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REVIEW

A Review of Nanotechnology Learning Resources for K-12, College and Informal Educators

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Resources are available to help educators teach nanotechnology topics and find curriculum materials for their classes, including published journal articles, video lectures, laboratory experiment procedures and in-person workshops. Educational materials shared by individual scientists and educators, nanotechnology research centers and professional organizations cover many fields of nanotechnology and all levels of education, both formal and informal. This article reviews these resources with the purpose of increasing their visibility and encouraging their use.

Keywords: Workshops, Online Media, Curriculum Materials, Review, Books and Journals, K-12, Undergraduate, Informal Learning, Outreach.

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1. INTRODUCTION

Educators integrate nanotechnology into their classes, create new courses and design academic programs in order to educate students and provide them with the skills needed to participate in the future nanotechnology workforce (Murday et al., 2010). To accommodate this demand, nanotechnology educators and scientists are disseminating ideas, information and experiences through workshops, conference presentations, journal articles, books, websites and professional organizations.

Effective dissemination of these resources by educators is important. Instructors new to this field may not know where to look. Those with a bit of experience teaching nanotechnology might need guidance for choosing the appropriate place to share the resources that they created. Even the most experienced nanotechnology educators can find themselves wanting to explore a new area within this field or trying to keep up with nanotechnology education as it grows and evolves. This article describes the available peer-reviewed journals, books, and professional organizations that offer curriculum materials and professional development opportunities devoted to nanotechnology education. Sources of background information about nanotechnology that are not designed for classroom use are not reviewed. For example, many major media outlets and government agencies provide informative articles and guides to nanotechnology but they are not presented as lesson plans, class activities or lecture presentations. This review is by no means exhaustive. The author limited the scope of the article to the sources with the most and highest quality materials to offer in English. Apologies are extended to any person or organization whose resource was unintentionally not included.

Goals of this article are to make new and current nanotechnology educators aware of the many resources that are available and to encourage their use. Sharing resources among educators is crucial for the continued growth of this field. While there is no shortage of curriculum materials, many of them are difficult to find, being posted by faculty on their own course webpages and accessed only by their students. Educators need to share their new curriculum materials with the venues described here and elsewhere. This increases the number of materials available and the act of posting the material can reveal to that educator what other resources already exist. Aggregating resources in a small number of locations limits the time and effort wasted in duplicating others' work. Sharing resources increases the interactions among fellow educators. For educators just beginning to learn about teaching nanotechnology, hopefully this article will help them find these curriculum materials. Table I summarizes the resources described in this article, listed in order of their appearance.

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2. PEER-REVIEWED JOURNALS AND BOOKS

The field of nanotechnology education has grown to the extent that it can support the peer-reviewed journal which you are reading now. The *Journal of Nano Education* (JNE, 2013) is the only peer-reviewed journal devoted exclusively to nanotechnology education. It was established in 2009 by American Scientific Publishers. It disseminates manuscripts concerning all areas of nanotechnology education with topics from education research to the practice of teaching in the classroom and laboratory. Most articles describe new experiments for undergraduate STEM classes but the journal also features articles about high school curriculum materials, teaching nanotechnology to liberal art students and methods of teaching nanotechnology ethics. The scope of JNE includes informal education as well. A subscription is required to access the journal's articles online and in print. The author serves as the journal's current Editor-in-Chief.

Due to its interdisciplinary nature, nanotechnology education articles often appear in education journals of other science and engineering disciplines and in education research journals. Recently, the inclusion of nanotechnology articles has also become more frequent. As an example, the number of articles about nanotechnology in the *Journal of Chemical Education* increased from a range of zero to two per year prior to 2001 to a range of nine to fourteen per year between 2008 and 2012. A review of even the most widely read academic education journals which have published relevant articles would be too extensive for this article. The authors' cursory search showed that nanotechnology was the subject of at least a few recent articles within education journals in all STEM fields, as well as education research journals.

Several books devoted to nanotechnology education are in print. These books go beyond the question, "What is nanotechnology?" and instead ask the question, "How can educators help their students learn about nanotechnology?" The former is answered by many books, from Nanotechnology: A Gentle Introduction to the Next Big Idea by Ratner & Ratner (2003) to more specialized college and

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Table I. Summary of nanotechnology resources reviewed in this article.

