AC 2011-1293: WORK-IN-PROGRESS: VIRTUAL RESEARCH EXPERIENCES FOR UNDERGRADUATES IN NANOTECHNOLOGY (VREUN)

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VIRTUAL RESEARCH EXPERIENCES FOR UNDERGRADUATES IN NANOTECHNOLOGY

Abstract

Nanotechnology, the ability to leverage and exploit fundamental processes at the nanometer length scale, suggests the potential for a technological revolution. To sustain and propagate technologies at the nanoscale, continued efforts toward understanding the fundamental principles governing nano-science must be coupled with a focus on nano-engineering to span the multiple length scales necessary to realize nanoscience pheneomena in real-world devices. The US National Nanotechnology Initiative recognizes the importance of the preparation of a diverse and educated workforce with the necessary training and background required to meet this challenge.

To partially address this challenge, in development are Virtual Research Experiences for Undergraduates in Nanotechnology (VREUN) modules to introduce undergraduate students (focusing on the freshmen year) to concepts of nanotechnology in the context of active research. These self-contained multimedia learning modules are based on video documentation of researchers contributing to the nanotechnology research currently underway in our labs. Each module presents the research project being documented, the nanoscale phenomena being investigated, key research questions raised and how they are being addressed in the lab, and how this understanding is necessary for ultimate commercialization of the technology.

Distinguishing characteristics of these modules include the use of current faculty research as the centerpiece for the educational materials, and the use of a multimedia format to enable an engaging and dynamic view of academic nanotechnology research accessible to all students within the curriculum. While these modules will be deployed within a new first year "Engineering Experiences" course being offered at our school, ultimate deployment of these self-contained modules in other academic settings is envisioned. The goals of this effort include: 1) invigorating the first year engineering curriculum with dynamic and engaging real-world examples of cutting edge research in the area of nanotechnology; 2) introducing undergraduates at the earliest stages to the enthusiasm, creativity, and excitement of the academic research environment; and 3) developing a methodology and mechanism with which faculty can utilize multimedia technology to further integrate their research and teaching efforts. The initial modules under development will form the basis of a sustainable and scalable library of materials documenting nanotechnology research and readily available to all students. It is hoped that exposure to academic research at the earliest stages of the curriculum will broaden the pool of undergraduates who participate in such research, and to encourage these students to do so earlier in their studies.

Introduction

According to ABET 2000, "engineering programs must be designed to prepare graduates for the practice of engineering at a professional level".[1] This suggests a call for engineering programs to not only provide traditional content knowledge related to engineering, but to actively foster the ability of students to apply this knowledge in professional practice. Focus groups on undergraduate education in science, math, engineering, and technology (SME&T) found that employers were specifically seeking individuals with initiative, problem-solving, and leadership skills who are capable of independent learning, and that SME&T graduates were generally unprepared in these areas.[2] However, changes to the ABET accreditation provided schools more opportunities to enact creative changes to the curriculum[3-6] with more emphasis being placed on student-directed learning.[7,8] For example, the importance of attitude development in undergraduate students (for example, a first-year electronics lab has been developed with the primary goal of "influencing student attitudes rather than imparting cognitive knowledge"[9]) and the impact of student attitudes on student performance[10] have already been recognized. In addition, the Boyer Commission issued a challenge to engineering educators to "make research-based learning the standard".[11] In particular, a number of researchers are developing various nanotechnology-based materials aimed at students at the freshmen level.[12]

While case-based learning has been used in a number of pre-professional training programs (such as medical, dentistry, nursing,[13] business, teacher-training, etc), its use in engineering education has been limited.[14-16] We believe that multimedia technology provides the opportunity to develop engaging learning materials that bring the practice of engineering into the classroom to strongly supplement traditional forms of undergraduate learning within the curriculum. It is hypothesized that observing authentic engineering practice will provide students:

i. a window into the practice of engineering;
ii. an understanding of the complexity of engineering problems encountered in practice;
iii. the framework to envision how their education will relate to their future engineering careers; and
iv. an opportunity to realize earlier in their the studies the benefits associated with students participating in activities such as internships and co-ops.[17]

A program to develop multimedia-based learning environments to expose undergraduate students to "real engineering" could take a number of forms as shown in Table 1. Here we will focus on our efforts to develop such multimedia learning modules based on nanotechnology research being performed in the academic labs on campus; a program we call Virtual Research Experiences for Undergraduates in Nanotechnology (VREUN). The benefit of engineering experiences for undergraduates is evident from the commitment that NSF (through its Research Experiences for Undergraduates (REU) program), industry (through undergraduate internships and co-op work experiences), and academia[17,18] dedicate to providing these learning experiences. While such programs are often very successful, opportunities are limited to the small number of students able to obtain such positions, and students at most can only participate in a small number of such experiences. We thus feel that a methodology to incorporate, in a virtual sense, these experiences into the undergraduate curriculum would greatly enhance the benefit and reach of such programs by increasing the number of students exposed to these activities.

