonash discusses what must be changed in schools for their nanoscience programs to flourish. Nanotechnology is a very broad field that will require a background in all life sciences, which most engineering programs try to avoid. Few schools have attempted to create this broad science background but it may be a necessary step. Rethinking educational background is part of developing a new topic in science but there are many different strategies that may be used in the early stages of a new field.

3.2 Conclusion

The information reviewed provided us with a sound vision and understanding of where undergraduate nanoscience education is now, and where it is headed. The NUE and ICEE papers present a vision on implementing nanotechnology related courses. This information can be used as a template for collecting data on current program creation methodologies. From this literature review, we developed an understanding of how we should approach our project.

4. Methodology

Two different surveys were developed to gather relevant information regarding efforts in the development of undergraduate nanoscience education. The methodology section discusses the survey information categorization, steps in creating the surveys, survey participant selection, and coding techniques. The word "Developed" will be used in reference to the survey pool containing schools with nanoscience courses or programs. The word "Developing" will be used for the survey pool of schools without programs, which may be interested in undergraduate nanoscience education development.

4.1 Survey Information Categorization

Variations between the survey questions for each pool of participants led to the need for two different surveys.

Developed Pool:

Under each category, there are several subcategories. This organization helped us in the survey creation process, as well as in categorizing the information obtained from the surveys. The three main categories used were: Program Administration, Program Implementation, and Insights. The description of each category and subcategory is summarized in Table 4.1.

Table 4.1: Categories of information for the developed pool

Main Category	Subsections	Description
Program Administration	*Program Creation & Development*	How the program was created. There is a description of the first course in nanoscience offered at the selected institution, which includes the course topic and the date of creation. The departments involved in this course are listed as well as new facilities allocated or created.
	Program Expansion	Long-term goals of the institution involving undergraduate nanoscience education.
Program Implementation	*Available Courses*	List of courses offered in nanoscience at the undergraduate level accompanied by course descriptions.
	Faculty/Student Numbers	Number of faculty and number of students involved in undergraduate nanoscience education.
	Lab Work	Hands-on experience available to students. Details on specific lab facilities and tools may be given.
Insights	*Highlights*	Effective steps that helped the institution in the development of undergraduate nanoscience education. Methods to improve student involvement.
	Problems	List of problems faced when trying to develop an undergraduate nanoscience education program and current concerns.
	Recommendations	Recommendations from the selected institution for other schools looking to become involved in undergraduate nanoscience education.

Developing Pool:

Table 4.2 summarizes the three main categories and subcategories for the developing pool and includes a description of each category.

Table 4.2: Categories of Information for the developing Pool

Category	**Subcategory**	**Description**
Program Administration	*Motivation*	Types of topics that motivate the institution to get involved in undergraduate nanoscience education.
	Goals for expansion	Intended means for nanoscience education, if it is applicable.
	Creating Interest	Plans to obtain students involved in undergraduate nanoscience education.
Program Resources	*Faculty/Student numbers*	Number of Faculty and Student involved in undergraduate nanoscience education.
	Facilities Available	Laboratory facilities are already available that might aid in the creation of a undergraduate nanoscience program.
Insights	*Problems*	Problems the institution has faced while trying to get involved in undergraduate nanoscience development.
	Questions	Questions the institution would like answered to help in the development of an undergraduate nanoscience program.

4.2 Survey Production Process

Each survey was created using the outlines presented in Tables 4.1 and 4.2. Contacts at the NSF-DUE reviewed the survey questions examining them for appropriateness, understanding, and organization. Comments centered on questions that should be avoided, as well as on wording of some questions. The reviewers expressed a concern that the second survey was too similar to the first and consequently, would not provide meaningful information.

After making substantial revisions to both surveys, a second pilot was done and extended throughout the NSF including people from the Division of Chemistry (CHE), Division of Elementary, Secondary, and Informal Education (EISE), Division of Engineering Education and Centers (EEC), and to survey specialists in the Division of Research, Evaluation, and Communication (REC). We asked questions centering on content and structure. Most of our contacts suggested that we make the survey questions less open-ended and more direct by integrating more multiple-choice questions. The surveys in their final form are in Appendix D and E.

4.3 Survey Pool Sampling Process

We sampled institutions according to the guidelines summarized in Table 4.3 on the following page.

Table 4.3: Survey Pool Criteria

	Pool 1 - Developed Schools	Pool 2 - Undeveloped/Developing Schools
Criteria to be in survey pool	Already supporting nanoscience course (s): Lecture or Laboratory Course(s)	Not currently supporting nanoscience course(s): In development or not.
Reason	To collect valuable information about successful development processes.	To gather information about problems and what else they would like to know.

Once a criterion was set for the survey pools, schools to be surveyed were identified for the respective pools. Information provided by the NSF and research journals were the main source to find and place schools in the proper survey pool. The resources used to compile a final list of survey participants are summarized in Table 4.4.

Table 4.4: Contact Sources

Means of Selection	Reason
NSF Nanoscience Funding Awards	
Nano-research	Schools currently researching may be able to educate
Nano-facilities	Nano-labs at universities may be able to aid education
Nano-education	Money for development of nanoscience course(s)
Research Journals	Researchers may be professors. If they can conduct research (materials and expertise), they may be able to teach nanoscience courses.
NSF Contacts	Professors/researchers involved in nanoscience identified by NSF employees.

The schools identified were then contacted by phone and e-mail to identify who would be the most appropriate survey participant from that school, as well as identifying whether the school fit in the 'developed' or 'developing' pool. Once the appropriate survey participant for the schools was found, the individuals would be told the criteria for the survey pools, allowing them to choose the most appropriate pool for their institution. The final pools are displayed in tabular form in Appendix G.

4.4 Data Collection

Web-based surveys were the main surveying technique employed. Some telephone interviews were conducted, but most of the information gathered came from our web-based surveys. Web-based surveys allowed the respondents to take their time and think about the questions, so a more careful response could be produced. Generating a form for the web-based survey required little knowledge of web programming languages, for surveying software is available.

4.4.1 Tracking of Participants' Progress

Tracking the participants' progress with the survey was a key factor in maintaining timely responses. We made a list of participants, including their email addresses, the date the survey was sent, and the date the survey was received. We sent two follow up e-mails in regular intervals and asked for continuous feedback regarding the presentation of the survey. Also, these e-mails set deadlines for the completion of the surveys. We asked whether the respondent is the proper person to complete the survey, and when we can expect a response. Additionally, we asked if there are any problems with the survey that needed to be addressed, before they can answer the questions. This process ensured accurate surveying and a better response rate.

4.4.2 Survey Information Expectations

In order to plan towards the analysis of the data and to achieve the goal of the project, it was necessary to predict some of the responses to the survey. This allowed us to produce a better and more focused survey.

Problems in Development:

The major problems reported in both survey pools in our opinion could have been a lack of student interest and administrative support. Since nanoscience is a relatively new field, most administrators do not have enough knowledge to be able to effectively make decisions on the support of ongoing nanoscience education development efforts, as there is much skepticism about the future of nanoscience. This applies to student interest as well, since most students are not aware of what nanoscience is and the potential impact it could have on science and engineering. This could affect enrollments in nanoscience courses, as well as any development efforts that schools in the developing pool are involved in.

Motivation for Development:

Often times, scientific journals can inspire someone to delve into a certain area of research interest, such as nanoscience. We thought that popular literature topics would be an influential factor in the development of undergraduate nanoscience courses, for professors can draw information from current research topics and integrate the topics of interest into their research. In relation to this, we thought that ongoing nano-research at the participant's school would inspire them to develop a nanoscience course for undergraduates.

Intended Means for Development:

For this question, our prediction was that the respondents would likely indicate that they are incorporating nanoscience topics into non-nanoscience courses and they either intend to develop a nanoscience course, or continue developing nanoscience courses for undergraduates. We did not feel that most institutions would be thinking about offering concentrations, minors, or majors due to the infancy of nanoscience.

Lab Experience in Nanoscience for Undergraduates:

This question was specific to the developed pool, and our prediction was that most institutions offer research opportunities in nanoscience for their undergraduate students, in addition to the following: individual nanoscience lab courses, nano-related labs in non-nano lab courses, and a laboratory component in nanoscience classes. The reason behind this is that institutions in the developed pool tend to have more funding available mainly in the form of grants. This will help offset the high cost associated with allowing undergraduate students to handle the expensive equipment utilized in research.

Facilities for Undergraduate Lab Experience:

We predicted that most developing schools would either have no facilities or facilities in development since many of these institutions do not necessarily have the funding sources to house such facilities let alone, let undergraduate students work with the costly instrumentation used primarily in research.

4.5 Coding Process

The information gathered was in the form of multiple choice selections and open-ended responses. For each multiple-choice question, we reported how many institutions selected each response. In the case of verbal responses, these were coded into commonly occurring categories. Multiple raters revised the coding and the categorization to ensure the reliability of the coding system.