Journal, book or organization	Notes[1–3]	Publication information
Journal of nano education	Grades 9–12 and post-secondary education peer reviewed journal international focus	Kurt Winkelmann (Editor-in-Chief), American scientific publishers
Big ideas of nanoscale science and engineering: a guidebook for secondary teachers	Grades 6–12 education	Shawn Stevens, LeeAnn Sutherland and Joseph Krajcik
Nanoscale science and engineering education	Grades K–12, post-secondary, graduate and informal education international focus	Aldrin Sweeney and Sudipta Seal (Eds.), American scientific publishers
Nanoscience education, workforce training, and K-12 resources	Grades K–12, post-secondary and informal education international focus	Judith Light Feather and Miguel F. Aznar, CRC Press
Nanotechnology in post-secondary education	Post-secondary education chemistry topics	Kimbery Pacheco, Richard Schwenz and Wayne Jones Jr. (Eds.), American chemical society symposium series
The role of life-long education in nanoscience and engineering	Post-secondary and informal education international focus	Materials research society
MRSEC education group	Grades 6–12, post-secondary and informal education	University of Wisconsin– Madison MRSEC
Nanotechnology center for learning and teaching	Grades 7–12 and post-secondary education	Northwestern university
Materials world modules	Grades 7–12 education international focus	Northwestern university
Nano-Ed community of scholars	Grades 7–12 and post-secondary education	Chemistry collaborations, workshops and communities of scholars
Nanotechnology applications and career knowledge network	Grades 9–12 and post-secondary education	Penn state university center for nanotechnology education and utilization
NanoHUB	Post-secondary and graduate education	Network for computational nanotechnology
Nano-link regional center	Grades 9–12 and post-secondary education	Midwest regional center for nanotechnology education
National nanotechnology infrastructure network	Grades K–12 education	National nanotechnology infrastructure network
TechNyou science education resources	Years 7–12 education Australian focus	University of Melbourne, Australia
Nanoscale informal science education network	Informal education	Nanoscale informal science education network

(1) Unless otherwise noted, all publications or organizations cover a variety of topics from STEM disciplines.
(2) Organizations and publications that specifically address nanotechnology education in two or more countries outside the United States are designated as having an international focus.
(3) Post-secondary education includes education at technical and community colleges and four year colleges and universities.

graduate level textbooks. Books described here answer the second question.

High school teachers can learn about teaching nanotechnology to their students by reading The Big Ideas of Nanoscale Science and Engineering: A Guidebook for Secondary Teachers by Shawn Stevens, LeeAnn Sutherland & Joseph Krajcik (2009). This book explores the Big Ideas of nanotechnology (i.e., quantum effects, structure of matter, interactions and forces, self-assembly, instrumentation, size and scale, models and simulations and the impact of science and technology on society). The authors explain why each Big Idea was included, describe the content knowledge that comprises each idea and present examples of how teachers can include the Big Ideas in their lesson plans. The final section of the book points out the challenges to teaching nanotechnology. The intended audience of the books is teachers of grades 6 through 12 in U.S. schools.

Prior to launching the *Journal of Nano Education*, American Scientific Publishers offered Nanoscale Science and Engineering Education, a 36 chapter compendium covering a great diversity of topics (Sweeney & Seal, 2008). Subject matter ranges from pedagogy to classroom and laboratory activities to course and program design. Chapters cover topics relevant to K-12, undergraduate, graduate and informal education in the United States and around the world. Authors describe undergraduate programs for small schools, large schools, primarily minority institutions and community and technical colleges. Chapters present curricula in physics, computer science, engineering, chemistry and biology. The discussion of undergraduate curricula is not limited to just science and engineering topics taught to students in those majors, though they are the focus of several chapters. Liberal arts and social sciences are also well-represented. Chapters describe ways of teaching nanotechnology to students in these fields and activities for teaching nanotechnology ethics and societal issues to students in STEM fields. Drs. Aldrin Sweeney and Sudipta Seal of the University of Central Florida edited the book which spans almost 700 pages. This is the single most useful resource for those searching for an introduction to the wide variety of nano education topics.

