Materials World Modules

Meeting the New Core Standards through Scientific Inquiry & Engineering Design

Imagine…

What if students could study nanotechnology from the 6th grade on? What if right in their classrooms, they could design and test high-efficiency solar cells, environmental photocatalysts, and drugs for targeting cancer? What if they could learn to innovate, collaborate, communicate and apply systems thinking at age 12, and use the same advanced visualization and modeling tools as professional scientists and engineers? What if schools had an easy, affordable way to update their STEM curricula to meet the latest standards?

What is MWM?

The ***Materials World Modules (MWM)*** is a highly successful national program for integrated STEM learning established at Northwestern University in 1993 with funding from the National Science Foundation.

Sixteen classroom modules describe how materials and their properties can solve global problems and transform our everyday lives. Module topics cut across science disciplines and link them to engineering, math, and technology applications.

Published MWM Modules:

- *Biodegradable Materials*
- *Biosensors*
- *Concrete*
- *Ceramics*
- *Composite Materials*
- *Food Packaging*
- *Polymers*
- *Smart Sensors*
- *Sports Materials*
- *Introduction to the Nanoscale*
- *Drug Delivery at the Nanoscale*
- *Dye-Sensitized Solar Cells*
- *Environmental Catalysis*
- *Nanopatterning*
- *Nanotechnology*
- *Manipulation of Light at the Nanoscale*

Scientific inquiry and engineering design activities let students perform the work of scientists, engineers, and entrepreneurs. Each module begins with a "hook" activity followed by inquiry activities that culminate in an engineering design challenge. Students work on teams to design engineering solutions and communicate their benefits.

MWM and the New STEM Curriculum

• • •

Next Generation Science Standards: MWM emphasizes crosscutting concepts, real-world relevance, and a close integration of content learning and hands-on practice. The iterative process of scientific inquiry and engineering design demonstrates relevance and deepens student content knowledge.

Common Core Math Standards: Students apply mathematical ways of thinking to real world issues and challenges and use mathematics to analyze, understand, and make decisions based on empirical situations.

Common Core Literacy in Science Standards: Inquiry activities require students to follow written procedures, make, test, and refine predictions based on activities, short summaries, and experiments. They must also support their claims with data and scientific findings.

Vertical Integration – Ensuring Progression Across Grade Levels: MWM introduces fundamental concepts early on and reinforces them over time to create strong and coherent learning trajectories. Many teachers use MWM as a "DNA spiral" to provide continuity across grade levels and connect STEM disciplines.

Co-authored by teachers and university researchers, modules are continuously updated with the latest interdisciplinary research concepts and technology applications from the nation's top university laboratories. Each module includes student and teacher manuals, assessment questions, and a kit of classroom supplies (above). Our nanotechnology modules also include interactive online tools that help students visualize and explore the nanoscale inside or outside class.

Flexibility for crowded curricula. Each module, from hook activity to design project, can be taught in just 10 class periods. Modules can be inserted into any math, science, or technology course, or combined to create semester-long courses on a variety of topics. Content is scalable from 6-12 grade.

Why Materials Science and Nanotechnology?

Materials Science and Engineering (MSE) and Nanotechnology are ideally suited for integrating the STEM curriculum and training a 21^{st} century workforce.

Both fields are inherently interdisciplinary, with fundamental concepts that cut across physics, chemistry, biology, math, and engineering. Materials and nano topics integrate, reinforce, and deepen STEM learning!

Nanotechnology has a "WOW" factor that inspires students to think differently about STEM. Unique properties at the nanoscale materials take everyday technologies to exciting new levels, driving everything from mobile devices to medical diagnostic instruments, solar cells, smart grids, and cloud computing!

Materials systems benefit society and the economy. Materials-based nano, bio, and green technologies play a vital role in solving global problems (energy, environment, health, communications, etc.) and will drive a large fraction of the world economy in the next century.

MWM Development

MWM was launched in 1993 at Northwestern University - home to the country's oldest Materials Science and Engineering department and a top-ranked School of Education and Social Policy - with **support from the National Science Foundation.**[i] MWM developers include experts in nanotechnology, materials science, physics, chemistry, biology, math, engineering, education, and computer science. We have **collaborated with thousands of STEM teachers** to author, test and refine our content and held numerous workshops to engage them in inquiry and design.