5. Results and Discussion

The information obtained from the surveys are presented, discussed, and analyzed in the following sections. To facilitate comparison of data, graphs and tables have been prepared that compare quantifiable factors between each pool of schools. Some questions are specific to each survey pool while other questions were asked to both groups. Therefore, it is necessary to discuss the specific questions asked to the developed schools and the developing schools separately and then discuss the questions that were common to both survey pools. Also, it is important to note that since our pool is small we cannot conclusively state that these findings constitute an accurate picture of development efforts at institutions across the United States.

5.1 Developed Pool Questions

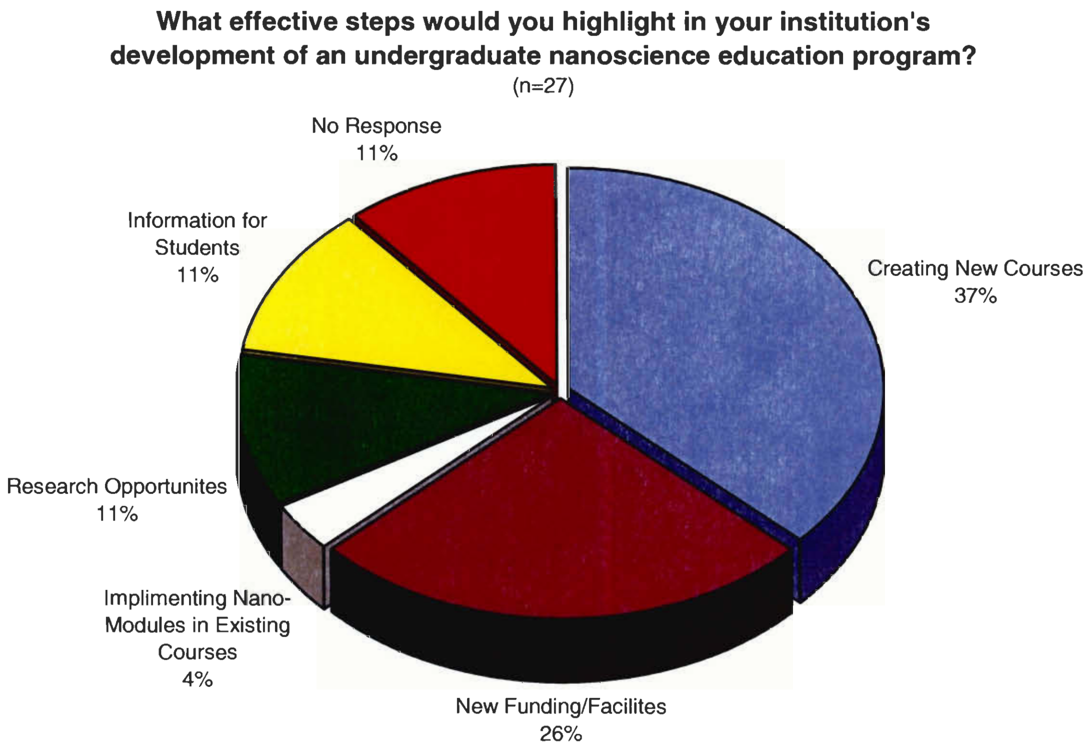
5.1.1 Key Developments

The purpose of this question was to find the milestones in development of undergraduate nanoscience education in the developed pool. This question specifically asked for the first course offered, the date it was offered, as well as other courses offered after the first course. Also included are the facilities built or planning to be built to help accommodate nanoscience growth as well as the departments involved. There is no analysis involved, as this question merely provides information about the development process. Appendix F is organized to display the responses given from each school. It is important to note that the appendix leaves out the course descriptions.

5.1.2 Highlights in Development

The "Development Highlights" question was left open-ended because the types of responses could not be predicted. After receiving over 15 responses, categories could be created to classify the responses, which were: Creating New Courses, Funding/Facilities, Implementing Nanoscience Modules in Existing Courses, Research Opportunities for Undergraduates, Facilitating Information, and No Response. Figure 5.1 summarizes this information.

Figure 5.1: Developed Pool - Highlights chart



Creating new courses:

Of all the responses, the creation of new courses was most frequently noted. Some of the responses that fall under this category include: courses not meant to be permanent, introductory/interdisciplinary courses, and new lab courses.

New funding/facilities:

New funding and facilities is the next most common response, with schools giving recommendations such as prioritizing funding proposals, developing new facilities, and obtaining new instrumentation.

Research Opportunities:

Of the responses, 11% of the participants indicated "Research Opportunities" as a highlight. These responses consisted of both paid and unpaid undergraduate nano-research.

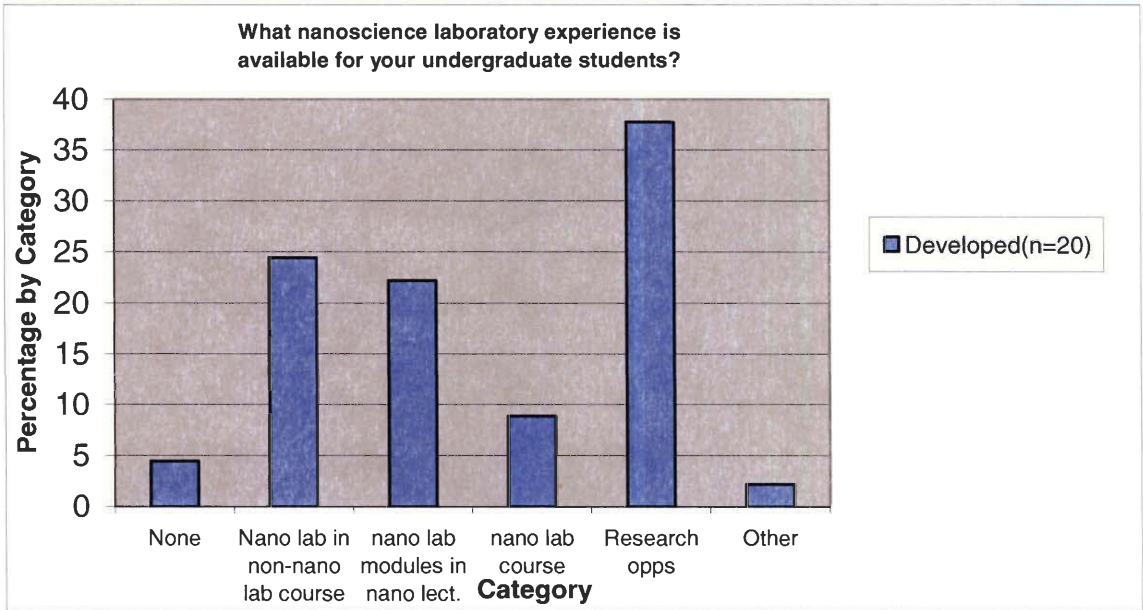
Information for Students:

For "Information for Students", 11% of participants included it as a highlight with responses like facilitating information with flyers, orientation, seminars, and guest speakers.

5.1.3 Lab Experience

A multiple-choice question about lab experience was posed to institutions in the developed pool. The aim of the question was to extract information pertaining to how schools are integrating nanoscience into undergraduate laboratory courses, whether they are providing compulsory laboratory experiences in nanotechnology classes, offering individual nanoscience laboratory courses, or providing research opportunities for undergraduates. Figure 5.2 summarizes the frequency in which each option was indicated.

Figure 5.2: Lab Experience for Undergraduates



None:

Only 4% of the participants in the developed pool indicated that they offer no nanoscience laboratory experiences to undergraduates. This means that most schools in the developed pool do provide some laboratory experience in nanoscience to undergraduate students, even though most research in nanoscience is performed at the graduate level.

Nano-laboratory Experiments in Non-nanoscience Laboratory Courses:

24% of the participants indicated that they integrate nano-related lab modules into existing laboratory courses. This shows that most institutions in the developed pool are revising laboratory course syllabi, to make space for nano-related topics, which will in turn inspire students to do further research in nanoscience. It must be noted that modifying existing syllabi for laboratory classes to include nanoscience labs can be a tedious process, and the ability to integrate nanoscience laboratory experiments into laboratory courses is a notable achievement.

Laboratory Component in Nanoscience Courses:

Of the participants, 24% of them indicated that they have a laboratory component to their nanoscience courses. Developing laboratory experiments based on nanoscience is a tedious task since it involves taking actual research in nanoscience, and converting it into a laboratory exercise that will not overwhelm students, and also one where results can be reproducible.

Nanoscience Lab Courses:

Of the 19 respondents in the developed pool, only 8% indicated that they offer a nanoscience laboratory course.