Judith Light Feather & Miguel F. Aznar (2011) explore the available nanotechnology education resources and many factors that affect its teaching in their book, Nanoscience Education, Workforce Training, and K-12 Resources. The first section explains how education policy is created in the United States, from the federal to local levels. It also provides examples of students and concerned scientists who challenged this system and improved education. The second section describes how teachers should present nanotechnology to their students. The third section is most relevant to this article as it describes hundreds of sources for K-12, workforce training and informal education resources both in the U.S. and around the world. These summaries can be short, sometimes only a few sentences, but they are all referenced. This section accounts for almost half of the 300-page book. The last part of the book recommends new ways for teachers to incorporate these resources into their classroom and suggests new policies to make it easier for teachers to do so. A more detailed review of this book has been published (Winkelmann, 2010).

Nanoscience education is the subject of several recent symposia at major research conferences. Presentations at two such events were collected for publication. The first, Nanotechnology in Undergraduate Education was published in 2009 as part of the American Chemical Society's (ACS) Symposium Series (Pacheco, Schwenz & Jones, 2009). Drs. Kimberly Pacheco, Richard Schwenz and Wayne Jones Jr. organized the 2007 *Nanotechnology in Undergraduate Education* symposium at the 233rd ACS National Meeting in Chicago and edited the resulting book. Thirteen chapters cover nanotechnology course, curriculum and laboratory innovations for chemical educators of undergraduate students. Some chapters, particularly those describing laboratory experiments, could be helpful for high school educators. Chemistry faculty interested in adding nanotechnology to their courses will find this volume useful as a source of new topics and experiments.

The final nanotechnology education book is The Role of Life-Long Education in Nanoscience and Engineering, based on a symposium at the spring 2008 Materials Research Society meeting in San Francisco (2009). The seven chapters of this 49 page book cover technical higher education, ways of engaging the general public in a discussion of nanotechnology science and policy, an overview of the Nanoscale Informal Science Education (NISE) Network (also described below) and nanotechnology outreach efforts in Puerto Rico. Although not extensive, this book has a variety of ideas that would interest informal educators.

3. PROFESSIONAL ORGANIZATIONS

Non-profit organizations serve many purposes in the field of nanotechnology education. They organize volunteers for outreach events, encourage communication and establish a sense of community among educators, promote conferences, workshops and meetings for disseminating innovative findings in nanotechnology education research and practice, and provide educators with curriculum materials either created by the organization or shared by its members. Organizations described in this section emphasize one or more of these tasks as their primary objective. Often, their websites require a registration to access content but this registration is free and the content described on the websites is also free. Some curriculum materials, such as experiment kits are sold by the organizatons and workshops often require a registration fee.

The University of Wisconsin–Madison's Materials Research Science and Engineering Center (MRSEC) Education Group provides a well-known collection of classroom and lab activities, including videos, text and images to introduce instructors and students to nanotechnology (MRSEC Education Group, 2013a). All content is freely available. For those who are already familiar with the basics of nanotechnology, there are lesson plans, syllabi, videos, background information, slide presentations, class activities, laboratory experiments and outreach activities. Topics include both nanotechnology and more traditional materials science. For the convenience of instructors, supplies for many activities and experiments found on the MRSEC Education Group's website can be purchased from the Institute for Chemical Education (ICE), also located at UW Madison (2010). Experiment procedures include vendors for purchasing items. The Internships in Public Science Education (IPSE) website offers many creative ideas for outreach events, including games and demonstrations of nanotechnology-based consumer products (IPSE, 2013).

The MRSEC Education Group's website organizes these resources in several ways. The Video Laboratory Manual links to a webpage for each experiment (almost 40 in total) and provides short video clips to show each step in the experiment's procedure (MRSEC Education Group, 2013b). If an educator wishes to incorporate many of the IEG resources for a single unit, such as ferrofluids, then the Topics A–Z webpage is useful because it organizes the content by subject (MRSEC Education Group, 2013c). For the example of ferrofluids, the Topics page provides links for two sets of presentation slides, two webpages with background information, two lessons, a laboratory experiment, two videos and one classroom activity. All the links are labeled with descriptive titles of their contents. Many resources are also available in Spanish language. Researchers and educators can contribute experiments to MRSEC Education Group for inclusion on the website by contacting the IEG staff but there is no online community forum for discussion.

The website of the Nanotechnology Center for Learning and Teaching (NCLT), promotes nano education for students in grades 7 through 12 and undergraduates (2011).

This organization was formerly the National Center for Learning and Teaching in Nanoscale Science and Engineering. It was headquartered at Northwestern University with core partners at nine other U.S. colleges and universities and also at Argonne National Laboratory. Funding for NCLT came from the National Science Foundation and expired in 2011. The NCLT website is extensive, with information for both educators and students and a portal for NCLT community members to collaborate. It appears that the organization was most active between 2004 and 2010, though posts about upcoming outreach activities such as NanoDays continue.