Topic	Module description
VREUN	- Introduce concepts of nanotechnology in the context of academic research
Virtual Senior Design projects	- Follows the year-long progress of Senior Design groups from initial design through prototype development and testing
Virtual Internship/co-op	- Follows students participating in internship/co-op experiences
Virtual Lab tours	- Introduction to the engineering disciplines via faculty interests and research labs

Table 1. Potential applications of the multimedia learning environment methodology.

Distinguishing characteristics of the VREUN modules, in particular, include the use of current faculty research as the centerpiece for the educational materials, and the use of a multimedia format to enable a dynamic view of academic nanotechnology research accessible to *all* students within the curriculum. The goals of this effort include:

1) invigorating the first year engineering curriculum with an engaging real-world examples of cutting edge research in the area of nanotechnology;

2) introducing undergraduates at the earliest stages to the academic research environment; and

3) developing a methodology and mechanism with which faculty can utilize multimedia technology to further integrate their research and teaching efforts.

The modules under development will form the basis of a growing library of materials documenting nanotechnology research and readily available to all students via the internet. Ongoing assessment and evaluation efforts are addressing whether exposure to academic research early in the curriculum will broaden the pool of undergraduates who consider participating in such research, encourage these students to do so earlier in their studies, and increase the number students who consider pursuing graduate studies in engineering.

Lastly, we note that in many respects, a detailed study of the sciences (biology, chemistry, physics, etc) is necessary before students can gain the level of expertise necessary to truly appreciate the complex details of science and engineering at the nanoscale. However, the goals of the present module development effort, to introduce students to concepts at the nanoscale while relating these phenomena to those materials covered in "traditional" science and engineering classes within the curriculum, are much more realistic. Further, it is hoped that exposure to the academic research environment coupled with the nanotechnology material will serve as motivation for further study and research activity on the part of the students.

Overview of the VREUN project

An overview of the VREUN project is shown in Figure 1. Video documentation of researchers working in the nanotechnology labs form the centerpiece of a VREUN module. The entire module is couched in a "storyline" based on commercialization of the underlying technology. With this 'hook', the module builds upon the nanoscale phenomena under investigated, the key research questions being pursued in the lab, how the traditional engineering disciplines (i.e. 'macroscale engineering') contribute to this work, and ultimately how this understanding is necessary for ultimate commercialization of the technology. Video snippets of the research efforts will be supplemented with additional information and explanatory materials to provide an introduction to the principles of nanotechnology that served as the focus of the work within the research group (see Figure 2 and Figure 3). In addition, each of these VREUN modules will be made accessible over the web, allowing an online library of such experiences to be accumulated. Each module will be self-contained, such that no additional materials or teacher instructions will be necessary for the student to complete the module.

The modules will also be made available to students within a 1-credit general education/exposure course called *Engineering Experiences* that is required for all incoming freshmen at our school. The purpose of this course is to introduce students to the field of engineering while facilitating their adjustment to college life. As currently offered, students select a number of experiences from a list of available activities including lab tours, guest speakers, mini-projects, and study and life skills classes. Individual VREUN modules will be offered to students as a means to partially satisfy the requirements of this class.

The nature of the nanotechnology projects, and the manner in which they will be documented and packaged within the VREUN modules, also lends itself to extensions as outreach materials for younger students. Such K-12 modules could be used to promote engineering as an exciting field of study while emphasizing the problem-solving, teamwork, and communication skills required of engineers. For these younger students, the opportunity to actually "see into" the sometimes mysterious world of engineering (and academic research) may encourage some students, particularly those from under-represented populations lacking role models in the science and engineering disciplines, to consider pursuing degrees in this area. It is hoped that such modules will increase the pool and persistence of students, particularly underrepresented groups, in engineering at the undergraduate level by illustrating for students the relevance of their undergraduate education to the solution of real-world problems.