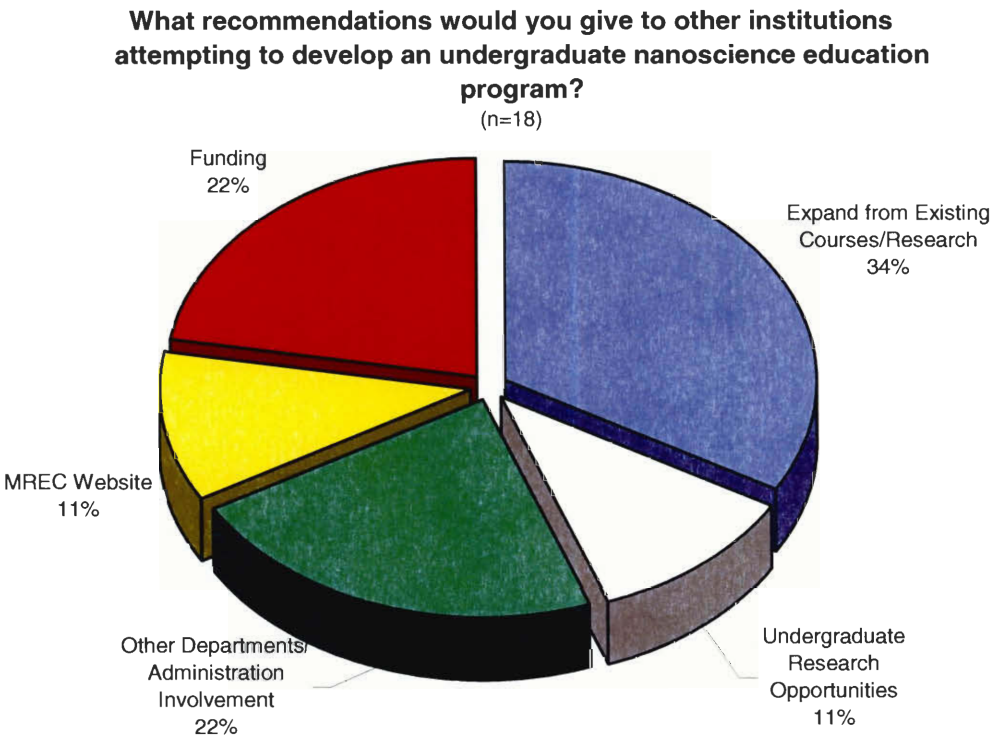
Undergraduate Research Opportunities:

Approximately 37% of the respondents in the developed pool make research opportunities in nanoscience available to undergraduate students. This is an excellent way of developing student interest in nanoscience/nanotechnology. Offering research opportunities to undergraduates may inspire them to do further research in nanoscience, or take on a more rigorous course load to help them with their research, which may involve taking nano-related classes at their school.

5.1.4 Recommendations

Developed schools were asked to provide recommendations to other schools on the topic of development.

Figure 5.3: Recommendations



Expand from Existing Courses/Research:

The most frequent response was the recommendation to expand from what is currently available at the school, whether by implementing nano-topics in existing science and engineering courses or building off of current on-campus research. Of the responses, 34% of the developed schools recommended this as a key step in development.

Funding:

The second most common recommendation was to obtain funding with 22% of participants in the developed pool recommending this as a key step. Developing a course or a set of courses requires substantial funding due to the amount of time a professor has to spend devoted to such a task. Also, without funding the departments involved cannot provide students with the necessary facilities.

Other Department/Administration Involvement & Undergraduate Research Opportunities:

Of the respondents, 22% suggested cross-disciplinary research opportunities. Getting departments involved in the program and providing research opportunities both seem like important steps that may make development efforts more successful. It must be noted that it is difficult to make a conclusion on its importance given the size of our survey pool.

MRSEC Website:

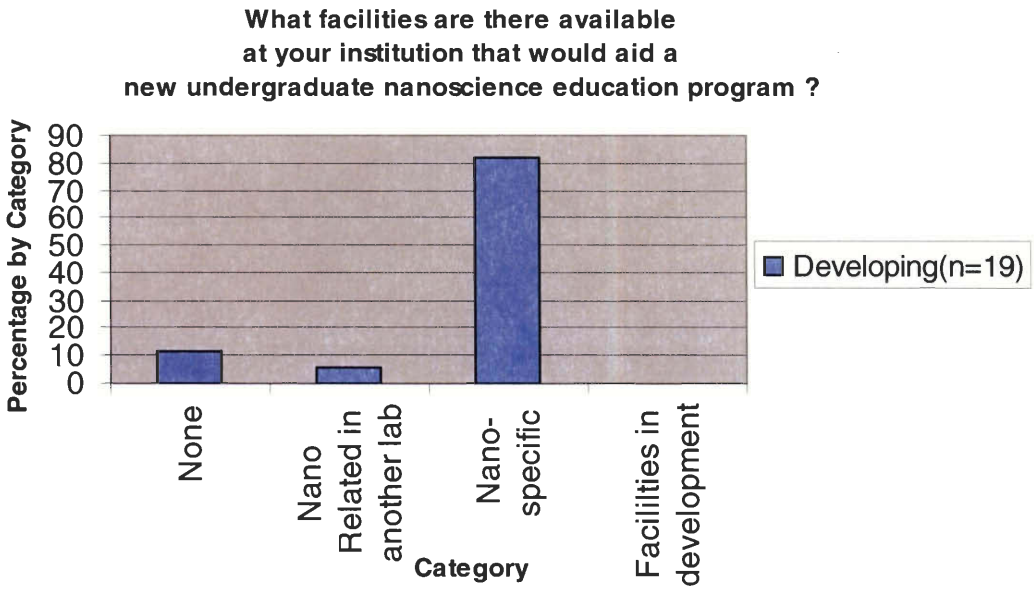
One website, http://www.mrsec.wisc.edu was cited by 11% of the respondents. Although the responses pointed to different subsections on the site, it was recommended more than once, therefore providing a separate category for the website was deemed reasonable.

5.2 Developing Pool Questions

5.2.1 Facilities

Developing schools were asked about their availability of lab facilities. The figure on the following page summarizes this data.

Figure 5.4: Facilities for Undergraduate Lab Experience graph

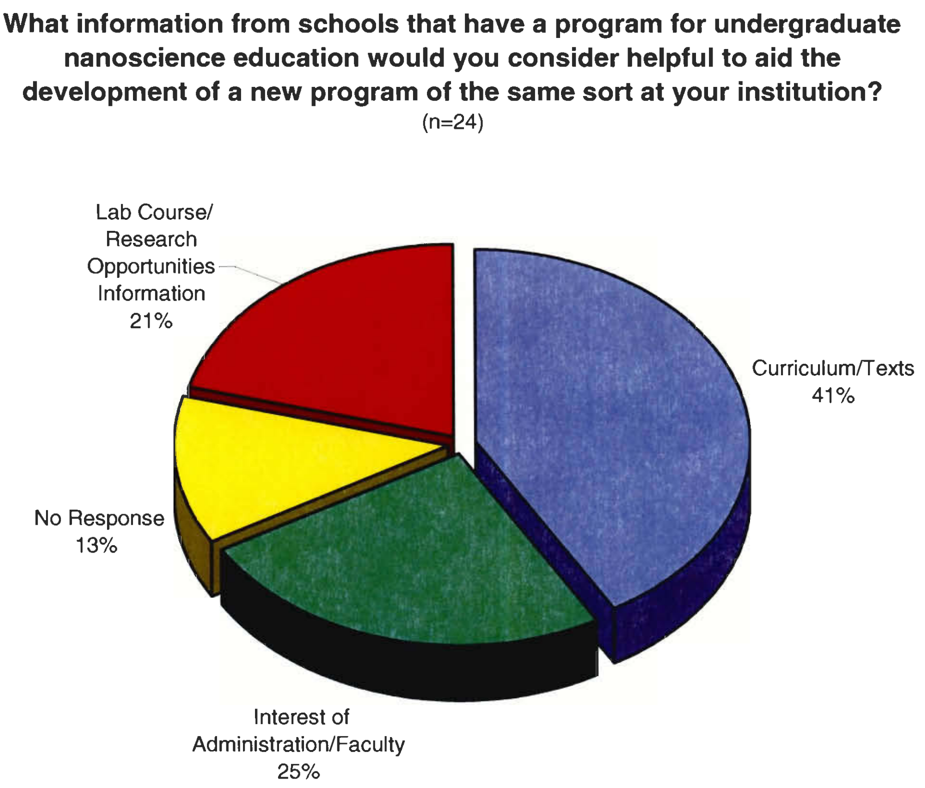


Roughly 82% of the participants indicated that they have nano-specific facilities at their respective institutions, while 12% of the participants indicated that they have no nano-specific facilities, which usually means they lack both instrumentation, as well as actual physical facilities to host such research or laboratory experiences for undergraduates. Another 3% indicated they have equipment used in nanoscience research in another laboratory.

5.2.2 What Schools Want to Know

Responses we received from our question to the developing survey pool fall into four categories: Curriculum/Textbooks, ways to gain student interest, laboratory information, and no questions. This information is summarized in Figure 5.5.

Figure 5.5: Questions



Curriculum/Textbooks:

Curriculum/Textbooks was the most dominant category for this question. Of the respondents, 41% asked questions about course descriptions, textbooks, courses being changed, removed, or added, and explanations for such decisions.

Interest of Administration/Faculty:

Gaining interest of administration and faculty also proved to be an important issue with 25% of participants giving this response. One individual mentioned that they are specifically looking for letters/essays written by administrators as to why nanoscience education is good for all schools. This respondent noted, “They don’t always listen to faculty and/or students and/or local industry.”