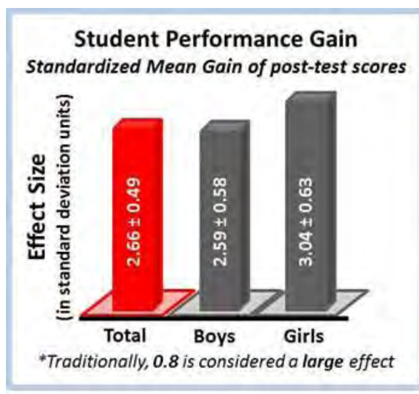
> ***"The methodology, based on the best practices developed by education researchers and put into place by lead teachers, is in perfect alignment with the developing National Standards for Science. There's no product out there that even comes close." – MWM teacher***

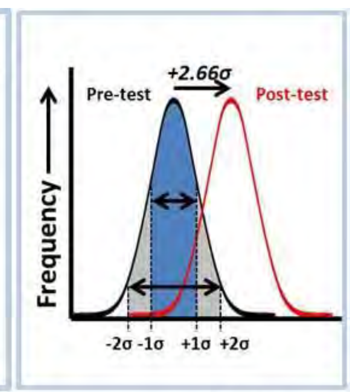
MWM Impact

National Reach: More than 100,000 students have used MWM since 1993. Our user network includes thousands of schools across the country. Teachers appreciate the program's flexibility, its seamless integration of content and practice, and its close alignment with national standards. Above all, they appreciate how actively it engages their students' curiosity, creativity, and critical thinking!

National Field Tests[ii] show an ***average student achievement gain of 2-3 standard deviations, regardless of classroom setting, level of teacher experience, student background knowledge, student gender, or student socio-economic background*** (right). These are the results of participating in a single 2-week MWM module - imagine the gains that will result from incorporating all sixteen MWM modules into the STEM curriculum!

National Recognition: The ***National Research Council*** has recognized MWM for its longevity and its transformative approach. ***The U.S. Department of Defense*** has purchased MWM for thousands of public school classrooms across the country (see map, right) and used MWM content to train thousands of teachers in nanotechnology and inquiry-and-design.





What MWM Can Do for Your School

***Put the "T" & "E" in STEM*:** Incorporating engineering design and relevant technology applications into classroom instruction is a major challenge facing STEM curriculum developers today. Twenty years ago, MWM pioneered the use of scientific inquiry and engineering design. Now, we stand ready to help your school make science and engineering practices an integral part of your curriculum.

Move Towards an Integrated STEM Curriculum: The ambitious Next Generation Science Standards cannot be met overnight, but MWM can ease the transition. Already proven successful as a supplement, MWM will provide a quick boost to your existing courses and help your school develop an integrated STEM curriculum that is grounded in cross-cutting concepts and hands-on practice.

***Professional Development Workshops*:** Since 1993, we have organized more than 100 professional development workshops at partnering schools, universities and community colleges across the country (right) to help teachers implement scientific inquiry and engineering design in their classrooms.

Online Support for Teachers: Our website offers year-round access to content demonstrations, interactive learning tools, webinars, and professional development lectures. Teachers can also download STEM curriculum and standards linkages, assessment items, and guidelines for implementing inquiry and design.

***Support for Curriculum Developers*:** We have experience helping schools develop integrated STEM courses based on MWM content. For example, we helped Taft High School in Los Angeles develop a STEM course that intersected with non-STEM disciplines, based on MWM and using nanotechnology as a unifying theme.[iii] We will be happy to work with you to design integrated courses for your curriculum.

Please let us know how we can help!