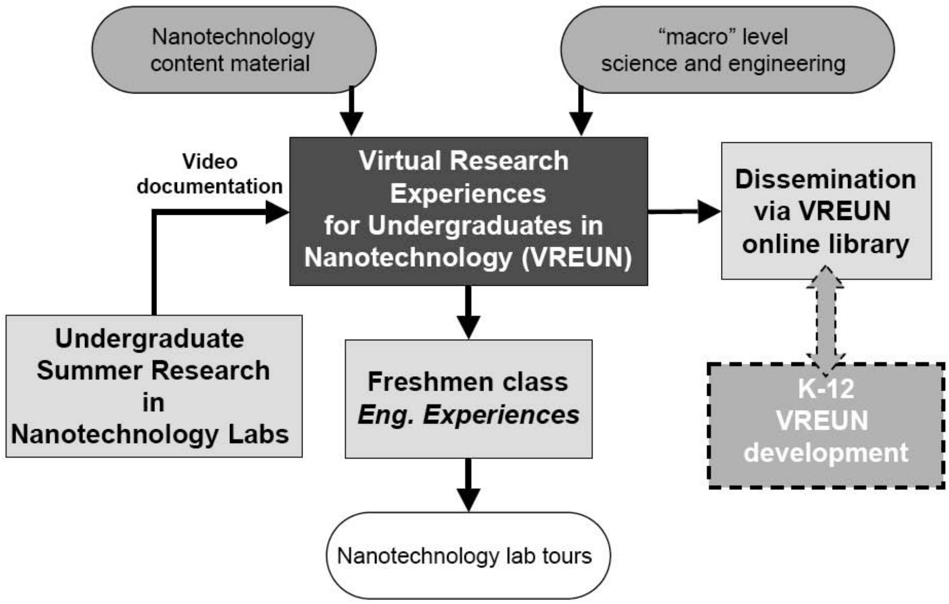

Figure 1. Online Virtual Research Experiences for Undergraduates in Nanotechnology (VREUN) library based on nanotechnology research. The natural extension of these modules for K-12 deployment is denoted by dashed lines.

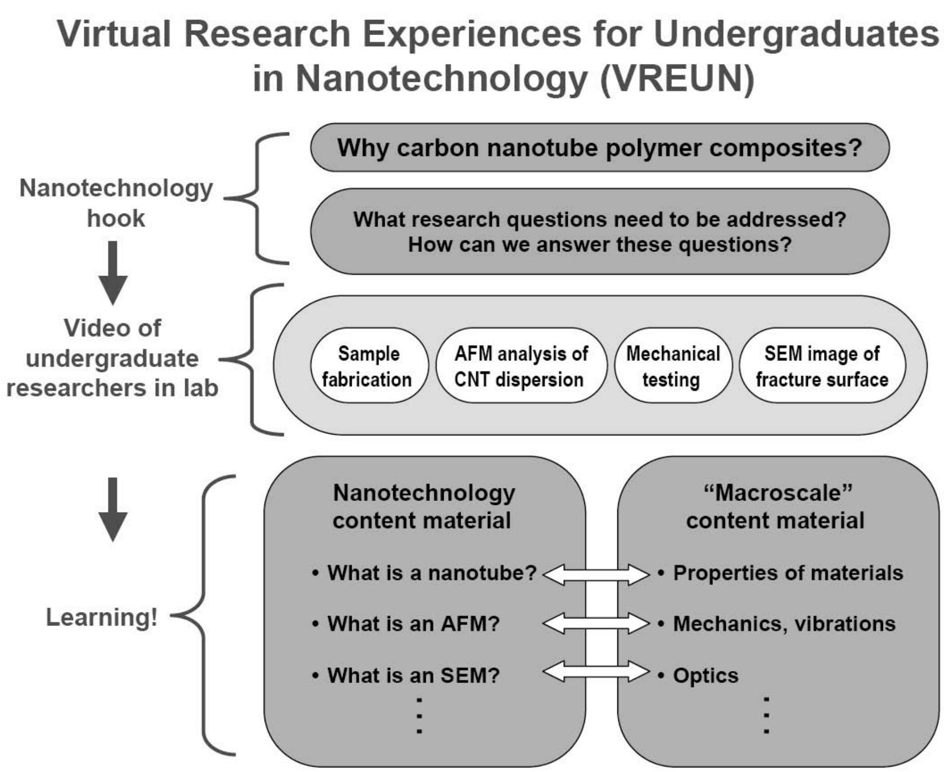

Figure 2. Individual VREUN module documenting a particular nanotechnology research project.