Lab Course/Research Opportunity Information:

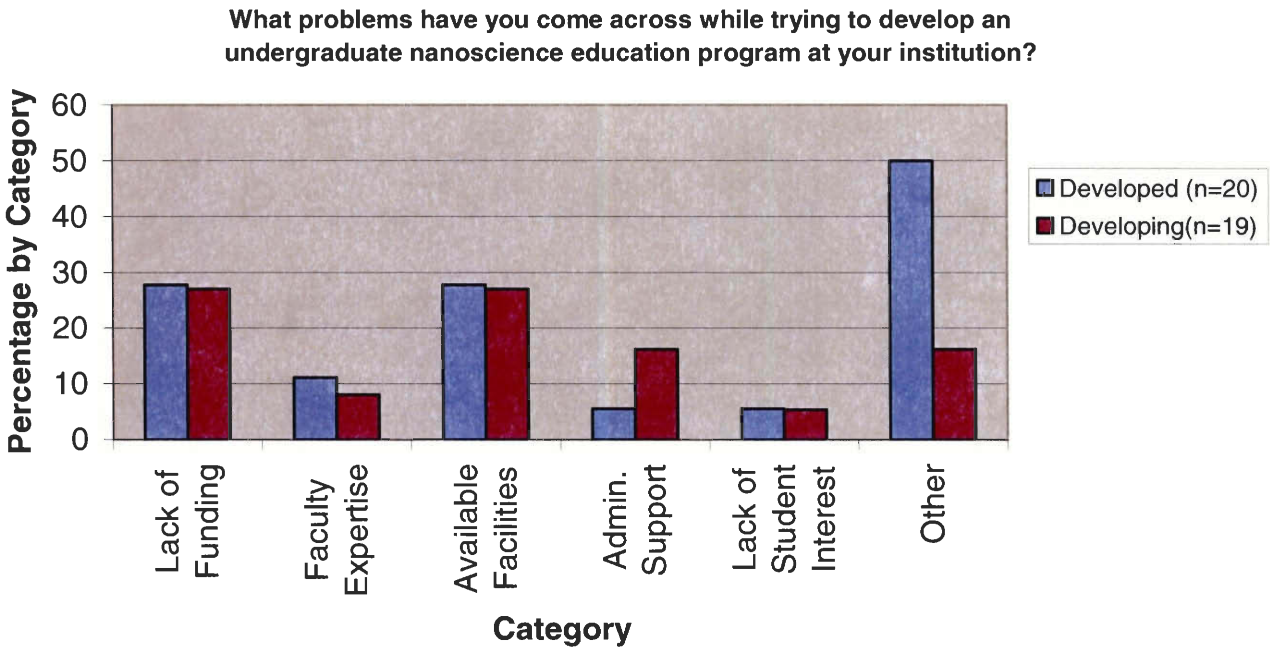
The last category of responses included laboratory information, both for courses and undergraduate nano-research opportunities. Hands-on education was stressed for nanoscience in the literature, so these questions are reasonable.

5.3 Common Questions

5.3.1 Problems in Development

Our intent in asking about problems in development was to compare common problems between institutions in the same pool, as well as different pools. This will ultimately help institutions in the development phase to identify common problems, so they may take proper steps to avoid complications in the future. This information is summarized in Figure 5.6 on the following page.

Figure 5.6: Problems in Development



Lack of Funding:

The first option for "Problems in Development" is "Lack of Funding". In the developed pool, 28% of the participants indicated lack of funding as a problem in their development process versus 27% of the respondents in the developing pool. This shows that schools in both pools are encountering problems in obtaining adequate funding for undergraduate nanoscience education programs.

Lack of Faculty Expertise:

Of the participants in the developed pool, 12% indicated lack of faculty expertise as a problem in the development process, while 8% of the respondents in the developing pool indicated that it is an issue in their development process. This further suggests that faculty expertise is a minor issue in the development process, and is irrelevant when it comes to teaching nanoscience courses to undergraduate students. One can infer that professors in each discipline have adequate exposure to the current-events in their field, thus suggesting that they have ample exposure to the various applications of nanoscience or that the department/institution hired faculty whose expertise is in nanotechnology.

Lack of Available Facilities:

Only 28% of the respondents in the developed pool indicated lack of facilities as a hindrance to development, which compares closely to 27% of the institutions in the developing pool indicating this choice as a problem in the development process.

Lack of Administrative Support:

In the developed pool, approximately 5% of the participants indicated that a lack of administrative support is hindering their development process, as opposed to 15% of the participants in the developing pool. These numbers show that administrative support is three times more prevalent as an issue in developing schools. Developed schools have already obtained the support to get a course developed so it makes sense that they are having less of a problem getting support from administration.

Lack of Student Interest:

Only 5% of the respondents in the developed pool indicated that a lack of student interest is preventing the development of undergraduate nanoscience courses and approximately 5% of the participants in the developing pool indicated this option as well. This shows that there is a remarkable interest in nanoscience among students, therefore, campaigns to boost student interest are not necessary.

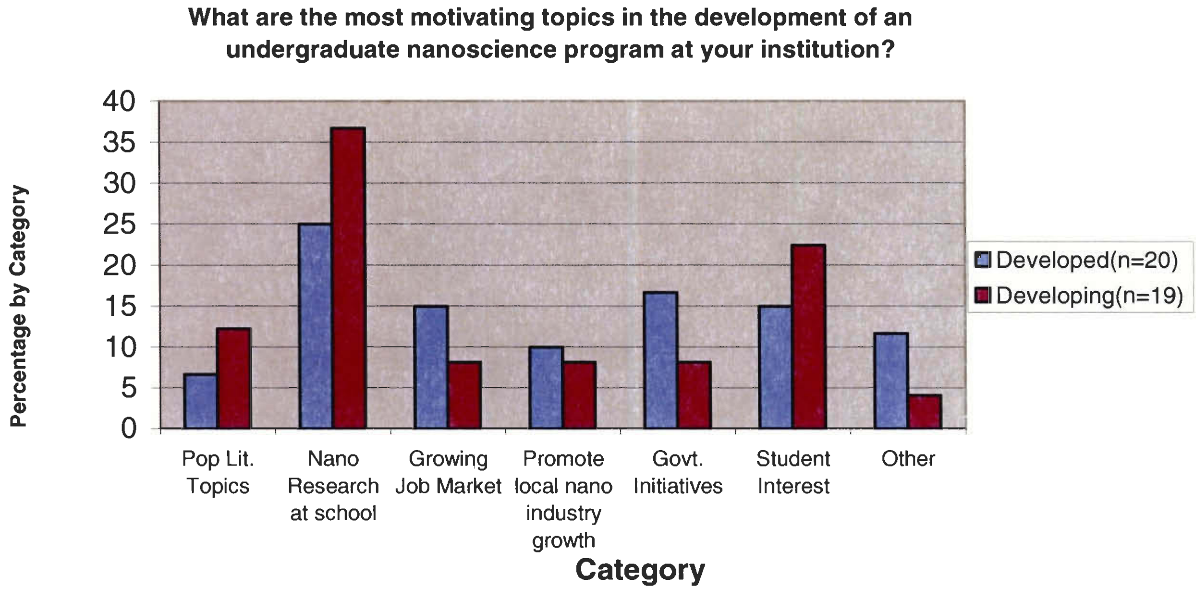
Other:

In the developed pool, 50% of the respondents indicated an "Other" response, compared to 15% of respondents in the developing pool. The most frequent response was lack of time to teach nanoscience courses, given current course load of professors as well as a lack of time to devote to a task such as curriculum development. Other less anticipated responses include "unproven job prospects", meaning that most professors are too skeptical about the future of nanoscience to teach it to students.

5.3.2 Motivation for Involvement

The second question in both surveys dealt with the motivation for the development of undergraduate nanoscience courses. The purpose of the question was to find common factors influencing the development of undergraduate nanoscience courses. On the following page, Figure 5.7 summarizes this information.

Figure 5.7: Motivation for Development graph



Popular Literature Topics:

Only 8% of the participants in the developed pool indicated that literature on nanoscience influenced their decision to introduce nanoscience courses at the undergraduate level. In the developing pool, 13% of the participants indicated that it was an influential factor in their course development. Thus, most participants do not feel that nanoscience literature is an influential factor in the development process.

Nanoscience Research at Your School:

In the developed pool, 25% of the participants indicated that nano-related research at their institution inspired them to develop a course or courses, while 37% of participants indicated this as a factor in development, in the developing pool. This shows that ongoing nanoscience research is a very influential factor in the ability to offer nanoscience courses to undergraduate students. If professors are conducting research in an area of nanoscience, then they have the ability to teach courses since they have the expertise.

Growing Job Market & Promotion of the growth of local nano-related industry:

Roughly 15% of participants in the developed pool indicated that a growing job market in nanoscience influenced their decision to develop undergraduate nanoscience courses, while 8% of participants in the developing pool indicated this as a factor. These numbers may be attributed to the fact that the job prospects in nanotechnology are not known yet, since the field is still in its infancy.

Participants were asked to indicate whether their motivation for developing nanoscience courses at the undergraduate level was to push the growth of nano-related industries in their area. Only 10% of the participants in the developed pool indicated that they desire to promote the growth of local nano-related industry while approximately 8% of the participants in the developing pool indicated this as a motivating factor in developing undergraduate nanoscience courses.

