Advancing Nanoscience Education Survey - Results

### 1. In your own words, what do you think nanoscience education should be? Specify the education level that you are most interested in.

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| I am most interested in college level. However, I am interested in all types of college students -- non-science majors through science grad students. So, it is very difficult to say what nanoscience education "should be." It will be something quite different for different students. |
| I think nanoscience education should be a true cross-disciplinary effort in leading to the fundamental understanding, fabrication and integration of nanoscale materials. I am interested in college level. |
| There are three categories of audience that I am particularly interested in reaching: a) The informal learner or accidental scientist: the pedestrian who may or may not know they are interested in science, but are interested citizens on this planet and curious about the world around them. b) Disenfranchised, at-risk youth who learn best in out-of-school settings, whether that be in online environments or roaming around town. c) The general public – families, teens, senior citizens, voters, students, consumers, policy makers, etc. |
| Hands-on (as much as that is possible). High School. |
| Most interested in early undergraduate years of education. My big question with regards to this question is - does nanoscience education play a role only in science majors' curricula or might there be a NanoScience for Poets course as well? |
| Community College Nanoscience Education: 1. Academic breadth and depth preparation in core areas required for further study. Subject areas Math, Sciences, Engineering, Communication, Computation, and Critical Thinking. 2. Instruction in Bio, Info, Nanotechnology core competences for job entry and mid-level positions 3. Survey courses to inform the general public as to what nanotechnology is. |
| I am most interested in reaching the casual, life long learner. Primarily the adult voter and parent who is curious about what they hear or read in the papers , and who is probably a parent. |
| As a developer for the Nanozone exhibition at the Lawrence Hall of Science, my experience is with middle school students and the general public. As such, my expectations for nanoscience education focus on basic ideas such as; an understanding of the nanoscale. potential applications of nano research, the unique properties of matter at the nanoscale, and the integration of research expertise across fields. |
| I am interested in all levels of nanoscience education, but right now am most focused on high school. I believe nanoscience education should be used a new and exciting way to teach traditional science concepts (measurement, bonding, forces, energy, etc.). It can also highlight the interdisciplinary nature of science. |
| Nanoscience education needs to be embedded into the existing curriculum. I see it almost as an extension or the "hook" into a particular science concept. There are so many real-life examples that students are interested in--these just need to be integrated appropriately. The education levels that I am most interested in are the high school level and undergraduate level. |
| Coverage of the nanoscale dimension physics, chemistry, math, biology. |
| At the high school level, it should introduce students to the interdisciplinary nature of nanoscience, and help them understand the underlying principles, applications, and implications of nanoscale science. |
| Nanoscience education is the study of the unique world that exists at the size of a billionth of a meter. At this scale, properties of matter (mechanical, magnetic, electrical, thermodynamic, and other types of properties) are dramatically different than in the macroscale. As the size of nanoscale materials approaches the scale associated with a physiochemical property of that material, such as the wavelength of light or the ballistic mean free path of an electron, the property often changes. Nanoscience education is an interdisciplinary approach that has roots and applications in biology, chemistry, physics and material science, many fields of engineering, and the earth and environmental sciences. My interests are in precollege education, teacher education, undergraduate, and adult education. |