Educators can find almost one hundred syllabi, lecture notes and videos for college-level nanotechnology classes and seminars. Visitors can view nanotechnology education research posters, freely available journal articles and slides of past NCLT research conference presentations. These resources include introductory material for learning about nanotechnology, ideas for curriculum, education research and best practices for teaching. Students can play education-inspired games to learn about differentiating objects' scale and size, building a dye-sensitized solar cell and other nanotechnology topics. Simulations and animations include a demonstration of Young's double slit experiment, plasmon resonance, and the many properties of nanomaterials. In all, there are about thirty games, simulations and animations designed for students in high school to graduate school. All education resources available on the NCLT website are provided by NCLT community members (NCLT NanoEd Resources, 2011). High school and college students can benefit by accessing NCLT home page links to other active sites which provide information about nanotechnology degrees (Associates through Ph.D.), certificate programs and career opportunities (NCLT 2011).

Educators interested in adapting these materials should check the date that the information was posted to see if it needs updating. Most materials were posted at least four years ago, although they may link to external websites that are updated more recently. Unfortunately, the community is no longer active. Hosting and managing websites like NCLT requires ongoing funding. This is an obvious challenge. The website of the Nanotechnology Center for Learning and Teaching demonstrates that even extensive online communities require support and, without funding or dedicated volunteers, communities will slowly dissipate.

Many of the curriculum resources for educators of grades 7–12 are available through Materials World Modules (MWM, 2012). Headquartered at Northwestern University, this program is separate from NCLT and continues to design and sell inquiry-based laboratory activities. These are not single classroom experiments but are modules consisting of an introduction, multiple activities for students to learn about different aspects of the topic, leading to a design challenge in which students build a device that requires them to apply all that they have learned. Almost half of the sixteen modules focus on nanotechnology topics with other modules introducing students to material science topics, such as polymers and sensors. MWM field tests all modules with the help of teachers from dozens of middle and high schools throughout the United States. Educators using the MWM laboratory kits can request that a workshop be held nearby so they can receive training, learn about the pedagogy and experiments MWM offers and meet other module users (MWM Workshops, 2012). Instructors can receive online help for integrating the experiments into classes, assessing their effectiveness and aligning the activities with state and national education standards. MWM actively promotes its laboratory curricula in other countries such as Mexico, China and Qatar (MWM Media Coverage, 2012).

The Nano-Ed Community of Scholars is a new online community for nanotechnology educators that is under development. The author serves on its leadership team. Nano-Ed will contain many of the same features that are available at the NCLT website, including free peer-reviewed curriculum materials, discussion boards for community members and news about upcoming relevant events. This site is one of several communities of scholars created as part of the NSF-funded Chemistry Collaborations, Workshops and Communities of Scholars (cCWCS). This organization continues to offer workshops for chemical educators in various fields, including nanotechnology, as it did under previous funding when it was known as the Center for Workshops in the Chemical Sciences. Although the discipline of chemistry plays a central role in cCWCS communities, they are not exclusively for chemical educators; especially in the case of nanotechnology, there is much overlap between STEM education fields. The Nano-Ed Community of Scholars wishes to include all areas of science and engineering. One purpose for creating a community of scholars is to encourage cCWCS workshop attendees to continue to stay connected with each other, foster long-lasting collaborations and remain active in the field after the workshop is over. By taking a long-term approach to building professional relationships among nanotechnology educators, the Nano-Ed Community of Scholars supports sustainable integration of nanotechnology into the undergraduate curriculum. All educators are welcome to join the communities, not just those who attend the cCWCS workshops.

Teaching nanotechnology and materials science in the college chemistry curriculum is the subject of a workshop offered by cCWCS (Collard, D. M., 2012). This five-day workshop is held during the summer at Beloit College in Wisconsin and is led by Dr. George Lisensky. Participants attend presentations to learn about many aspects of nanotechnology then they perform several laboratory experiments each day. The presentations and experiments are among those hosted on the MRSEC Education Group's

Video Lab Manual website (Guide to Our Materials, 2013b).