Government Initiatives:

In the developed pool, 17% of the participants indicated government initiatives as a factor in the push for undergraduate nanoscience course development, compared to only 8% of the participants in the developing pool. This category tends to be a more influential factor among schools in the developed pool, as they typically have more experts in nanoscience/nanotechnology so they may secure more grants from organizations such as: National Science Foundation (NSF), National Institutes of Health (NIH), and the Department of Defense (DOD). Since schools in the developing pool generally tend to have fewer resources at their disposal, they most likely have difficulty securing such grants due to heavy competition from institutions with developed programs.

Student Interest:

In the developed pool, 15% of the respondents cited student interest as a motivating factor for developing nanoscience courses, while roughly 23% of the participants in the developing pool cited this as an influential factor in development.

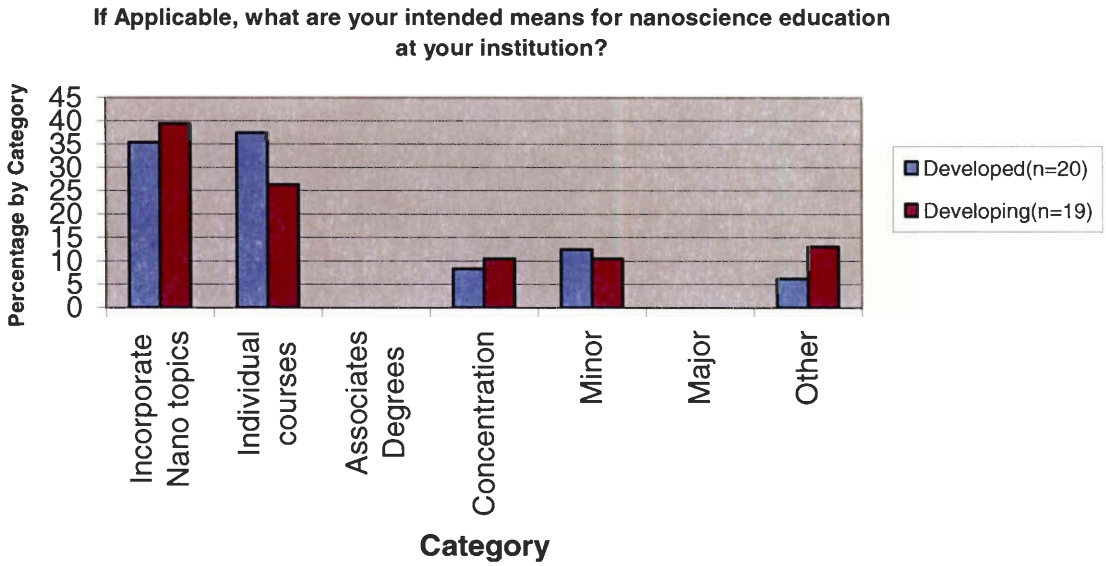
Other:

For institutions in the developed pool, roughly 13% of the participants indicated an "Other" response, compared to 9% of the respondents in the developing pool. One participant noted that the growth of nano-related research on campus, and its relation to graduate programs was a motivating factor in developing nanoscience courses at the undergraduate level. Another participant cited personal initiative in developing nanoscience courses at the undergraduate level.

5.3.3 Intended Means

The purpose of this question was to identify future goals of institutions in developing undergraduate nanoscience education. Also, we wanted to identify similar goals of institutions in both pools, so that patterns in the steps of the development process may be found.

Figure 5.8: Intended Means for Nanoscience Curricula Development



Incorporate Nanoscience Topics into Existing Courses:

In the developed pool, approximately 36% of the participants indicated that they desire to incorporate nanoscience topics into existing courses, which compares closely to 40% of the participants in the developing pool that cited this as an eventual goal of their program. Most institutions desire to integrate specific nano-related concepts in existing courses. This is an effective way of testing how successful a nanoscience course or courses could be.

Individual Courses in Nanoscience:

In the developed pool, roughly 38% of the participants indicated that they desire to implement individual courses in nanoscience in the future, compared to 27% of the participants in the developing pool. Most institutions desire to implement nanoscience courses in the future, however, they do not necessarily have the time to offer individual nanoscience courses to undergraduates.

Concentrations and Minors:

Of the participants in the developed pool, 8% indicated that they wished to offer concentrations in nanotechnology, compared to 11% of the institutions in the developing pool. These low numbers can be attributed to the fact that most institutions have not even developed a first course in nanoscience, or are still piloting their first course and have not even considered offering concentrations in nanoscience yet. This applies to minors in nanoscience as well. Roughly 12% of the participants in the developed pool indicated they intend to offer a minor, while approximately 11% of participants in the developing pool cited this choice, which was close to our personal expectations.

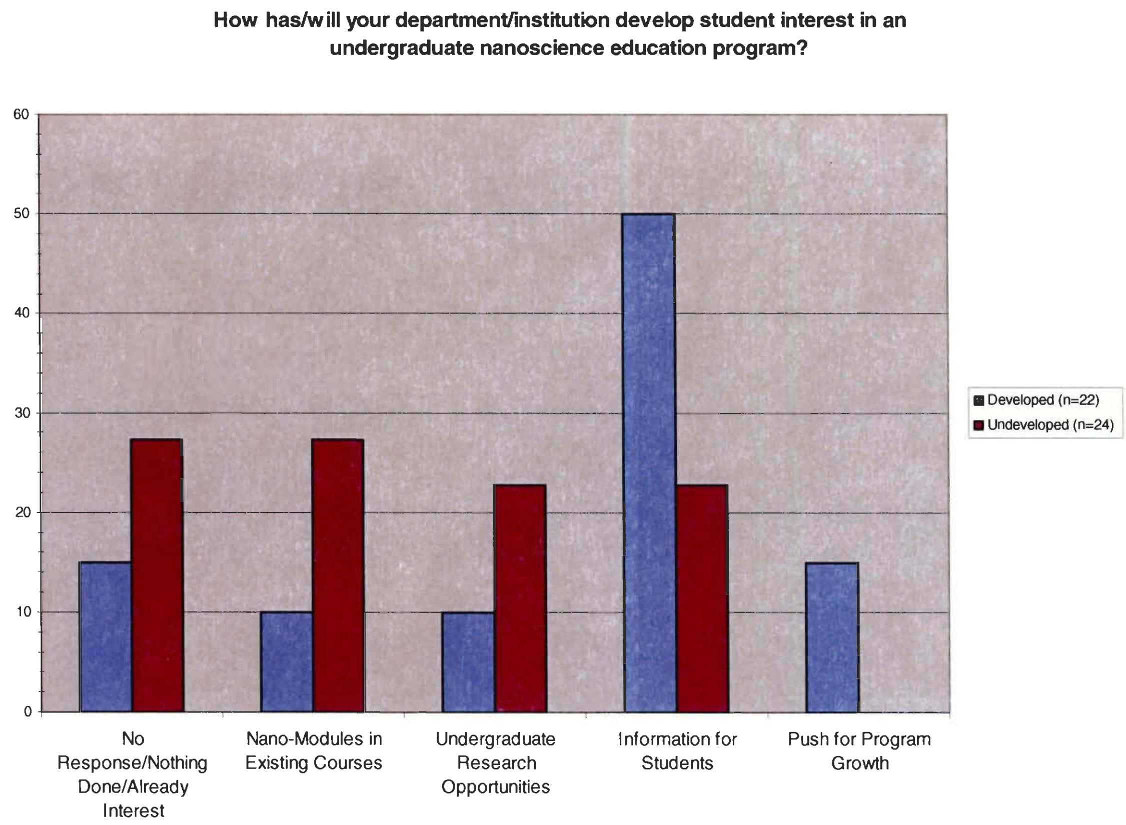
Other:

Among the developed pool, 8% of participants indicated an "other" response, while 12% of participants in the developing pool did. One participant indicated that they planned to offer a nanoscience course to non-science majors, while another stated that they intended to offer a nanotechnology certificate at their school. A participant indicated that they intend to incorporate nanoscience related experiments into compulsory laboratory courses, while another indicated that they are going to incorporate a nanoscience track into the Physics major.

5.3.4 Student Interest

The "attempts at gaining student interest" is an open-ended question but the same categories for both survey pools could be made, which are the following: Research Opportunities, Nano-topics in other courses, no response/nothing done/already interest, direct information. However, the developed pool had one category that the developing pool did not: Pushes for Funding/Space/Facilities/Growth. The following graph compares the responses from the two survey pools.

Figure 5.9: Student Interest chart



Information for Students:

For the developed pool, 50% of the respondents make information on nanoscience available to students. This included seminars, guest lecturers, alerting students in related courses, nanoscience information on campus, brochures of new nanoscience developments on campus, as well as making flyers advertising newly created nanoscience courses. For developing schools, roughly 22% of the schools reported that they make information available to students, however, this magnitude of response matched other responses providing no real distinction as to what they feel is the best technique in gaining student interest.

Research Opportunities for Undergraduates:

Amongst the developed schools, 10% of them stated that they offer research opportunities to undergraduates, even though developing schools had research opportunities as a common approach, and 22% of them noted that fact in their response. If this pattern were to continue after surveying more schools, it could be said that developing schools need to try and focus their methods of getting student interest elsewhere.