## 2. What knowledge should students have prior to starting a nanoscience program in college?

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| I assume that by "nanoscience program" you mean some curriculum that leads to a degree. In that case some basic knowledge of fundamental sciences and math. Most importantly, they need good problem solving and communication skills. I would prefer that most of the science topics be taught in the context of nanoscience rather than as isolated topics. |
| A broad knowledge of chemistry, physics, life science and engineering principles that govern the material behavior at the atomic level. A solid training of independent, highly motivated self-starters who can think outside the box and identify and solve technical problems. |
| Students should have a basic understanding of the science that is in the national science education standards. (The problem is that so little science is being taught and taught so poorly right now....) They should know the basics of physical, biological, and earth sciences: scale, force, viscosity, light, heat, energy, magnetism, physical and chemical properties of matter, cells, proteins, building blocks, some basic thermodynamics. Students should also learn something about the social Implications of nano-technology or “Nanoscience Appreciation” unit to gain a broad understanding of the technologies that enable nanoscientists to do their work. This includes the practices of nanoscientists, the places they work, why nanoscientists are passionate about their work, policy perspectives, commercial enterprise perspectives, and other views. This knowledge can also include implications for nanoscience developments to dispel any myths or early conceptions about the risks and rewards of working in this area. While this is more a skill than background knowledge, kids should have strategies for critiquing and discussing current events. Students should have enough background knowledge and some basic critiquing skills for reading newspaper articles and questioning information in the news and different media view points. |
| A basic knowledge of the scale and applications. |
| A firm grasp of the concepts of quantum mechanics :-) Seriously - good sense of scale and the way basic chemical and physical properties e.g. friction or solubility manifest themselves at the molecular level. |
| Community College Prerequisites: *High school chemistry, physics, computer sciences, biology, and math through algebra *Ability to read well, communicate, critical thinking & quantitative reasoning skills, combined with strong study and time management skills. |
| I expect that to work in nano science students must have advanced chemistry and some calculus. I would hope students are also somewhat grounded in environmental sciences and genetics and have had at least a taste of ethics. |
| Introductory coursework in all four major science fields - biology, physics, engineering and chemistry. |
| Bonding, forces, energy, atomic structure, bulk material properties. |
| Students need to have strong foundations in chemistry, physics and math. |
| Physics, math, chem, molecular bio, computer science. |
| Basic physics, chemistry, biology. |
| Basic chemistry and biology are necessary, physics very desirable. |
| They should have a good understanding of size and scale, and how properties at the nanoscale level differ from those above and below (e.g., at the nanoscale level, different rules predominate). |
| Students need a firm understanding of basic principles of chemistry and physics prior to starting a study of college nanoscience. |

### 3. In high school, what concepts should students understand before going into a college nanoscience program?

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| General skills -- problem solving, communications, math, how to learn -- are the critical items. Some knowledge of what nanoscience is and why it is interesting and useful would be very valuable. This knowledge would motivate students to be interested in nanoscience and even in science. However, just as is true for any college level science program, the general skills form a foundation that is most important. |
| Chemistry -- atomic structure, chemical bonding, oxidation and reduction, adhesion, absorption, adoption, electrochemical reaction. Physics -- electronic and magnetic properties, electro-optical interaction(photoluminescence), density, energy Biology -- cells, molecules, DNA, protein. |
| I'm not sure, but I imagine there are a host of diSessa-like p-prims that would characterize concepts of nanoscience that should be part of a research program. |
| A basic knowledge of the scale and applications. |
| Just the basics of physics and chemistry - molecular level conceptual understanding rather than fancy equation solving. |
| Again, I suspect it would have to be organic chemistry although I am not really qualified to answer the question. |
| Nano size and scale. Techniques and tools used to work at the nano scale. Basic knowledge of the unique properties of matter at this scale which enables new processes and solutions to be explored. |
| Metric system, calculation of surface area and volume, atoms and molecules, types of bonding, energy. |
| Students need to have a basic understanding of molecular structure and interactions. They should understand different types of forces and have an appreciation for the math involved to calculate forces, etc. |
| Atomic structure, periodic table, elementary physics, electromagnetism. |
| Atoms, molecules, cells, cell organelles, and protein molecules; Basic units of the metric system and knowledge of prefixes; how to manipulate exponential and scientific notation. |
| Our research suggests that precollege students may hold different levels of knowledge about nanoscale science. We have found that students who may not be able to completely conceptualize the magnitude of nanoscale (quantitatively) may instead be able to "jump" to that world and develop some understandings of nanoscale phenomena (qualitatively). Students need conceptual anchors to help them make transitions from one scale to the next. |