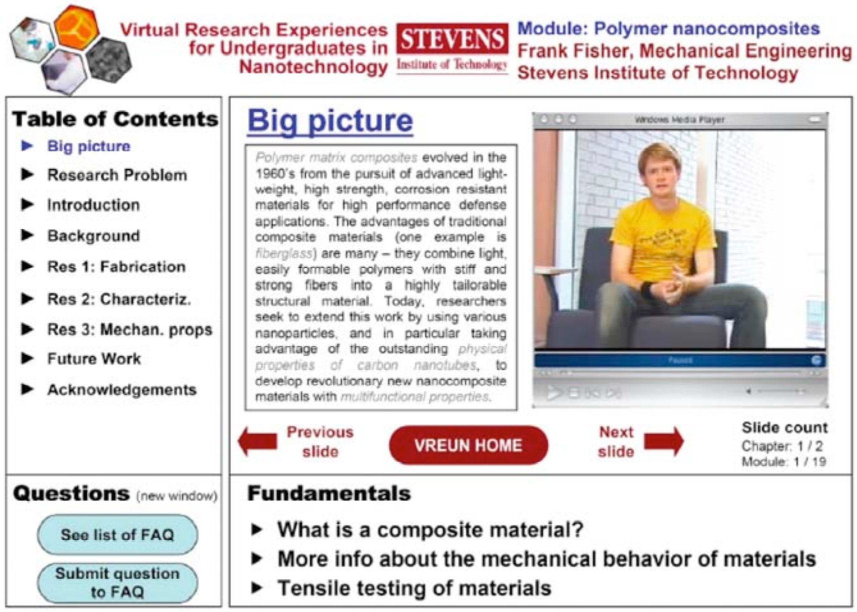

Figure 3. Screenshots from one of the VREUN modules. (top) An overview of the 'Big Picture' describing why researchers are interested in this particular research topic. Text on the left hand side of the main window provides a summary of the video and links to definitions additional content information readily available on the web. (bottom) Video of one of the researchers in the laboratory as part of the module.

Pedagogy of the learning environment design

The goal of the VREUN modules is to provide a means to provide introductory nanotechnology materials for the undergraduate curriculum in a manner that also exposes students to the academic research environment. While anecdotal evidence of the value of REUs (and, analogously, internships, co-op experiences, etc) within undergraduate engineering education abound, detailed studies characterizing the exactly what it is about these opportunities which are so valuable for students are lacking. In one study, undergraduate students overwhelmingly identified specific instances of exposure to authentic engineering practice (design projects, internships, co-ops) as factors that facilitated their intellectual growth and the manner in which they approached their engineering education. In such situations students encounter ill-defined, ambiguous, and complex problems providing the opportunity to develop characteristics that have been referred to as that of an adaptive expert.[19] Preliminary results have suggested a correlation between students who score high in these characteristics and grade point average, leading to the hypothesis that exposure to the practice of "real-world engineering" leads to positive student development exactly because they lead students to develop higher levels of adaptiveness.[19] These students develop a better framework for assimilation of new information in the classroom as well as the ability to apply this content knowledge in practice.

While the goal of these modules is not to mimic or replicate the actual undergraduate research experience, an presentation of the research being conducted in the nanotechnology labs can provide a motivating and interesting hook with which to introduce basic nanotechnology concepts and their relationship to the traditional engineering disciplines. Such learning modules will provide students the motivation and context of how such information is used in practice, which enables students to better index, utilize, and later retrieve the information they have learned. While these multimedia learning modules will clearly not match the levels of student growth observed via direct exposure to undergraduate research experiences, it is hoped that exposure to a "virtual experience" may at least mimic some of the advantages of such activities. A large library of such modules (see Table 1), once realized, would also provide a manner to expose undergraduates to authentic engineering in a variety of fields, which may assist with issues such as recruitment, retention, and discipline selection by providing students an opportunity to see the different fields of engineering in practice.

Nanotechnology projects as the basis of the project

The novelty of the proposed approach is the use of multimedia technology to build upon the type of research experiences typically available to only a limited number of active participants to *all* students within the curriculum. As described previously in Table 1, a number of other examples of "real world engineering" could also be used as the basis for these modules, and faculty research in other research areas could be used as the basis for similar modules. While research projects are obviously dependent on faculty interests, projects that can be presented in a way that catches the interest of students, projects the excitement of the faculty researcher, and represents cutting-edge technology with societal implications, are particularly appropriate.