The Nanotechnology Applications and Career Knowledge (NACK) Network emphasizes the need for students at community and technical colleges to learn about nanotechnology in order for them to join the nanotechnology workforce (2013). The NACK Network is part of the Penn State University Center for Nanotechnology Education and Utilization (CNEU). NACK is supported through the NSF Advanced Technological Education (ATE) program with the objective of supporting nanotechnology education at two-year schools and encouraging four-year colleges and universities to collaborate with technical and community colleges. While organizations like NCLT and Nano-Ed are broadly concerned with undergraduate nanotechnology education, goals of the NACK Network highlight the need for providing nanotechnology education to students in worker training programs, associate's degree programs as well as students in community colleges who choose to matriculate to four year schools. Since workforce training by definition involves preparing students for careers, NACK has developed many industrial partnerships with companies who might need nanotechnology workers, such as PPG, DuPont, Boeing, General Electric, Corning, Semiconductor Research Corporation and Northrop Grumman.

NACK provides free educational resources for K-12 and post-secondary instructors (NACK Network Educator Resources, 2013). Undergraduate lesson plans include PowerPoint slides with embedded multimedia for such topics as nanotechnology introduction, characterization methods, top-down and bottom-up nanomanufacturing and the impact of nanotechnology on medicine and electronics. Video recordings of lectures can be viewed by students or educators can learn from the recordings as they create their own curriculum materials. Laboratory activities have a definite industrial emphasis. Topics include chemical and equipment safety training, a vacuum system simulator and instructions for using advanced laboratory equipment not ordinarily found in college teaching facilities. Simulations for other pumps, leak detectors, cleanroom procedures and animations of processes, such as diffusion, chemical vapor deposition and plasma etching, are also available. NACK provides remote access to atomic force and scanning electron microscopes and other instrumentation. An instructor and students can remotely access the instrument through a desktop software program and communicate with the instrument technician via Skype. Students can characterize nickel nanowires, gold nanoparticles, a dye-sensitized solar cell and other samples remotely and they can synthesize them using published laboratory procedures or using kits available through the Institute for Chemical Education (ICE Overview, 2010).

High school laboratory activities provided by NACK require no advanced instrumentation. They are appropriate for a college science laboratory course as well. The three laboratory experiments are: microencapsulation, synthesis of silver nanoparticles and the study of silver nanoparticles' antibacterial properties. Lecture materials for introducing high school students to nanotechnology and related topics are also available but are the same presentations as those found in the post-secondary education resource section. Educators interested in activities for a high school nanotechnology day camp can find ideas for activities in the Nanotech Academy section. The NACK Network provides high school students with many examples of nanotechnology applications which are familiar to them, such as stain-resistant pants and DVDs. Students and workers interested in learning more about nanotechnology can visit the Student section of the NACK website to find two-year schools which offer nanotechnology degrees (NACK Network Students, 2013).

The NACK Network approaches community building from a different perspective. Instead of focusing on building connections between educators, their website has a separate section devoted to alumni of two-year nanotechnology degree programs throughout the United States, including those not affiliated with the NACK Network. Their alumni section provides career resources, professional networking and mentoring to help nanotechnology graduates get the most out of their degree and their future career (NACK Alumni Network, 2013).

NACK offers webinars for educators and students interested in nanotechnology (NACK Network Webinars, 2013). Currently, webinars are free and occur once a month. NACK also archives the webinars as far back as 2009. Topics include several different nanotechnology introductions, applications, characterization methods, integration into a classroom curriculum or degree program, safety and societal implications. NACK also offers workshops for educators (NACK Network Workshops, 2013). In 2013, NACK hosts a 3-day workshop introducing educators to nanotechnology, once during the spring and again in the fall. Unlike the cCWCS workshop, this event focuses on industrial uses of nanotechnology, including bionanotechnology, MEMS, optoelectronics and nanofabrication. Attendees also tour the Penn State cleanroom facilities and the CNEU teaching cleanroom and perform experiments using these facilities. NACK recommends this workshop for science educators at high schools and vocational, technical and community colleges. Two other workshops are designed for educators at undergraduate colleges and universities with an interest in nanotechnology. In the first workshop, attendees receive guidance for teaching students about the safety, equipment and methods for processing nanomaterials. The second workshop reviews such topics as nanoscale patterning, materials used in nanotechnology applications, characterization methods and nanomaterial testing. Workshop activities include both presentations and hands-on laboratory experiments.