**4. Do you think nanoscience is better taught as interdisciplinary, integrated courses, or through traditional, discipline-specific courses (i.e., bio, chem, physics, math)? If both, what would you emphasize?**

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| Nanoscience is much too broad of a "concept" to be able to answer this question. It really depends on what one is doing. Most nanoscience activities would be broader than one discipline, but some could be rather narrowly defined. Others would require input from many different disciplines. I guess that I am saying that I would like to see options rather than one set curriculum. (But that does not seem to answer your question.) |
| A goal-oriented, integrated interdisciplinary course. An emphasis can be placed on a cohesive theme such as understanding the characteristics of a nanostructured material. Both synthesis and characterization techniques can be utilized. |
| The more interesting high school courses being taught in high school are in interdisciplinary in nature, so there is my bias. Courses might be organized to have macrocontexts of study, then delving deep into the disciplinary knowledge as 'just-in-time' to learn key concepts. For example using design, a macrocontext would be to design a candy dispenser or fax machine, and later you find that you need to know about actuators and controls, programming and logic for payment, torque and rotation of helices to dispense the candy, light, motors, digital information into ink transfers, etc. This could also be applied to learning chemistry by creating a macrocontext of designing an airbag or artificial kidney. |
| Both--I believe it lends itself mostly to integrated courses, but those are being phased out due to standardized testing and UC lab requirement pressures. Even in traditional courses, we do some integration. |
| Interdisciplinary with more examples in the discipline courses (back of the book problems). |
| Depends on the student and what they know coming in. In general, I prefer integrated courses as a learning community. For example, in a support science course teaching examples used for key concepts would be taken for nanoscience. In nanotechnology courses those key concepts learned in the support science course is reinforced and built upon. |
| I really couldn't say. I would offer that the direction of science is towards synthesis and interdisciplinary research. And it seems that students who are well rounded would be better able to make the intellectual leaps that will be required of science in the future. |
| Interdisciplinary. |
| I think it can be taught in both. I prefer interdisciplinary, integrated courses since it better approximates the reality of the field of nanoscience. If taught in a discipline, I think the best fit is chemistry. |
| Ideally, it would be great to teach nanoscience as an interdisciplinary, integrated course, but, in reality, change is slow in academia. So, more than likely, our best bet is to integrate it into existing courses at the lower division. However, at the upper division, there is a better chance to create an interdisciplinary, integrated capstone-type course in nanoscience. |
| Integrated interdisciplinary when possible. |
| Interdisciplinary. Emphasis on chemistry and bio chemistry. |
| Actually – both. |
| Both. I'd emphasize interdisciplinary slightly in an ideal world, though that might be difficult in practice (there are many more discipline-specific courses). |
| Some of our research suggests that an interdisciplinary approach to nanoscale science and nanotechnology is more interesting to students (such as females) who may be less interested in traditional domains (such as physics). An interdisciplinary approach allows students to think across domains and to develop an appreciation for the unique and exciting developments that are taking place in nanoscience today. However, understanding the nanoscale foundations of science is important for all the domains. We lack research that documents whether or not an integrated or independent approach to nanoscale science is most effective. |

**5. What foundational concepts from nanoscience do you think are most crucial to teach? For example, scale and energy are often cited. What others can you suggest?**