Examples of the on-campus nanotechnology projects that are being pursued for VREUN module development are shown in Figure 4. These projects were chosen based on ongoing research efforts in these areas and faculty interest. Also note that the projects represent a variety of disciplines, and in many cases will explicitly or implicitly illustrate the interdisciplinary nature of nanotechnology.

The goal of each module is to document the step-by-step research progress of researchers in the form of video and audio clips, which will be supplemented with related tutorial text, graphic illustrations, and other publicly available educational materials. Each module will be self-contained and designed to provide all information necessary for sufficient coverage on a specific subject and research topic at the appropriate level of description given the target audience. Depending on the status of the individual research projects, modules developed in subsequent years may either add to existing VREUN modules (such that students will be able to follow the progress of the research over time) or be based on new nanotechnology projects. Over time a library of such modules will be made available over the web. Adaptation of the modules to make the material more accessible for younger students for the purposes of K12 outreach is also envisioned.

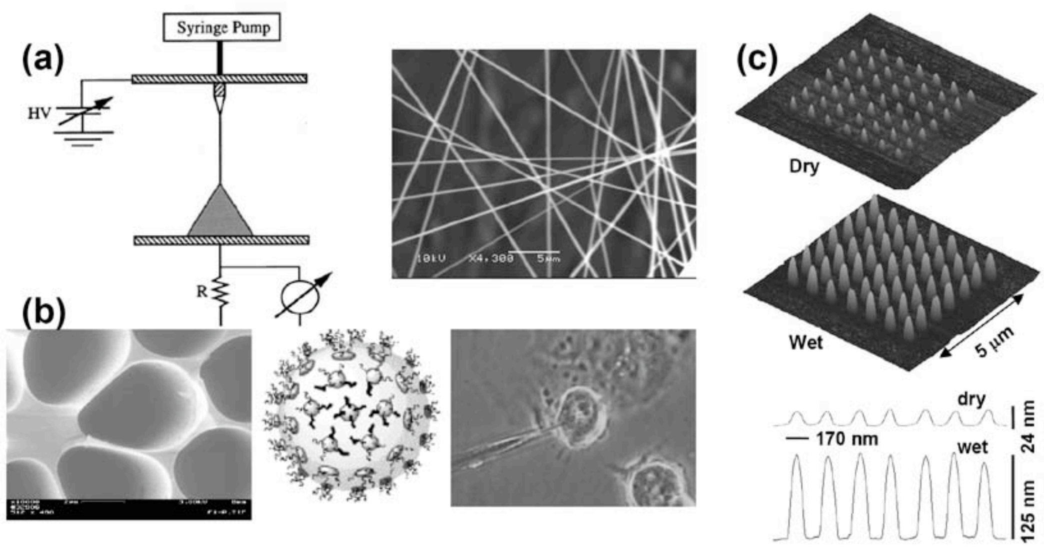

Figure 4. Examples of nanotechnology topics for the initial VREUN modules: (a) electrospinning of nanofibers, (b) fabrication of nanoshells for surface-enhanced Raman scattering, (c) nanohydrogels.

Conclusions

Traditionally the most significant usage of computers with regards to Engineering Education, as adopted by most educators, is related to their assistance in course communication and administration, with a small but rapidly growing class of course-specific modules and applets (so-called 'skills drills') being developed to provide students opportunities to practice and hone problem-solving skills for a particular class. However, the potentially transformative manner in which computers could change the pedagogical approach to how Engineering is taught at the undergraduate level has perhaps yet to be fully exploited. The methodology of video documentation and multimedia presentation of nanotechnology research presented here may suggest one manner in which computers, and in particular multimedia technologies, can be better leveraged to change how students are introduced to various topics in engineering.

In particular, these modules seek to expose young undergraduate students to academic research and an introduction to nanotechnology in a manner which fosters the development of adaptiveness in students in a manner which is not easily addressed in a traditional classroom environment. Such modules may also increase the number of students exposed to such research while leveraging the excitement and wonder of academic research to create a compelling learning experience. The goals of such a collection of multimedia modules are to 1) invigorate the first year engineering curriculum with engaging real-world examples of engineering (for example, academic research and/or industrial practice); 2) introduce undergraduates at the earliest stages to "real engineering" (again, either within the academic research environment or industry); 3) develop a methodology and mechanism with which faculty can utilize multimedia technology to further integrate their research and teaching efforts; and 4) demonstrate a methodology compatible with a growing a sustainable library of authentic engineering experiences for incorporation into the undergraduate curriculum. Such an approach could also be readily adapted to provide virtual exposure of more authentic engineering activities such as co-op experiences and large-scale design projects earlier in the curriculum.