The Network for Computational Nanotechnology (NCN) offers NanoHUB, a freely accessible website devoted to nanotechnology simulations and animations for education. NanoHUB contains a collection of diverse content (NanoHUB Resources, 2009). Animations include YouTube videos explaining nanotechnology and quantum phenomena at a level appropriate for first-year students and instructional videos showing how to use more advanced simulations found on the site. In total, there are over fifty animations and videos available. Almost 300 files are found in the Tools section. Most are simulations that illustrate advanced topics such as transistor design and properties, band structures of nanomaterials and prediction of spectroscopic peaks and other data. Other tools are designed to perform tasks such as differential functional theory calculations using Quantum ESPRESSO software.

NanoHUB provides a significant amount of user support. The instructional videos found in the Animations section described previously are one example. All items in NanoHUB are tagged and categorized for easy searching. Each tool is rated to describe the potential audience for the tool (from beginner to expert). Users can acquire code for some simulations in the Downloads section (NanoHUB Resources, 2009). Before launching a tool or animation, the user can see feedback from other members who have used it. This includes user reviews and ratings, comments and questions asked by users and the item's frequency of use. A registered user of NanoHUB can select items to add to a personal favorites list. Some tools are posted by NanoHUB community members and others are developed through the Network for Computational Nanotechnology. Tools in the latter group are labeled as "NCN supported," which means that users can receive technical support in case they find a bug or have a question about the software. To learn how to best use their resources, NanoHUB provides a set of case studies and best practices in the Teach & Learn section found in the About menu (2009). There are separate Frequently Asked Questions pages for students and instructors on the Teach & Learn page as well.

In addition to stand-alone items, NanoHUB community members can access curriculum materials in a variety of formats under the Resources menu (2009). Content is provided by NanoHUB members. Posted items in the Courses may contain ten hours of lectures or span an entire semester of class time. These are audio recordings with slides of instructors actually teaching the course along with lecture notes and supplementary information. Some of these items also appear in the Workshops section. Videos of in-class lectures and seminars are found in the Online Presentations section. A separate portion of the NanoHUB website contains Learning Modules. These are similar to the other sets of presentation audio and slide files but with some minor differences. They are shorter with specific learning objectives, often teach how to use a NanoHUB tool and include a pre-test or a post-test. Teaching Materials is fourth category of content which include lecture slides, homework exercises and instruction sheets, some of which are part of courses posted at NanoHUB.

A final set of curriculum materials are found in the Tool-Powered Curricula section (2009). Instructors who teach STEM courses and wish to add nanotechnology and quantum mechanics content found at NanoHUB will find this page most useful. NanoHUB content is organized according to the topics taught in common courses, such as General Chemistry, Quantum Chemistry for Engineers, and Introduction to Semiconductor Devices. The webpage for each course contains a list of NanoHUB content for topics of the course with links to the animations, tools and support materials necessary. Instructors can choose which topics they want to augment with NanoHUB content, follow instructions that show how to use the simulations and software for teaching those specific topics, and access course materials which they can provide to their students. This eliminates the need for an instructor to search through the list of NanoHUB content in many categories to piece together the activities for a particular course.

NanoHUB's arrangement of files could confuse first-time users as they navigate through many different menus and webpages. NanoHUB separates curriculum materials into somewhat arbitrary categories. Some sections are particularly useful for educators, such as teaching best practices and the Tool-Powered Curriculum but are found buried in the About menu. These problems are relatively easy to overcome with experience using the site and well worth the effort.

NanoHUB is likely to receive more attention from nanotechnology educators due to its connection to the National Science Foundation's Nanotechnology for Undergraduate Education (NUE) in Engineering program. The 2013 NUE request for proposals included a requirement that all awardees must post curriculum materials and maintain a grant program page (National Science Foundation, 2013). The choice of NanoHUB seems appropriate due to the website's features described above (e.g., user feedback and searchability). This NUE program was encouraged to enact this requirement by the 2012 evaluation of the NSF program by the Manhattan Strategy Group (2012). The use of NanoHUB for disseminating nanotechnology education curriculum materials also satisfies recent recommendations for the greater use of online resources that make content easier to find and share (Murday, Hersam, Chang, Fonash, & Bell, 2010).