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| The relation between atomic/molecular and macroscopic properties of objects. By macroscopic I mean anything more than a few atoms. For example, nano-scale gold particles can look green. there is some fundamental physics/chemistry underlying these type of property differences. Students need to know how the how the macro- and nano- scale properties come from the collection of atoms. Surface area to volume is important in many nanoscale applications. |
| Surface technology of materials energy band gap corrosion electrochemistry size effect on properties molecular interaction. |
| Not being a nanoscience expert, I am guessing here. Surface area/shape, material properties, time scales (diffusion, transport, transfer), magnetism/magnetic particles. |
| Practical applications, skills, job opportunities. |
| Possibly a sense of statistics - that there are fewer molecules to deal with and that ensembles can have characteristics that individual particles don't exhibit. |
| I'm not a scientist. I suppose I would look at what physics is involved...magnetism, scale, current, metallurgy, etc and go from there. One thing I notice is there are a lot of pretty, yet static images out there of different nano materials -atoms of copper or whatever. No one ever explains that what you are actually seeing is (at least as I understand it) a sort of average of the orbiting electrons. You cant see atoms and you cant see electrons. Someone needs to explain to the general public what all of those bumpy pictures really are. |
| Understanding of the nanoscale, potential applications of nano research, the unique properties of matter at the nanoscale, and the integration of research expertise across fields. |
| Measurement, bonding, forces, ethics. |
| Molecular interactions. Also, the physical and chemical property differences between bulk materials and nanomaterials, focusing on how one manipulates particles and the outcome. |
| Self-assembly surface area to volume ratio. |
| Scale-energy self assembly quantum states. |
| Size and scale, number and aggregation effects, surface effects. |
| A. Quantum Mechanical Properties<br>B. Scale and Scaling<br>C. Control and Manipulation at the nanoscale (H Bonds, van der Walls Forces. Electrostatic. Dipolar, Fluidics)<br>D. Technology and Engineering<br>• Molecular electronics<br>• Guided self assembly<br>• Sensors<br>i. Color<br>ii. Conductivity<br>iii. Fluorescence<br>iv. Weight<br>• Electronics<br>• Biomedical nanostructures<br>• Optics (quantum size effect)<br>• Thermal applications<br>• Magnetic application<br>• Fabrication<br>• Tools of nanotechnology<br>• Materials<br>E. Societal Implications |

**6. What are a few of your favorite examples that illustrate the concepts mentioned in question 3?**

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| Metal nanoparticles -- size and/or temperature effect on properties Carbon nanotubes -- electrical and thermal conductivity Self-cleaning clothes -- oxidation and reduction Nanomembrane -- molecule separation. |
| I don’t have specific examples, but general heuristics. To reach the public, you need everyday hooks to get them interested in a topic, like the clothes they wear, hobbies, objects used in everyday life, or things you can find in the kitchen. The other hooks are the typical media grabbers like trivial, cool, or bizarre stories or curious phenomena that captures attention. |
| Molecular Workbench tools from Concord Consortium - almost any of their modules. |
| Real things: Any exhibit that makes use of ferro fluids is inherently fascinating and aesthetically pleasing to the learner. Any time you can provide someone with the ability to "see" beyond their range of vision (scanning tunneling microscopes). |
| Gecko, need for a clean room. |
| I like the nanocare fabric, quantum dots, clear sunscreens--all wonderful chemistry. |
| Improved solar panels, nano fog, nano mayonnaise. |
| Viral self-assembly, Tobacco mosaic virus, T4 bacteriophage, quantum computing. |
| Quantum Dots (e.g., nanogold), clear sunscreen (nanopowders of zinc oxide), nano solar cells and clean fuel examples, nanotubes. |
| Favorite examples include Nanopants (textiles treated with nano-coatings that repel dirt), self-cleaning toilets, and gold nanoparticles as sensors. |

**7. What do you think is the role of laboratory experiences and demonstrations in nanoscience education? Can you give a few examples and specify how they contribute to student understanding?**