Acknowledgements

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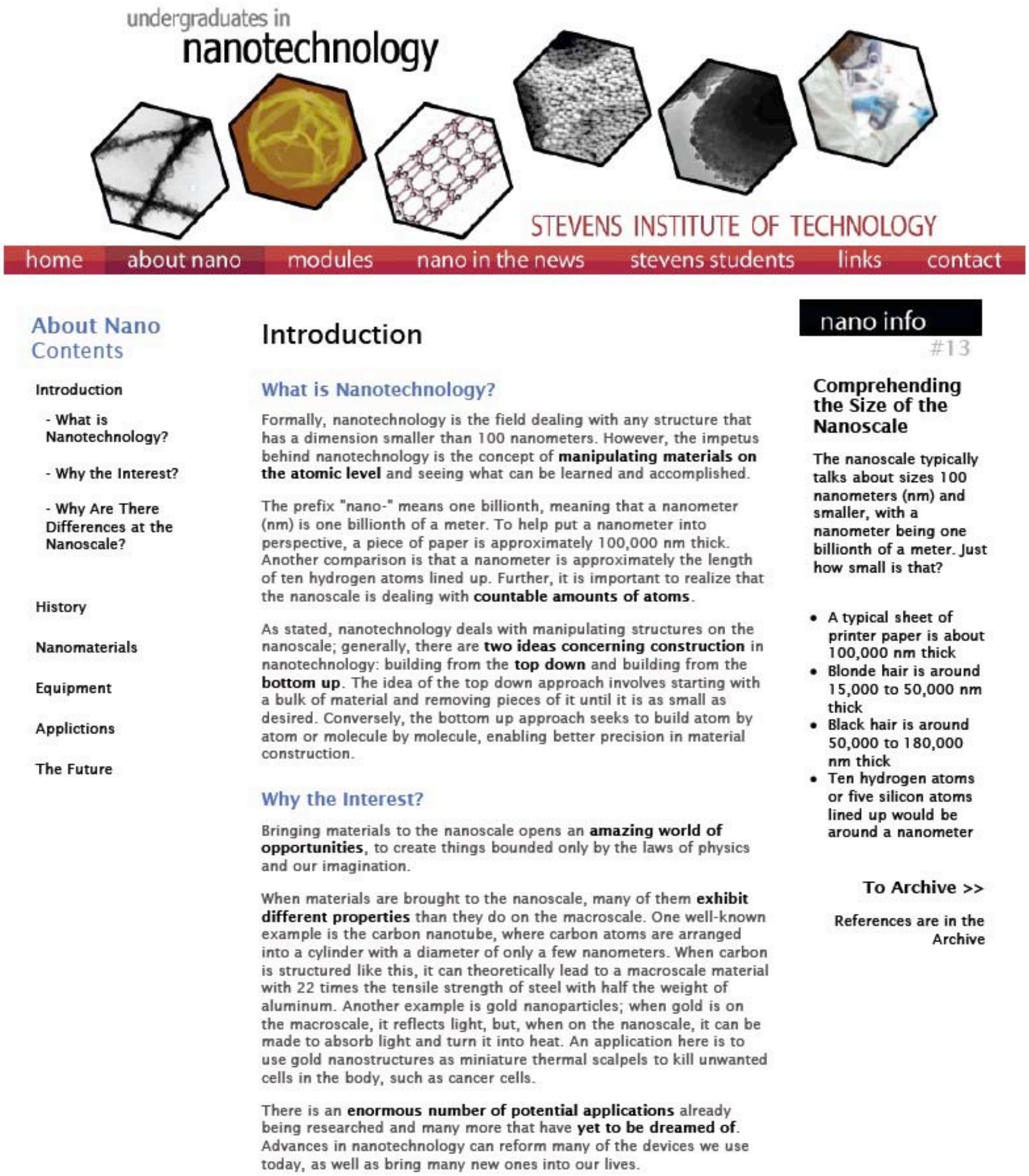
Appendix

The individual VREUN modules are housed within a general web-based environment that provides an overview of general nanotechnology concepts and links to various stories and facts that may be of interest to the students. For example, the description of a topic such as Scanning Electron Microscopy (SEM) could be presented as a stand-alone topic, such that the various modules where SEM is used could link to this common information source. Figures A1-A3 illustrate representative screenshots of the overall web environment.