The Nano-Link Regional Center (Nano-Link) is a regional nanotechnology education organization located in the upper Midwest of the United States (2013). Its mission is to improve students' skills that the nanotechnology industry desires. Their Nano-Infusion project provides high school teachers with course materials for teaching nanotechnology modules in a flexible format (Nano-Link Nano-Infusion, 2013). A set of class materials contains a lesson plan, worksheets, background information for a short lecture and instructions for the activity. Each module is designed to be completed within a single class period,

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though the activity instructions allow the instructor to perform it as a short demonstration or expand it into a longer experiment. All course materials are freely available on the Nano-Link website, along with videos of the activities being performed. A complete guide to teaching a two semester, introductory nanotechnology class is also available (Newberry, D., 2008a, b). The two volume teacher's guide is almost 200 pages long and richly illustrated. It describes the background and basic information needed to design a course that is appropriate for advanced high school or first-year college students. Topics covered by the course guide include: size and scale, characterization tools, societal impacts, biological applications, physical science and engineering applications, materials science, semiconductors and properties of optical nanodevices. A forum for Nano-Link community members provides a place to meet and discuss ideas. The Nano-Link website lists many meetings and conferences of interest to its members, including some for high school teachers. The organization offers onsite, two-day workshops to demonstrate the Nano-Infusion program to high school and college instructors (Nano-Link Workshops, 2013).

The National Nanotechnology Infrastructure Network (NNIN) is an organization of nanotechnology research centers at fourteen U.S. universities (NNIN, n.d.). While their primary objective is to advance research, NNIN also provides some unique educational resources for K-12 students. The first among these is Nanooze, a magazine about nanotechnology written for kids in grades 5–8 (NNIN Nanooze Magazine, n.d.). Nanooze is available to download from the NNIN website and teachers can order free copies for their classes. Young students can find ideas for nanotechnology-related projects for science fair and read articles written to their grade level about nanotechnology (NNIN Nanotechnology Science Projects, n.d.; NNIN Educational Articles, n.d.). Primary and secondary school teachers can learn how nanotechnology fits within Common Core and National Science Standards. Since teachers often lack the class time for lengthy nanotechnology activities, NNIN provides a guide for short activities and demonstrations for class or for use in an outreach event (NNIN Outreach Demonstration Guide, n.d.). Teachers can expand these activities as needed to create more in-depth lessons. NNIN also provides curriculum materials for elementary, middle and high school teachers for about fifty nanotechnology topics, including the Big Ideas (e.g., size and scale), applications and societal implications (NNIN Nanotechnology Curriculum Materials, n.d.). Each lesson includes separate guides for students and teachers, as well as any necessary supplementary information, such as presentation slides and quiz questions. Some lessons include laboratory experiments and others are designed for class discussions. Although not part of their education section, NNIN shares their view of how ethics and safety should influence nanotechnology research (NNIN Society and Ethics, n.d.). Educators may find these resources useful when discussing the potential societal benefits and concerns of nanotechnology advances.

TechNyou Science Education Resources (formerly AccessNano) shares nano-, bio- and bionanotechnology curriculum materials that are consistent with Australian middle and high school education standards for years 7–10 (TechNyou, n.d.). Modules are separated into one of these three topics and by academic year. Modules include experiments, writing assignments and class discussions for students and assessment rubrics, presentation slides and background information for teachers. A single module can contain information for two or more activities which require many hours of class to complete, though each activity can be performed individually. This website is noteworthy for two reasons. It offers worksheets for many activities, resulting in teachers spending less time preparing for the lesson and TechNyou includes many activities addressing bionanotechnology, a topic that is not emphasized by other organizations.

Both educators and researchers understand that awareness of nanotechnology among the general public is critical for its continued growth. Researchers share their latest discoveries, educators recruit potential students and the general public increases its scientific knowledge. The primary purpose of the Nanoscale Informal Science Education Network (NISE Net, n.d.) is to create and share outreach activities with the public. They develop their programs with the involvement of nanoscience and engineering professionals, experts in informal science education and members of the general public. Programs include short demonstrations of scientific phenomena, in-class activities, stage and theatrical performances, exhibits and science cafe and forum events in which the public contributes to the discussion. They are peer reviewed during development and evaluated by their audience (NISE Network Programs, n.d.). The NISE Net catalog lists over 100 different programs, most of which are available in Spanish language (NISE Network Catalog, n.d.). All are tagged with keywords for easy searching by type of audience, topic and other information. Each item in the catalog contains an overview, learning objectives, resources needed, relevant K-12 education standards and user comments.