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| Laboratory experiences are absolutely necessary for any science education. Demonstrations are OK to make a point but not as important as hands-on activities. While I am on the topic, I do not like the traditional mode of separating the lab from other aspects of the teaching. All components of any course should be integrated so that the students do not know if they are in a "lecture" or a "lab". |
| Lab rotation and demonstrations among science and engineering departments will give students the greatest possible exposure to interesting topics. STEM --atom manipulation, AFM-surface characterization, SEM--pictures of ZnO nanowires, TEM-picture of CdSe quantum dots or metal nano particles, Ramon Spectroscopy -- peak shifts |
| The labs/demos will be important in a nanoscience program, but these new experiences will look very different than current school science laboratories that tend to drive girls away. The labs will look more like interactive playgrounds or artist studios with different work/study areas with a blend of networked computers, science instruments (e.g., atomic force microscopes), physical modeling tools, group meeting tables, remote cameras, links to other people at nanoschools, museums, nanocenters and universities. |
| Very important. I can't give examples since I am new to nanotechnology, but my work in DNA fingerprinting and transgenic manipulation labs to illustrate the applications of microtechnology have been successful. |
| AFMs are a great tool to help students understand what the surface of a material might look like in profile. |
| Laboratory experiences should be a logical extension of the key theoretical concepts being taught in the course. They should assist deep learning through application of those theory. Additionally, good labs facilitate other "soft skills" such as working with equipment, calibration, safety, interacting with others, research design and method, as well as powers of observation, data recording, deduction, and reasoning. |
| Physical, direct interaction with phenomenon is always the most important. |
| Given the highly conceptual nature of nanoscience - one can never "see" or "touch" matter at the nanoscale without specialized tools and processes - lab experiences and demonstrations are critical! For the Nanozone exhibition, we developed models of tools and emerging applications. These models are used in demonstrations and are essential in helping students to develop an understanding of how these things work at the nanoscale. |
| I think hands-on, inquiry-based experiences are very important. Inquiry-based teaching and learning experiences enable scientific concepts to be mastered through designing and conducting investigations. Through this students learn principles of science, reasoning and procedural skills and understand the nature of science. |
| I like the AFM because it illustrates size and amplification of size. I like the demonstrations that illustrate self-assembly such as using magnets in geometrical shaped foam pieces that can float on water. This is probably more of a middle school demonstration though. I also like any experiment where students can prepare nanomaterials and then used instrumentation to quantify/verify its properties. |
| To teach basic concepts to excite students. |
| They play a key role. For example, interacting with AFM and MFM models can help students understand how instruments used in nanotechnology allow scientists to study surfaces at the molecular and atomic levels, and introduce students to a new type of microscope used in science investigations. Students could compare traces from the different instruments and, given unidentified traces made by other students, try to infer the surface type. These activities could lead to discussions of measurement error, identification of impurities in samples, and the advantages and appropriateness of different imaging techniques for different surface types. These activities would provide a revealing view of the instruments and principles behind them. |
| We have used a nanomanipulator and an Atomic Force Microscope for students to conduct experiments at the nanoscale. There are a number of direct and indirect experiments that students can do to explore the processes of nanoscale research at a variety of levels. |

**8. What tools, in general (including modeling tools) do you know of or can recommend that can be adapted for labs or demonstrations?**

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| To be self serving, I think that much of our Visual Quantum Mechanics materials could be adapted. |
| Web sites for virtual lab and simulation Web sites for distance learning Internet links to nanotechnology centers, NIST, and NSF funded project web pages. |
| Molecular Workbench from Concord Consortium. |
| Molecular Workbench tools from Concord Consortium - almost any of their modules. |
| Again I'm not a teacher ...Any school that wants to teach nano should be making nano objects with the students. If that requires a really high current and a really good vacuum-so be it. Students can build this with their teachers and do a little 19th century physics to get to the 21st century stuff. |
| A teacher working with us developed a unit on probes for middle school ("Probing the Unknown"). |
| AFM is a key tool. Of course, the NanoSense project will provide some wonderful modeling modules. |
| Chemica, ChemSense. |
| Molecular modeling. |
| A large-scale wood model of an AFM, developed by Dr. Scharberg at San Jose State University. Pedagogica and its simulations engines for chemistry (e.g., Chemica), and Molecular Workbench. Netlogo Nanomanipulator http://www.cs.unc.edu/Research/nano/cismm/nm/ MRSEC (Wisconsin) Exploring the NanoWorld http://www.mrsec.wisc.edu/Edetc/index.html |
| We have developed precollege software with simulations using atomic force microscopy images that are embedded in an inquiry. There are a number of tools and demonstrations (such as using legos in self-assembly simulations) that can be used to model nanoscale science. |