Materials World Modules

Northwestern University
1801 Maple Ave., Box 37, Ste. 3230
Evanston, IL 60201
www.materialsworldmodules.org
For module purchases, please contact Anne Muller at amuller@northwestern.edu or (847) 467-4369
For programming and partnerships, please contact Prof. R.P.H. (Bob) Chang at r-chang@northwestern.edu or (847) 491-3598

---

[i] The first nine MWM modules were developed under an initial grant from NSF in 1993 (*NSF-9353833*). A second grant in 1999 (*NSF-9617698*) funded assessments and a national field test. From 2004-2010, seven more modules were developed by the National Center for Nanotechnology Learning and Teaching (NCLT) - (*NSF-0426328*). Established under the National Nanotechnology Initiative (www.nano.gov) as the nation's only center for formal nano-education, NCLT inserted nanotechnology concepts into grades 7-16 to enrich the STEM curriculum and train a nano-literate workforce.

[ii] Pellegrini, B. (2010) Materials world modules – 2002: A nationally representative evaluation of classroom gains. *Journal of Materials Education, 32*(5-6), pp. 185-230.

[iii] The prototype was implemented at Taft High School in the Los Angeles Unified School District with additional funding from the State of California and a "Small Learning Community" grant from the U.S. Dept. of Education.

Materials World Modules

Meeting the New Core Standards through Scientific Inquiry & Engineering Design

Alignment with the Next Generation Science Standards (NGSS)

MWM content and methodology seamlessly integrate the three dimensions – Practices, Cross-Cutting Elements, and Content - outlined in the NGSS, with a strong emphasis on Engineering Design.

Dimension 1: Practices

The new standards call for more hands-on practice – a tall order when curricula are already so crowded!

MWM's inquiry[i] and design[ii] methodology simultaneously develops all eight of the science and engineering practices outlined in the standards (right), making it a quick and flexible way to incorporate hands-on science and engineering practices into your curriculum! For example: the "**Manipulation of Light in the Nanoworld**" module prompts students to ask questions about how photons interact with matter ***(Practice 1A)*** and how this behavior can be used to improve signal (information) processing and other applications ***(Practice 1).*** Students make a CD-ROM spectroscope and use online simulations (right) to study the behavior of different light sources upon interaction with structured matter ***(Practices 2&3).*** Students work on teams to collect, analyze, and interpret data ***(Practices 4&5)*** to explain the scattering, diffraction, and reflection of light ***(Practices 6A, 7, & 8).*** Then, they design a photonic crystal to solve the problem of reflecting and transmitting light of particular wavelengths ***(Practice 6B),*** using an online simulation ***(Practice 2)*** to vary the structure of the photonic crystal, the wavelength, and the angle of incidence to optimize its performance ***(Practices 4, 5, 7, 8).*** After performing tests and making improvements ***(Practice 6B),*** they make presentations describing their designs and the foundational concepts involved ***(Practice 8).***

Dimension 1: NGSS Practices

1. A) Asking questions (science)
   B) defining problems (engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. A) Constructing explanations (for science) and
   B) designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Light diffracts from CD grooves *Design opals from structural simulations*

Dimension 2: Crosscutting Concepts

The new standards prescribe a new type of interdisciplinarity – one that prepares students to synthesize STEM concepts and apply them to diverse situations. MWM is ideal for teaching STEM in this integrated way!

Since 1993, MWM has provided students with an integrated STEM learning experience that:

- demonstrates how STEM disciplines are related to one another,
- applies crosscutting concepts to natural phenomena and global engineering challenges, and
- uses math to solve science and engineering problems.

Because our module topics come from the crosscutting field of materials science and engineering, they naturally address all of the crosscutting concepts outlined in the new core standards (right).

Dimension 2: Crosscutting Concepts	
1. Patterns	All modules
2. Cause and Effect	All modules
3. Scale Proportion and Quantity	All modules, especially the eight Nano modules
4. Systems and Systems Models	Solar Cells, Food Packaging, Sports Materials
5. Energy and Matter	Solar Cells, Manipulation of Light, Environmental Catalysis
6. Structure and Function	All modules
7. Stability and Change	Biosensors and Biodegradable Materials

Dimension 3: Core Disciplinary Ideas

Because MWM topics are highly relevant to society and the natural world, they naturally address most of the core disciplinary ideas outlined in the NGSS – including most of the individual core ideas from:

- Physical Sciences (PS)
- Life Sciences (LS)
- Earth and Space Sciences (ESS)
- Engineering, Technology and Applications of Science (ETS)