Figure A1. Screenshot of the front page of the VREUN website environment.



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Introduction

What is Nanotechnology?

Formally, nanotechnology is the field dealing with any structure that has a dimension smaller than 100 nanometers. However, the impetus behind nanotechnology is the concept of **manipulating materials on the atomic level** and seeing what can be learned and accomplished.

The prefix "nano-" means one billionth, meaning that a nanometer (nm) is one billionth of a meter. To help put a nanometer into perspective, a piece of paper is approximately 100,000 nm thick. Another comparison is that a nanometer is approximately the length of ten hydrogen atoms lined up. Further, it is important to realize that the nanoscale is dealing with **countable amounts of atoms**.

As stated, nanotechnology deals with manipulating structures on the nanoscale; generally, there are **two ideas concerning construction** in nanotechnology: building from the **top down** and building from the **bottom up**. The idea of the top down approach involves starting with a bulk of material and removing pieces of it until it is as small as desired. Conversely, the bottom up approach seeks to build atom by atom or molecule by molecule, enabling better precision in material construction.

Why the Interest?

Bringing materials to the nanoscale opens an **amazing world of opportunities**, to create things bounded only by the laws of physics and our imagination.

When materials are brought to the nanoscale, many of them **exhibit different properties** than they do on the macroscale. One well-known example is the carbon nanotube, where carbon atoms are arranged into a cylinder with a diameter of only a few nanometers. When carbon is structured like this, it can theoretically lead to a macroscale material with 22 times the tensile strength of steel with half the weight of aluminum. Another example is gold nanoparticles; when gold is on the macroscale, it reflects light, but, when on the nanoscale, it can be made to absorb light and turn it into heat. An application here is to use gold nanostructures as miniature thermal scalpels to kill unwanted cells in the body, such as cancer cells.

There is an **enormous number of potential applications** already being researched and many more that have **yet to be dreamed of**. Advances in nanotechnology can reform many of the devices we use today, as well as bring many new ones into our lives.

nano info

#13

Comprehending the Size of the Nanoscale

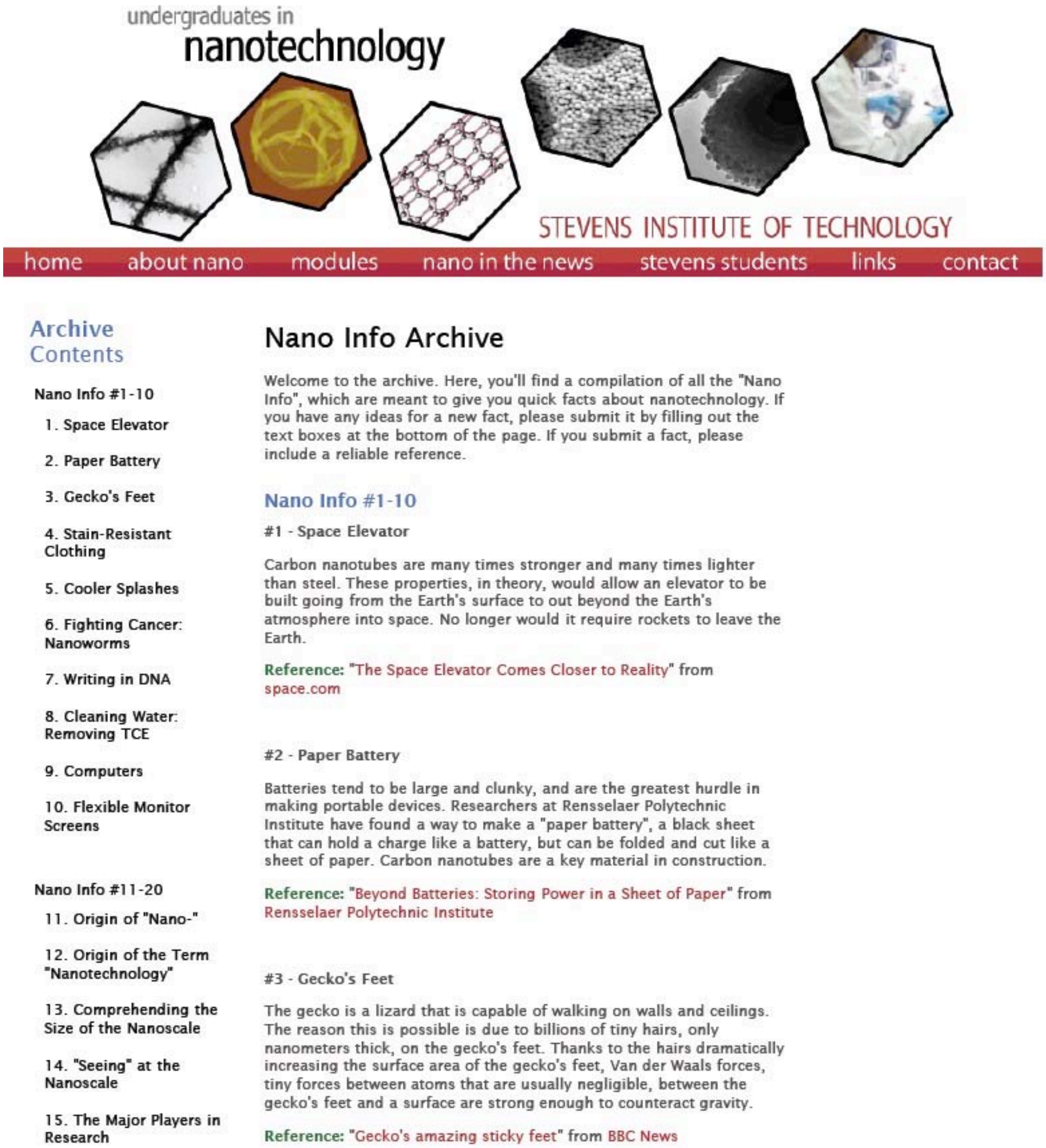
The nanoscale typically talks about sizes 100 nanometers (nm) and smaller, with a nanometer being one billionth of a meter. Just how small is that?