### 9. What nanoscience education materials are you aware of that you think are particularly good?

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| I have not used anything that was specifically for nanoscience other than a few things that we developed ourselves (which, of course, I think are great.) |
| Teaching Nanotechnology in the High School Curriculum: A Teacher's Guide, was developed by Ken Bowles, Apopka High School, Florida. This guide was created under the RET program at UCF NANOPAC - 2004. |
| There are a handful of multimedia exhibits as part of Nanozone at the Lawrence Hall of Science. There is also a traveling exhibition called "It's a NanoWorld" that was co-designed and fabricated by Painted Universe, Inc. (the CEO Tom Rockwell who is now our Director of Public Exhibitions at Exploratorium.) |
| I was shown a powerpoint/slide presentation of scale once that I found helpful for scale. |
| Visual Quantum Mechanics Molecular Workbench models. |
| I have yet to see, in person, anything very compelling. |
| www.nanozone.org Can't make claims if it's particularly good, since I'm on the team that helped develop it, but hopefully it will support future education efforts. This website is an outreach component to the nanozone exhibition and is intended for 8-14 yr olds. |
| The University of Wisconsin's MRSEC has developed some materials using LEGO bricks. |
| Although I have not checked them recently, I thought UCLA's Nanotech program had produced some nice labs. |
| **S**ome nano encyclopedia tools. |
| For K-12: NanoKids http://nanokids.rice.edu/ Office of Basic Energy Sciences "The Scale Of Things - Nanometers and More" chart at http://www.science.doe.gov/bes/scale_of_things.html Molecular Expressions interactive "Powers of 10" applet http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/ and Perspectives lesson at http://micro.magnet.fsu.edu/optics/activities/students/perspectives.html and Virtual Scanning Electron Microscope applet at http://micro.magnet.fsu.edu/primer/java/electronmicroscopy/magnify1/ InVSEE Size and Scale module that (1) identifies key concepts, learning objectives, mapping to standards, (2) shows an introductory video (requires real audio), and then (3) presents a nice long explanation (several pages) of issues of size and scale http://invsee.asu.edu/Modules/modsum/ssSUM.htm Nanoscale Science Education Group at North Carolina State University. Scale and Scaling: What is a nanometer? http://www.ncsu.edu/project/scienceEd/scale.htm For college-level or professional development: Stanford's nanoscience and nanotechnology seminars and courses http://scpd.stanford.edu/SCPD/courses/contentView/nanotechnology/ |
| NCSU- simulations and software; Wisconsin- instructional activities; Rice- NanoKids. |

**10. In a nanoscience program, what do you see as the balance between academic learning, laboratory training, and on the job training?**

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| I would say 1/3 of each. Students are provided with theoretical background, lab hands-on projects and industry internships. |
| Learners are so different in the ways they approach learning that you'd have to have a good mix of each to reach the diversity. |
| For high school: 40:50:10 (but I mostly teach freshmen, so the on the job part could increase for junior/seniors). |
| Should be tightly integrated - what ARE the jobs? |
| All are important and are a logical extension of one another. |
| "Doing"-making and building and working it out should be the wellspring of all other teaching and learning strategies. |
| It depends on the level. At the high school level, academic learning (including hands-on activities/labs) are most important. At the college level, it depends on a student's ultimate goal. Academic learning and laboratory training are very important. On the job training will depend on the job. |
| In the Silicon Valley, I think we can provide an excellent learning environment that includes laboratory training. However, I am still unsure of the types of jobs that would be available via interns or entering B.S. students. |
| All equally important. |
| For young adults, academic learning and labs, some job training for trained professionals, fast skilling and job training. |
| Academic and lab together and first, and slowly integrate on-the-job training. |
| The balance of academic learning, laboratory training, and on the job training will differ depending on the level of the student. All three are important but depending on whether the student is a graduate student in material science or a high school student exploring options the weights of these objectives may differ. |