Nano-Modules in Existing Courses:

Amongst developing schools, 27% of them indicated they provide nanoscience in early or other courses. We found this to be interesting, since discussing nanoscience in other courses might get students to learn about nanoscience and become interested. Only 10% of the developed pool indicated that they have utilized this approach in their courses, which may indicate that this approach did not work for them or it is no longer necessary now that they have a course in nanoscience.

No Response/Nothing Done/Already Interest:

For developing schools, 28% of the respondents wrote a response that fits into a non-response category. This may indicate that they have not considered the need to gain student interest or they feel the interest is already there. Among developed schools, 12% fell into these categories, and a majority of them indicated that student interest is already present.

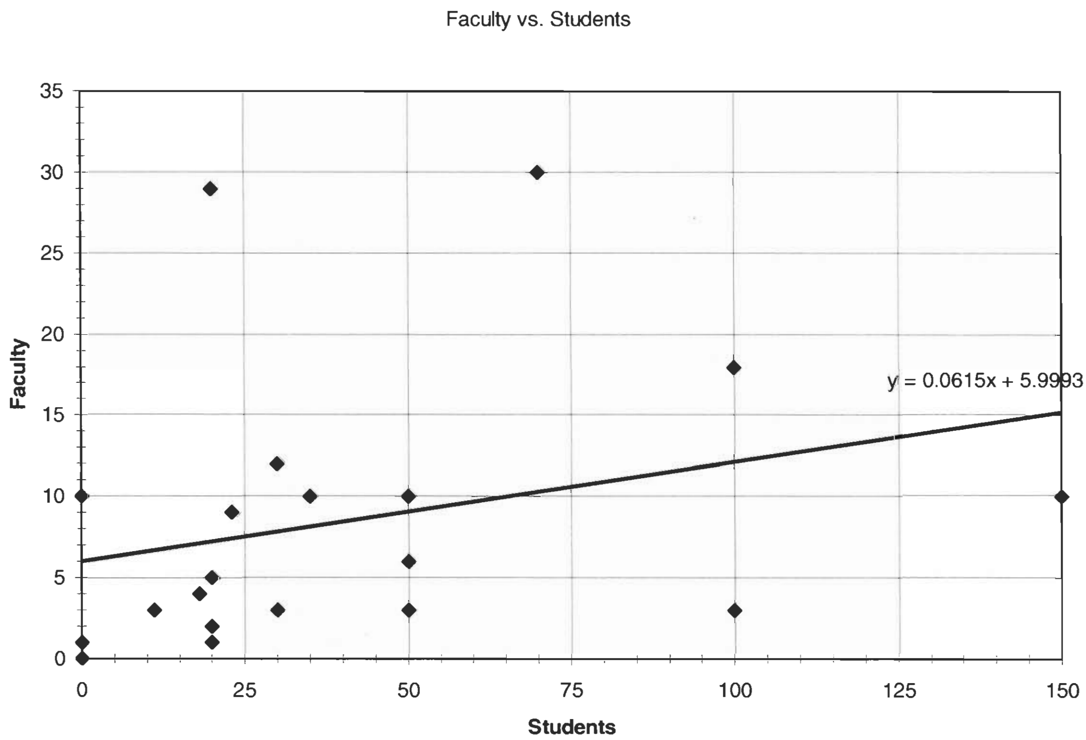
Push for Program Growth:

This was a response that only developed schools answered, and 14% indicated that they have been pushing for further growth of their program. It is important to note that it is their second most common approach to gaining student interest. Specifically, this entailed prioritizing nanoscience growth at the school, prioritizing funding proposals, allotting land/space for new facilities/instruments, and overall growth of current courses and research programs. Developing schools did not mention this technique mainly because it involves the actual implementation of a program which developing schools are yet to see. Once they begin providing courses and labs, they may see how providing courses in nanoscience stimulates student interest.

5.3.5 Student/Faculty Numbers

Figure 5.6 shows the ratios of faculty to students at the developed schools. The average of the individual ratios yielded a 0.2304 faculty to student ratio, roughly 1-to-4. The trend line calculates to $Y=0.0615X+5.9993$, which fits to a roughly 1-to-7 ratio. With such a fledgling topic like nanoscience, a ratio from 1-to-4 to 1-to-7 is a reasonable number. When more students get involved in a nanoscience program, this number will begin to decline.

Figure 5.10: Faculty v. Students plot



5.4 Discussion

5.4.1 Combination Questions

Tables 4.1 and 4.2 on the following pages summarize the hypotheses and results of each combination question. Each hypothesis is complemented by the actual results for each question, which facilitates efficient comparison between the hypotheses and results.

Table 5.1: Hypotheses/Results table for "Motivation"

Hypotheses	Results
We had predicted that popular literature would be an influential factor in the development of nanoscience programs at the undergraduate level.	a) 8% of the participants in the developed pool indicated that literature on nanoscience influenced their decision to introduce nanoscience courses at the undergraduate level. b) In the developing pool, 12% of the participants indicated that it was an influential factor in their course development.
We had predicted that professors who are active in nanoscience research would desire to either involve undergraduate students in their research, or teach a course in nanoscience.	a) 25% of the participants in the developed pool indicated that nano-related research at their institution inspired them to develop a course or courses. b) 37% of participants indicated this as a factor in development, in the developing pool.
We predicted that increased funding from the government for nanoscience education & research would in turn inspire institutions to pursue research in this area, and possibly inspire them to develop courses in nanoscience for undergraduates.	a) 17% of the participants in the developed pool indicated government initiatives as a factor in the push for undergraduate nanoscience course development. b) 8% of the participants in the developing pool indicated this option.
We had postulated that most institutions would not offer a course based solely on student interest in a particular subject.	a) 15% of the respondents cited student interest as a motivating factor for developing nanoscience courses in the developed pool. b) 22% institutions in the developing pool cited student interest as an influential factor in development.

Table 5.2: Hypotheses/Results table for other questions

Hypotheses	Results
Major problems amongst both survey pools are lack of student interest as well as lack of administrative support.	a) Only 5% of the respondents in the developed pool indicated that a lack of student interest is preventing the development undergraduate nanoscience courses. b) Approximately 5% of the participants in the developing pool indicated lack of student interest as a factor. c) In the developed pool, approximately 5% of the participants indicated that a lack of administrative support is hindering their development process compared to 16% of the participants in the developing pool.
For Intended Means, we had predicted that the respondents would likely indicate that they are incorporating nanoscience topics into non-nanoscience courses and they either intend to develop a nanoscience course, or continue developing nanoscience courses for undergraduates. We did not feel that most institutions would be thinking about offering concentrations, minors, or majors due to the infancy of nanoscience.	a) 36% of the participants in the developed pool indicated that they desire to incorporate nanoscience topics into existing courses b) 39% of the participants in the developing pool that want to make incorporation of nanoscience topics into other courses as an eventual goal of their program. c) 38% of the participants in the developed pool indicated they want to develop more courses in nanoscience in the future. d) 26% of participants in the developing pool indicated they want to develop individual courses in nanoscience in the future. e) Within the developing pool, 12% of participants want to offer concentrations in nanoscience, 11% want to offer minors, and 0% want to offer majors.
The "Lab Experience for Undergraduates" question was specific to the developed pool, and we predicted that most institutions offer research opportunities in nanoscience for their undergraduate students, in addition to the following: individual nanoscience lab courses, nano-	a) 22% indicated that they integrate nano-related lab modules into existing laboratory courses. b) 22% of the participants indicated that they have a laboratory component to their nanoscience courses. c) 8% indicated they offer a nanoscience

related labs in non-nano lab courses, and a laboratory component in nanoscience classes.	laboratory course. d) 38% of the respondents make research opportunities in nanoscience available to undergraduate students.
The "Facilities for Undergraduate Lab Experience" question was specific to the developing pool. We predicted that most developing schools would either have no facilities or facilities in development.	a) 82% of the participants indicated that they have nano-specific facilities at their respective institutions. b) 11% of the participants indicated that they have no nano-specific facilities c) 6% indicated they have nano-related facilities in another lab.

6. Conclusions and Recommendations

6.1: Introduction

This section describes the conclusions drawn from our surveying process, as well as our recommendations to the Division of Undergraduate Education. For the sake of readability, the recommendations will follow the conclusions. Also, it is important to note that these conclusions and recommendations are being made based on a small pool of schools, and does not necessarily represent the state of undergraduate nanoscience education at all institutions in the United States.

6.2 Conclusions

6.2.1 Commonalities in Development

Based on information gathered from the surveys, the most effective method in undergraduate nanoscience education development is the incorporation of nanoscience topics into other courses. Most schools are utilizing existing resources in their development efforts, in addition to gaining student interest by showing students how nanoscience will affect their chosen field of study. The developed schools indicated the first course in nanoscience is usually offered in the freshman or sophomore years. This helps students gain interest in nanoscience early on and may inspire some students to delve further into the applications of nanoscience in their chosen field of study. Also, most schools noted that involving undergraduate students in nanoscience research is an effective method for encouraging students to examine the possibilities of nanoscience.