Learning Core Content Through Practice

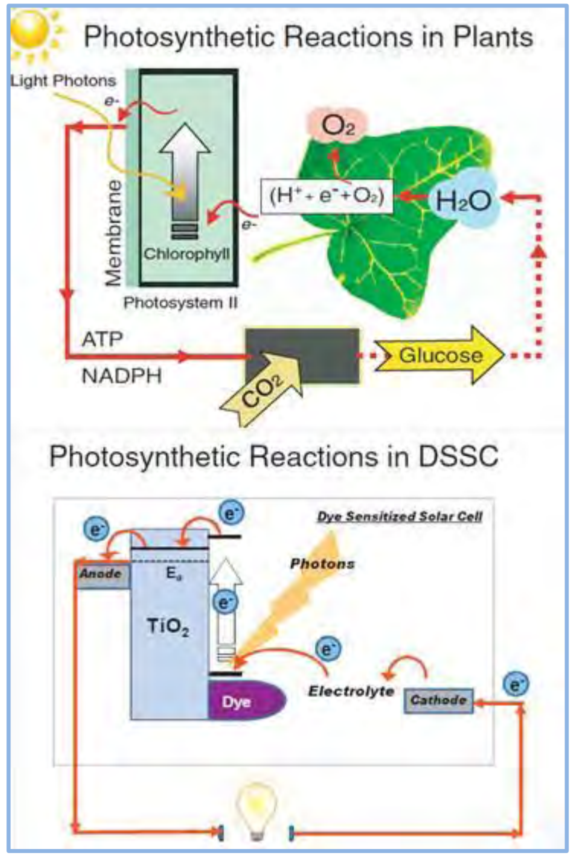
***MWM teaches core ideas through practice rather than by rote, within the framework of an engineering problem and a design challenge.* For example:**

In the "Polymers" module, students learn that different chemical structures of polyethylene confer different properties to a bulk substance, including ***strength, viscosity, and absorption (PS1-3)*** and apply this knowledge to the design of a humidity sensor, or novel polymer product.

The "Manipulation of Light in the Nanoworld" and "Nanotechnology" modules use simulations and hands-on experiments to discuss the use of light spectra, including the ***reflection, refraction, and scattering of light (PS4)*** - concepts that are essential to discovery in astronomy and the geosciences.

In the "Food Packaging" module, students must optimize packaging to leave a minimal ***impact on the environment (ESS3-4)***, while ensuring that food is safe for consumption. The "Environmental Catalysis" module addresses the ***impact of humans on weather, life cycles, and climate change (ESS3).***

The "Biosensors" module teaches students about ***bioluminescence*** and asks them to consider ***the advantages that it may give to an organism (LS1-4).*** The "Solar Cells" module uses principles of ***photosynthesis (LS1-6)*** to discuss and design a device that ***translates energy from solar to electric (PS3-3***, right).

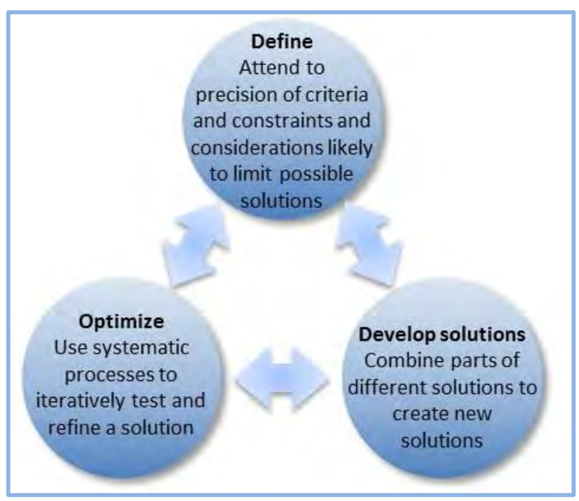


Focus on Engineering Design

Created by teachers and professional engineers, MWM is a natural fit for the new standards in Engineering Design (ETS1) and Links Among Engineering, Technology, Science and Society (ETS2).