- A typical sheet of printer paper is about 100,000 nm thick
- Blonde hair is around 15,000 to 50,000 nm thick
- Black hair is around 50,000 to 180,000 nm thick
- Ten hydrogen atoms or five silicon atoms lined up would be around a nanometer

To Archive >>

References are in the Archive

Figure A2. Screenshot of the 'About Nano' page on the site. This area provides general motivation and information regarding nanotechnology, which supports the individual video-based research modules elsewhere on the site.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Archive Contents

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2. Paper Battery
3. Gecko's Feet
4. Stain-Resistant Clothing
5. Cooler Splashes
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7. Writing in DNA
8. Cleaning Water: Removing TCE
9. Computers
10. Flexible Monitor Screens

Nano Info #11-20

11. Origin of "Nano-"
12. Origin of the Term "Nanotechnology"
13. Comprehending the Size of the Nanoscale
14. "Seeing" at the Nanoscale
15. The Major Players in Research

Nano Info Archive

Welcome to the archive. Here, you'll find a compilation of all the "Nano Info", which are meant to give you quick facts about nanotechnology. If you have any ideas for a new fact, please submit it by filling out the text boxes at the bottom of the page. If you submit a fact, please include a reliable reference.

Nano Info #1-10

#1 - Space Elevator

Carbon nanotubes are many times stronger and many times lighter than steel. These properties, in theory, would allow an elevator to be built going from the Earth's surface to out beyond the Earth's atmosphere into space. No longer would it require rockets to leave the Earth.

Reference: "The Space Elevator Comes Closer to Reality" from space.com

#2 - Paper Battery

Batteries tend to be large and clunky, and are the greatest hurdle in making portable devices. Researchers at Rensselaer Polytechnic Institute have found a way to make a "paper battery", a black sheet that can hold a charge like a battery, but can be folded and cut like a sheet of paper. Carbon nanotubes are a key material in construction.

Reference: "Beyond Batteries: Storing Power in a Sheet of Paper" from Rensselaer Polytechnic Institute

#3 - Gecko's Feet

The gecko is a lizard that is capable of walking on walls and ceilings. The reason this is possible is due to billions of tiny hairs, only nanometers thick, on the gecko's feet. Thanks to the hairs dramatically increasing the surface area of the gecko's feet, Van der Waals forces, tiny forces between atoms that are usually negligible, between the gecko's feet and a surface are strong enough to counteract gravity.

Reference: "Gecko's amazing sticky feet" from BBC News

Figure A3. Screen-shot of the 'Nano In the News' Archive. This site is a collection of interesting nanotechnology research and application blurbs (with links to the original source) from general information outlets such CNN.com and reputable research blogs. (Note that these research blurbs are not necessarily from Stevens faculty.) Other pages of the site randomly draw from these stories (as shown in Figures A1 and A2).

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