Another NISE Net goal is to encourage formal and informal educators and researchers to collaborate in an effort to increase the nanotechnology literacy among members of the general public. This is accomplished through the Community section of their website. NISE Net members can contact each other through the member directory, join scheduled online discussions, learn about upcoming scientific conferences and keep abreast of NISE Net news by reading the monthly newsletter and blog (NISE Network Nano Bite Newsletter Archive, n.d.; NISE Network Blog, n.d.). Members can use the Find a Scientist tool to contact a scientist volunteer to answer questions or collaborate in an outreach event. Although NISE Net is a national organization, it is divided into seven regional hubs to facilitate greater communication among members who are geographically near each other. A major event among the NISE Net community is NanoDays, a nationwide, annual education festival celebrating nanoscale science and engineering with the public (NISE Network NanoDays, n.d.). Organizers of NanoDays activities can download files containing a planning guide, descriptions of activities, promotional materials, staff and volunteer training materials and educational media.

Getting the public into a museum or classroom can be challenging so NISE Net also provides a website for people to learn about nanotechnology on their own (What is Nano?, 2012). "What Is Nano?" provides easy access to NISE Net media that anybody can read, watch and play online and a set of simple experiments and hands-on activities, called DIY Nano, which children can explore at home. The website promotes NanoDays and museums exhibits designed by NISE Net.

NISE Net is involved in two additional activities that can influence the future of informal education. Inclusive Audiences seeks to improve educators' capacity to effectively teach nanotechnology to groups that are traditionally underrepresented in audiences for informal science education (NISE Network Inclusive Audiences, n.d.). Targeted groups include people lacking access to informal education at a museum or science center because of language, disability, income or their geographic distance from such places. Inclusive Audiences is also studying how modifications to the design and distribution of NISE Net materials can increase their appeal to girls and underserved racial and ethnic groups. NISE Net engages in three research projects to understand how people and organizations benefit from their informal education activities (NISE Network Research, n.d.). NISE Net is investigating how partnerships between a practicing scientist and an informal science institution affect the quality of educational materials. A second project studies the ways in which the partnerships between NISE Net and different museums improve or impede the museums' abilities to adopt new educational practices and other organizational changes. The third research study is an effort to improve the manner in which NISE Net can engage the public in a discussion of the societal and ethical implications of nanotechnology.

Even more resources are available on and offline. Readers can consult the National Science Digital Library, the largest repository of such information (n.d.). A search for "nanotechnology" resulted in almost 1000 items from the database. Users can refine a search by keyword, education level, resource type and discipline. An item can be marked as "classroom ready" to indicate that it is considered easily adaptable and effective for classroom education. Research conferences may include symposia devoted to nanotechnology education and sometimes offer workshops for learning about laboratory experiments and classroom activities.

Many more organizations are devoted to nanotechnology research. They too promote communication among their members, disseminate information and organize research conferences. Since nanotechnology education is not a major part of their mission, they form an extensive, separate category whose description is beyond the scope of this article. Also not included here are trade organizations that promote fee-based short courses and professional training. Educators might still find those organizations useful as sources of nanotechnology news, research findings and policy ideas which instructors and students can use in their courses.

4. CONCLUSIONS

Education resources provide abundant animations, video lectures, simulations, experiment procedures and lesson plans for instructors wishing to add nanotechnology to their curriculum. Publication in print and online ensures educators will continue to have access to them, at least for the foreseeable future. The NCLT website is an example of a respository of high quality resources and an online community that is no longer active. Maintaining such a site is requires significant time and funding and is likely a challenge for many of the other websites described here.

The nanotechnology education community has grown and continues to increase both the quality of education materials and also its visibility within the broader STEM fields. Organizations such as American Scientific Publishers, the University of Wisconsin Madison's MRSECEducation Group, the NISE Network, NanoHUB and the NACK Network illustrate that groups can be prosperous and influential in this discipline. Each focuses on certain aspects of nanotechnology and is designed for an audience of a particular educational level (e.g., K-12).

All of the organizations described here encourage educators to use their freely available content and in return share new ideas and discoveries with them. Orgranizations often augment their online communities with face-to-face workshops. New social networking tools will make building and maintaining online communities even easier. Support from funding agencies, such as NSF NUE program's endorsement received by NanoHUB provide more publicity for the organization and will be a source of funding as well.

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