The Design Process: Modules employ the engineering design process prescribed by the NGSS (right). Students must ***define an engineering problem*** and ***develop a creative solution*** to that problem, using their own research findings to define contraints and evaluate possible solutions. But the process doesn't stop there - they must also ***test and optimize their design*** through an iterative process by answering questions such as:

- Which aspects of the design worked?
- Which aspect was the "weak link" and how can it be mitigated?
- Is there a point when further improvement to one aspect of a product is no longer beneficial to the whole?



The Interdependence of Science, Engineering, and Technology: By participating in the entire process of technology development, from scientific discovery to prototype design, ***students learn how asking the right questions, accurately performing experiments, and carefully analyzing data can prepare them to solve engineering problems and design new technology!***

Example of MWM Alignment in Engineering Design

Here is an example of how our modules meet the new core standards in Engineering Design.

MWM and Engineering Design	*Example from the "Solar Cells" Module*
Each module has several design project options. Working as a team, students come up with their own design of a product or a process with a **given set of constraints and criteria**, such as cost, utility, safety, and/or time to produce. Each module also has at least one design project that asks the design team to meet given specifications. Each module and design project has **relevance to societal needs and/or solving a global problem relating to health, energy, security, or environment.** *MS/HS ETS1-1*	This module asks students to design a solar cell that has a maximum absorption spectrum using natural dyes and pigments obtained from things like berries or leaves. Several components must be optimized, first individually, then as a group, to create the most efficient dye-sensitized solar cell (DSSC): 1. Choice of a good dye – how broad of a spectrum does it absorb vs. the energy output. 2. TiO_2 coating – the thickness affects how much dye can be bonded and the packing density of particles, which will alter the access of the electrolyte to the TiO_2 particles. 3. Size of the conductive glass plate – more surface area can be useful, but it is costly.
Most modules, especially those relating to nanotechnology, ask students to **consider the choice of each component and part to be used in the system** (i.e., the final product). *MS/HS ETS1-2*	Before building their own solar cell, students perform chromatography experiments to identify pigments in a spinach leaf and learn about the spectrum of light absorbed by each pigment to determine which pigments are best for different kinds of light. They also learn how to assess the limits of their equipment by measuring the internal resistance of their solar cell.
Once the product is developed, students **make measurements** to see how close they have come to the optimal solution of their design, within the given constraints. Students are asked **to improve their design models and compare those of the other teams** to adopt components from couple different models to obtain the overall ultimate design. *MS/HS ETS1-3*	After the design project, students are asked to present their project to the class, using data to support their claims, and evaluate which parts of the design were most and least successful. Classes then have the option to compare multiple solar cell designs in order to evaluate their efficiency and choose components that can work optimally together.
With further **simulation and modeling**, students carry out an iterative design process. *MS/HS ETS1-4*	Students can use a simulation that helps them understand the relationship between different dye molecules and their absorption spectra. The simulation also adds the factor of cost to encourage students to consider the practicality of implementing their designs.

[i] Drayton, Brian and Falk, Joni. Inquiry-Oriented Science As a Feature of Your School System: What Does It Take? *Science Educator*, v11 n1 p9-17 Spr (2002)

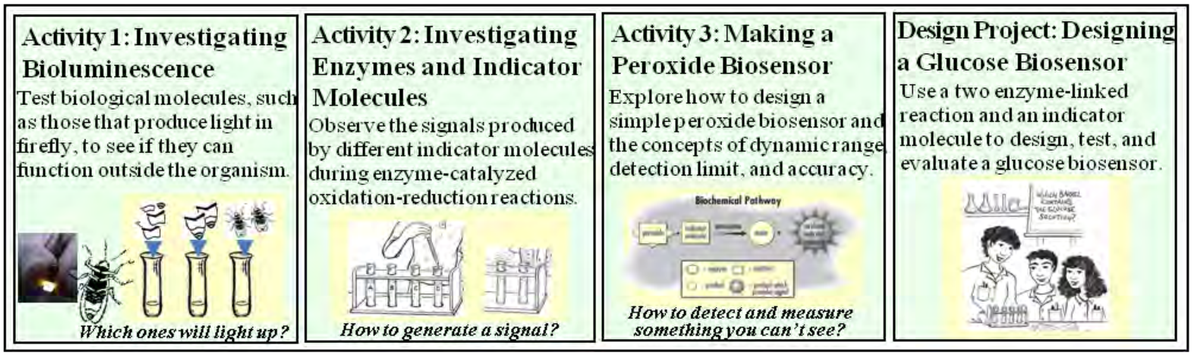
Khishfe, Rola; Abd-El-Khalick, Fouad, Influence of Explicit and Reflective versus Implicit Inquiry-Oriented Instruction on Sixth Graders' Views of Nature of Science. *Journal of Research in Science Teaching*, v39 n7 p551-78 Sep (2002)