6.2.2 Common Problems in Development

"Lack of Funding" and "Lack of Available Facilities" were the most frequently indicated issues in development, in addition to Lack of Administrative support, and "Lack of Time". This shows that most schools are struggling with the ability to allocate funds to devote to the task of curriculum development. This is inherently related to "Lack of Time", as schools that do not have time to devote to curriculum development, are naturally unable to write grant proposals to obtain adequate funding. "Lack of Administrative support" was typically attributed to a lack of awareness among administrators regarding nanoscience/nanotechnology. It was also found through the surveying process that many administrators remain skeptical about the future of nanoscience/nanotechnology and do not want to commit resources to promote a field that is relatively new. This issue is also rooted in the fact that other courses in the engineering curriculum will have to be removed to make space available for new nanoscience courses.

6.3 Recommendations

6.3.1 Forging Alliances with Colleges: Following Penn State's approach

In the process of searching for schools to survey we found an approach used by Penn State to get community colleges involved in nanoscience. The DUE should ensure that funding mechanisms are in place so that major research universities can form partnerships with smaller colleges through "Nanotechnology Centers". This will ensure that all college students interested in nanotechnology may have access to equipment used in nanoscience research, which their home college may not possess. It is important that these partnerships grow through the nanotechnology centers, as a technician level workforce skilled in nanotechnology is needed to produce products that will be used by the general public.

6.3.2 Public website

Utilizing information we collected, the DUE could design a public, searchable, database that would help schools that have not started developing, or are in the early stages of development of a nanoscience course or courses. This website can also be used by schools that have already developed undergraduate courses in nanoscience to further their expansion efforts. This would be of great use to all schools, as they will be able to find commonalities in successful development, as well as common problems. This website would be a step in ensuring successful undergraduate nanoscience education development.

A possible step in creating this public, searchable database is to implement another survey that is similar to ours, with a larger sample of schools. Then, they could return to our sample to follow up on their progress. If the schools in the developing pool have successfully implemented either their first course, or subsequent courses, then their development efforts can be used as a model for other institutions still in the development process.

6.3.3 Project Idea

Industry is going to be ultimately benefiting from students who are educated in nanotechnology therefore, it is important to know what they are looking for in students. A follow up project to our work can include the design of a survey specifically for companies utilizing nanotechnology. Questions should range from why there is an industry need for nanotechnology, to why it is beneficial to educate students in nanoscience/nanotechnology. A second survey can be specifically for schools that are active in nanotechnology education. Questions should range from why they chose to teach nanotechnology to students to why nanotechnology is important for industry as well as society. Questions should center on curriculum. Analysis can involve comparing industry versus academia regarding appropriate curricula. If schools are emphasizing too much or too little theory, then this should be noted and recommendations from experts in industry can be made. This can help establish common goals for both industry and academia.

6.3.4 Conference for Administrators

The NSF should host a conference specifically to educate administrators about why having a nanoscience curriculum at the undergraduate level is beneficial to the university as a whole. Administrators at universities that currently have strong nanoscience programs can be invited to speak. Specific topics in the conference can deal with successful development efforts in nanoscience education. Professors conducting research in nanotechnology can also make presentations about their work.

Poster Sessions can be held which display research that undergraduates around the country have done at their respective schools or at Research Experience for Undergraduates (REU) programs. Program Directors from the NSF who deal specifically with nanotechnology research and education can present how the government views the future of nanotechnology, and they can also publicize the number of grants awarded each year in nanotechnology research and education. This will help administrators see that there is generally a strong interest in nanoscience amongst students, professors, as well as government.

Notable experts in nanoscience/nanotechnology research and education should be invited as well, such as Dr. George Whitesides of Harvard University, Richard Smalley of Rice University, and Dr. Stephen Fonash of Penn State. Their talks should center on why nanotechnology and nanoscience education are needed in society. The expertise these people provide will help debunk the misconceptions relating to nanotechnology and will help administrators understand the field much better.

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Appendix A – NSF background

The NSF is broken down into 10 program areas.

These programs are:

- Biology, Computer-information sciences, Education, Engineering, Geosciences, International, Mathematical-Physical Sciences, Polar Research, Social-Behavioral-Economic, and Environmental Sciences.
- Nationwide and international investments in research and education have generated many benefits for the United States and because of these benefits the NSF is requesting 5.48 Billion for FY 2004, which is about 9% more than its budget for 2003.
- The NSF splits this budget up into four major groups of 1) development, 2) people, 3) ideas, and 4) tools.

Appendix B – Universities leading in Nanotechnology

University of Washington

- The University of Washington is the first school that offered a PhD in Nanotechnology (Center for Nanotechnology, 1997, Homepage). The National Science Foundation as the first step in building a nanotechnology curriculum funded this program.

- The requirements for this program involve about 50 courses that cover the very broad field of nanotechnology.

Penn State

- Penn State offer an associate degree in Nanofabrication Manufacturing Technology (NMT), on the condition that the student complete coursework at a home institution, then come to Penn State for a semester, doing capstone research (Penn State: Nanomanufacturing Team, 2003, Homepage).

- Some courses that Penn State offers through the NMT range from Nanofabrication instrumentation, which includes major experimental techniques used for manufacturing devices such as "lab-on-a-chip" technology.

Cornell University

- Cornell University's Center for Materials Research is playing a key role in establishing nanotechnology courses at the Undergraduate level. One of the courses the Center for Materials Research designed is an introductory course in nanoscience and nanoengineering (Brand, 2001, p.1).

- Students gain very practical knowledge in nanotechnology, as well as various applications including piezo-electronic materials, and quantum mechanical tunneling (Brand, 2001, p.1). Cornell program has yet to reach the depth of Penn State or Washington University but the development of their first intro course will be just as useful to our project goal.

Appendix C – National Nanotechnology Initiative

- With a budget allocation of $500 million under the Clinton administration (National Science and Technology Center, 2001, p. 3), the National Nanotechnology Initiative (NNI) was created to meet the need to understand, and explore the possibilities of the emerging field of nanotechnology.

- The initiative's purpose is to support research and education efforts in nanotechnology through R&D investment in the following areas: biology, medicine, green engineering, space, computers, and energy.

- Participating government agencies include the National Science Foundation, Department of Defense, Department of Energy, National Institute of Health, and the National Institute of Standards and Technology.

- According to the NNI Implementation report, roughly 70% of the new funding proposed under the NNI will go to university-based research, funds that will help meet the growing demand for workers with nanoscale science and engineering skills (National Science and Technology Center, 2001, p.15).

- In order to provide sustained support, and infrastructure to academia, in addition to the Grand Challenges, some smaller goals include: the establishment of nanotechnology research centers, where information can be exchanged freely between academic institutions, and where facilities can be shared.

- The NNI also wishes to provide educational support for students, thus preparing students well for the workforce, and academic positions. Another major purpose is to assess the effect of nanotechnology on society, specifically in the areas of policy, ethics, economy, and social dimensions.

- The NNI plans on funding ten nanotechnology Centers of Excellence, for approximately five years. The centers of excellence will be vital to the NNI, in establishing unity in this rather diverse and multidisciplinary field.

- NNI essentially desires to foster longtime partnerships between researchers from around the country, and it also wishes to get industry involved. These centers of excellence will be places where common equipment may be shared, thus reducing financial burden on individual groups.

- These centers will also have a tremendous focus on educating students, as well as giving students hands-on experience in nanotechnology efforts. The focus should be on high school students through postdoctoral students.

- The NNI also recognizes the importance of giving sufficient fellowship grants to postdoctoral students, based on their research ideas, and academic merit. It also recognizes the need to push for collaboration between research groups in academia, which it hopes to promote through grants.

- The NNI recognizes the need to improve funding, in an incremental fashion, of university based nanotechnology initiatives. This way, researchers at universities have funding to support undergraduate research efforts, which will in turn inspire young people to pursue research on their own accord.

- The NNI has a rather unique and multifaceted approach to implementing an effective nanotechnology plan, for the United States. It has strong support, and funding from the government to actually make nanotechnology a viable field within the next 20 years.

Appendix D – “Developed Pool” Survey

Developed Pool: Schools Currently Involved in Nanoscience Education
(Please Note: This survey INCLUDES courses that will be available the Spring semester of this academic school year)

1. Please provide dates for key developments in your nanoscience education program, such as:
   - Current nanoscience courses offered (please list topics and denote first course)
   - Degrees offered
   - New facilities (nano-specific or nano-related in other labs)

2. What problems have you come across while trying to develop an undergraduate nanoscience education program at your institution? (Check all that apply):

   [ ] Lack of funding
   [ ] Lack of administrative support
   [ ] Lack of faculty expertise
   [ ] Lack of student interest
   [ ] Lack of available facilities (labs, instrumentation)
   [ ] Other: ____

3. What was your institution’s motivation for developing an undergraduate nanoscience education program? (Check all that apply):

   [ ] Popular Literature Topics
   [ ] Nano-research at Your School
   [ ] Growing Job Market
   [ ] Promote Local nano-related Industry Growth
   [ ] Government Iniatives
   [ ] Student Interest
   [ ] Other: ____

4. What has your department/institution done to develop student interest in an undergraduate nanoscience education program?