[ii] Garmire, Elsa, The EngineeringDesign Method. *Technology Teacher*, v62 n4 p22-28 Dec 2002-Jan (2003)

Sadler, Phillip, Coyle, Harold P., Schwartz, Marc, Engineering Competitions in the Middle School Classroom: Key Elements in Developing Effective Design Challenges. *Journal of the Learning Sciences*, v9 n3 p299-327 (2000)

About Scientific Inquiry and Engineering Design

MWM deepens and reinforces content knowledge by allowing students to perform the work of scientists and engineers. Each module begins with a ***hook activity*** that captivates interest in a crosscutting foundational concept. Then a ***series of inquiry activities*** teaches them to ask effective questions, perform experiments, collect and analyze data.[i] Finally, a ***team-based engineering design project*** challenges them to apply what they've learned to create a useful product. Here is an example from the "Biosensors" module:



The design process incorporates:

- ***Testing and re-design***, so students learn from what doesn't work as well as from what does[ii]
- ***Systems thinking***,[iii] which requires students to consider not just the problem at hand, but also the needs of the end user (e.g. cost, aesthetic appeal, ease of use), the needs of society (e.g. safety, environmental impact), and the overall feasibility of their design
- ***A team presentation*** that asks students to communicate the benefits of their designs using their experimental data. Students learn even more by explaining their design process to someone else!

Outcomes

Golf Business in School?

Science and Engineering Practices: Student build competencies in all eight practices outlined in the Next Generation Science Standards, from asking questions and defining problems to analyzing data and communicating findings.

Motivation: Students are highly motivated by the design challenge. A group studying the Sports Materials module was inspired to launch a golf business (right). A team of girls working on the Concrete module was excited to file a patent for their innovative glow-in-the-dark sidewalk!

Confidence: Students emerge with a strong confidence that STEM is something they are capable of doing, both on their own and in collaboration with others.

Relevance: Design challenges are tied to global challenges in energy, environment, and health. Students learn how science, engineering, and technology relate to society, the economy, and potential careers.

---

[i] Drayton, B., Falk, J. (2002) Inquiry-Oriented Science As a Feature of Your School System: What Does It Take? *Science Educator*, *11*(1), pp. 9-17. Khishfe, R., Abd-El-Khalick, F. (2002) Influence of Explicit and Reflective versus Implicit Inquiry- Oriented Instruction on Sixth Graders' Views of Nature of Science. *Journal of Research in Science Teaching*, *39*(7), pp. 551-78.

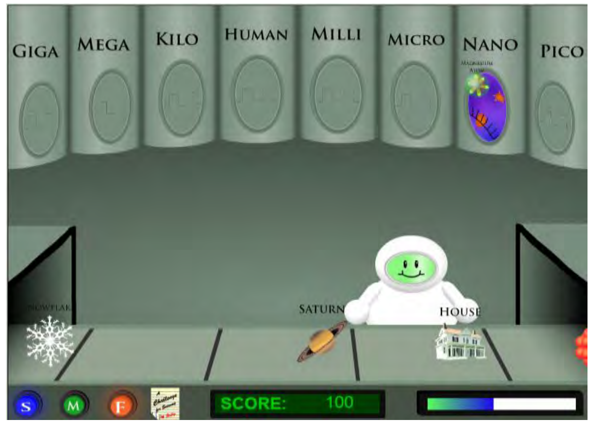
[ii] National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. The National Academies Press, (2004). http://www.nap.edu/openbook.php?record_id=10999&page=1

[iii] Defined as "analyzing how parts of a whole interact with each other to produce overall outcomes in complex systems" Source: Partnership for 21st Century Learning. *Framework for 21st Century Learning*. (March, 2011). http://www.p21.org/overview/skills-framework

Integration of Classroom and Cyber-learning

Interactive learning tools allow students to experience instant responses to their actions, piquing their curiosity, keeping them engaged,[i] and prompting self-led inquiry and discovery.[ii]

Our nanotechnology modules include online interactive learning tools developed with computer scientists at Northwestern and the University of Illinois at Urbana Champaign that let students explore the nanoscale without expensive classroom equipment. ***Interactive games*** give them an intuitive grasp of the nanoscale and its properties. ***Interactive simulations*** allow them to model nanoscale objects and perform nanoscale design processes. ***Multimedia animations*** convey complex 3-D spatial and time-dependent phenomena better than static textbooks.



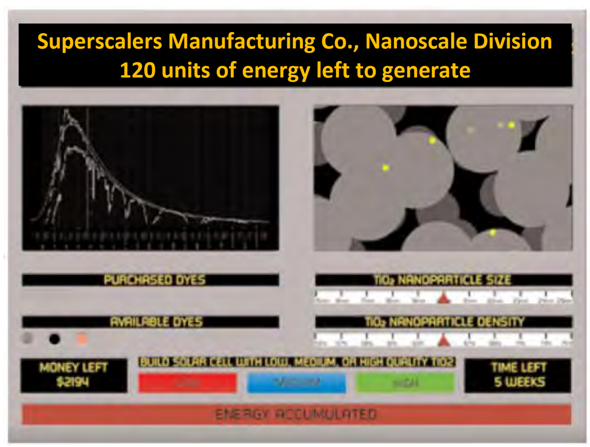
These online learning experiences are fully integrated with hands-on activities in the classroom to deepen understanding of fundamental nanotechnology concepts.[iii]

For example: Surface-Area-to-Volume (SAV) ratio is a key physical property of objects. Nanostructured materials have very large SAVs, which gives them their unique properties. Many students – including Northwestern undergraduates - struggle with the SAV concept, which is integral to nanoscience and nanotechnology.

Computational animation of nanomaterials using a cube building illustration

Design Project: "CO_2 Geyser" cola reacting to sand

Our "Introduction to the Nanoscale" module uses online and real-space activities to teach the concept of SAV: ***A computer game called "Sammy and the Sorting Factory"*** - teaches how small "nano" is, and how large "mega" is in relation to the human scale. Sammy the Superscaler asks students to help him sort objects according to their scale (top right). Students then perform ***hands-on inquiry*** in the classroom. At the end of the module, students perform a ***hands-on design project ("Building a CO_2 Geyser") aided by an online cube-building animation*** that reinforces their understanding of SAV (middle right).



Subsequent nanotechnology modules use interactive tools to deepen understanding of SAV and demonstrate its engineering applications to energy, health, communications, and the environment. For example, in learning about wavelength absorption spectra in the "Solar Cells" module, students play an ***optimization game*** (bottom right) that asks students to get the most energy out of dye molecules that they can buy – but they have to stay under budget! A true engineering challenge, this game ***teaches students about trade-offs in designs***, and allows them to explore how dyes absorb different spectra of light.

---

[i] Federation of American Scientists. *Summit on educational games: harnessing the power of video games for learning.* (2006) http://www.fas.org/gamesummit/

[ii] Mayo, M. (2009) Video Games: A Route to Large-Scale STEM Education? *Science, 323*, pp. 79-82.

Gee, J.P., *What Video Games Have to Teach Us About Learning and Literacy*. Palgrave MacMillan, New York. (2003)

[iii] Users of interactive simulations and games significantly outperform peers using traditional classroom methods. Source: Vogel, J.J., Vogel D.S., Cannon-Bowers, J., Bowers C.A., Muse, K., Wright, M. (2006) Computer Gaming and Interactive Simulations for Learning: A Meta-Analysis. *Journal of Educational Computing Research. 34*(3), pp. 229-243.