5. What effective steps would you highlight in your institution’s development of an undergraduate nanoscience education program?

6. What are your intended means for nanoscience education at your institution? (Check all that apply):

   [ ] Incorporate nanoscience topics into other courses.
   [ ] Individual undergraduate courses in nanoscience.
   [ ] An associate’s degree in nanoscience.
   [ ] A concentration in nanoscience in another field.
   [ ] A minor in nanoscience.
   [ ] A major in nanoscience.
   [ ] Other: ___________________________

7. Please state the number of…

a. Professors currently involved in your undergraduate nanoscience education program.
b. Students involved in your undergraduate nanoscience education program.

8. What nanoscience laboratory experience is available for undergraduate students? (Check all that apply):

   [ ] Nanoscience Lab Modules in Non-Nano Lab Courses
   (Physics, Chemistry, Biology, Material Sciences, etc.)
   [ ] Lab Modules in Nanoscience Lecture Courses
   [ ] Nanoscience Lab Courses
   [ ] Research Opportunities
   [ ] None
   [ ] Other: ___________________________________

9. What recommendations would you give to other institutions attempting to develop an undergraduate nanoscience education program?

Appendix E: "Developing Pool" Survey

1. What problems have you come across while trying to develop an undergraduate nanoscience education program at your institution? (Check all that apply):

   [ ] Lack of funding
   [ ] Lack of administrative support
   [ ] Lack of faculty expertise
   [ ] Lack of student interest
   [ ] Lack of available facilities (labs, instrumentation)
   [ ] Other: ____________________

2. What are the most motivating topics in the development of an undergraduate nanoscience program at your institution? (Check all that apply):

   [ ] Popular Literature Topics
   [ ] Nano-research at Your School
   [ ] Growing Job Market
   [ ] Promotion of Local Nano-related Industry
   [ ] Government Iniatives
   [ ] Student Interest
   [ ] Other: ____________________

3. If applicable, what are your intended means for a nanoscience education at your institution? (Check all that apply):

   [ ] Incorporate nanoscience topics into other courses.
   [ ] Individual undergraduate courses in nanoscience.
   [ ] An associate's degree in nanoscience.
   [ ] A concentration in nanoscience in another field.
   [ ] A minor in nanoscience.
   [ ] A major in nanoscience.
   [ ] Other: ____________________

4. How will your department/institution develop student interest in an undergraduate nanoscience education program?

5. If applicable, please estimate the number of faculty and graduate students currently involved with nanoscience research.

6. What facilities are there available at your institution that would aid a new undergraduate nanoscience education program?

7. What information from schools that have a program for undergraduate nanoscience education would you consider helpful to aid the development of a new program of the same sort at your institution?

Appendix F – Key Developments

School	First Course	Other Courses	Facilities	Departments Involved
Hamilton College	Spring 2004 - Chemistry 254 "Introduction to Nanoscience and Materials"	None	May 2004 - Biocleanroom. Will include BioAFM, Fluorescent scope, resist spinner.	No response
Lawrence University	Winter term – 2004 Interdiscpinary Nanoscience and Nanotechnology	None	One laboratory dedicated to this program. It is ~ 300 sq. ft. It is where we keep some of the new equipment acquired for the program.	Chemistry (which includes biochemistry) and Physics Departments
Northwestern University	Spring 2001 Materials Science and Engineering 376 – Nanomaterials	Mechanical Engineering 320 - Nanomechanical Properties of Surfaces Mechanical Engineering 385 - Nanotechnology	Nanoscale science instrumentation is available in the Department of materials science and Engineering facility	No response
RPI	Spring 2004 – Elective Nanotechnology Course	None	None	No response
Florida Tech	Unknown	PHY 1091 Nanoscience/Nanotechnology Laboratory CHE 3260 Materials Science and Engineering CHE 3265 Materials Laboratory CHE 5567 Nanotechnology ECE 4311 Microelectronics Fabrication Laboratory	Funding for equipment provided under NSF 2002 NUE program	Chemistry, Chemical Engineering, Electrical Engineering, and Physics.
University of Puerto Rico	Fall 2003 – Nanotechnology	None	Nanoscience Lab Under Development	No response
University of Nevada	Spring 2001 – ME 493 Special Topics (Nano and Micro-technology)	None	Transmission Electron Microscope (just purchased), Scanning electron microscope (1.5 years), Atomic force microscopy lab (1.5 years), Nanotube	Biomedical engineering, Civil Engineering, Chemistry, Chemical and Metallugical engineering, Electrical

			synthesis lab (less than one year).	engineering, Mechanical Engineering, Physics
Ohio University	First Course: "Nanoscience and Nanotechnology"	None	None	Physics and Astronomy department.
SUNY Binghamton	Spring 2004 - First interdisciplinary course in nanotechnology	None	None	Materials Science
Umass Amherst	2000 - Physics of Nanosystems	Self-assembly of Nanosystems - 2002	MRSEC (Materials Research Science and Engineering Center) Keck Microscopy facility	Chemistry, Polymer Science, Chem. Eng., Physics, Elec. and Comp. Eng., and Mech. Eng.
Worcester Polytechnic Institute	Introduction to Engineering (MEMS)	None	Three AFM Labs, two MEMS labs, molecular biology labs	Physics, Chemistry, Bio, Chem Eng, Mech Eng, Elec Eng
University of Minnesota	2001 - Nanoparticle Technology - (Mechanical Engineering)	2002 - Nanoparticle Technology Lab (Mechanical Engineering)	None	No response
Beloit College	Sept 2003 - First Year Studies course on Nanotechnology	None	Use Nanotechnology modules in General Chemistry and Organic Chemistry.	No response

University of Wisconsin	Unkown	Chemistry 801 Nanostructured Materials and Interfaces Physics 801 Nanostructures in Science and Technology Engineering Mechanics and Astronautics: EMA 601 Micro- and Nanoscale Mechanics	nano-specific or nano-related in other labs	Biomedical Eng, Chemical and Biological Eng, Chemistry Civil and Environmental Eng, Electrical and Computer Eng, Eng Physics, Materials Science and Eng, Mechanical Eng, Physics
Washington University – St Louis	Spring 2003 - "Topics in Nanotechnology" (sen ior level)	None	None	Mechanical Engineering, Chem ical Engineering, and C ivil Engineering.
University of Georgia	Spring Semester 2003 – "Nanotechnology: From Molecules to Machines"	None	None	Physics and Astronomy, Biological and Agricultural Engineering, Physiology and Pharmacology, Chemistry, Biochemical and Molecular Biology, Cellular Biology, and Genetics.
University of Delaware	Unknown	ELEG 421/621: Solid State Nanotechnology ELEG 444/644: Micro-Electro-Mechanical Systems ELEG 446/646: Nanoelectronic Device Principles ELEG 449/649: Nanotechnology & Applications Many other course containing some nano-related topics	fabrication facility (opened 2002)	Chemical Eng Materials Science and Eng Electrical Eng Mechanical Eng Physics and Astronomy Chemistry and Biochemistry

University of Pennsylvania	2001- Nanotechnology (seniors)	2004 - Introduction to Nanotechnology (freshman) Processing Nano and Microstructured Materials	Nanoscience lab modules in non-nano lab courses	Materials Science, Mechanical Eng and Applied Science, Electrical and Systems Eng, Chemical and Biomolecular Eng, Bioeng

Appendix G – Schools Surveyed

Developed Nanoscience Programs

Beloit College
Brown University
Carnegie Mellon University
Case Western Reserve University
Cornell University
Drexel University
Florida Institute of Technology
Hamilton College
Jackson State University
Lawrence University
North Carolina A & T State University
Northwestern University
Ohio University
Penn State University
Princeton University
Puerto Rico-Mayaguez
Rensselaer Polytechnic Institute
Rochester Institute of Technology
Rutgers University
SUNY Binghamton
Texas A&M University
Union College
University of California Irvine
University of Delaware
University of Delaware Newark
University of Georgia
University of Maryland
University of Massachusetts Amherst
University of Minnesota
University of Nevada, Reno
University of Wisconsin Madison
UPENN
Washington University - St. Louis
Yale University
Worcester Polytechnic Institute

Undeveloped/Developed Nanoscience Programs

Armstrong Atlantic State University
Clarkson University
Columbia University
CUNY Hunter College
Georgetown University
Harvey Mudd College
Iowa State
Lehigh University
Miami University - Middletown
Michigan State University
Michigan Tech
New Mexico Tech
New York University
Ohio State University
Oklahoma State University
Purdue University
Rice University
Rose-Hulman Institute of Technology
Seton Hall
SUNY Stony Brook
Texas Christian University
UCLA
University of Alabama
University of Arizona – College of Engineering
University of Buffalo
University of Central Florida
University of Colorado at Boulder
University of Florida
University of Houston
University of Idaho
University of Illinois at Urbana-Champaign
University of Kentucky
University of Maine
University of Michigan
University of Missouri-Columbia
University of North Carolina - Chapel Hill
University of South Carolina
University of Southern California
University of Texas Austin
University of Wyoming
Valdosta State University
Vanderbilt University