Nanotechnology Learning Modules Using Technology Assisted Science, Engineering and Mathematics

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Abstract

Technology Assisted Science, Engineering and Mathematics (TASEM) focuses on innovative use of technology to explain new and complicated concepts rather than on education research. The explanation of nanotechnology is challenging because nano-dimensions require high-magnification electron microscopes to see them. Hand-on learning modules are difficult if not impossible. However, if macro/micro technologies and minirobots are used to explain nano concepts in a fun way, the formal and informal learners can be engaged. For example, learners get very excited when they use a bubble maker robot to study bubbles. As they watch the skin of soap bubbles changing their color a few times before they break, their excitement and fascination is evident from the level of interest seen in over 300 learners at K12, undergraduate and graduate levels during 2005-07. This paper reveals the use of Lego creations and programmable robots for nanotechnology education for the first time using the TASEM concept. The learning starts with watching videos explaining the concepts of size followed by hands-on activities that lead to nano learning. Using digital calipers and microscopes the hands-on activities focus on studying size variations of identical Lego pieces (quality control), leaves, flowers, samples of microchips, optical fibers, human hair, and spider silk. The impact of *the* learning modules reported in the present study seems very high because they explain ***(a)*** *technologies that are in the market today as well as the technologies that are going to be in the market in the near term,* ***(b)*** *how these technologies are used to build complete systems or Microsystems, and* ***(c)*** *what technologies will be used to build Nanosystems.*

Introduction

The macro (fabrication of cell phones) and micro (fabrication of microchips) technologies, which are responsible for ever increasing presence of new technologies in consumer products, are now becoming enabling technologies for bringing nanotechnology into our daily lives. Perhaps the best example is an integration of ever increasing functionality into cell phones (Fig. 1). The introduction of projection capability in cell phones in 2008 will initiate the integration of HDTV and computer (operating system, RAM and storage may be placed on a network server) in cell phones. The integration of an air quality monitor (equipped with nano sensors) into cell phones, expected in the next few years, will provide 'air labeling' making it possible to monitor the air we are breathing and any toxins that might be threatening our health. This means that the impact of ***those*** learning techniques and modules will be very high, which explain *(a) technologies that are in the market today as well as the technologies that are going to be in the market in the near term, (b) how these technologies are used to build complete systems or Microsystems, and (c) what technologies will be used to build Nanosystems*. Thus, this paper reveals an innovative use of technology to explain nano-concepts without focusing on education research.

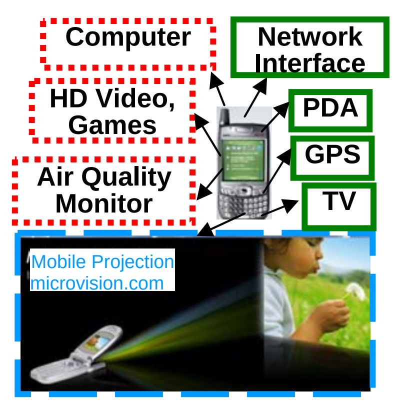

Fig 1 Cell phone: Integration of new technologies; current (solid), in 2008 (dashed) and future (dotted).

Historically, efforts to increase impact of learning techniques have focused on a number of ideas; a restructuring of school science around real-world problems [1], inquiry based studies [2][3][4][5] including Design-Based Science (DBS) [6][7][8][9][10][11][12][13][14][15] and Learning By Design (LBD) [16][17][18], augmented reality (AR) [19][20][21][22][23][24][25], and Technology Assisted Science, Engineering and Mathematics (TASEM) [26][27][28]. The explanation of nano-structures and nanotechnology are particularly challenging because nano-dimensions require high-magnification electron microscopes to see them. Effective and realistic hand-on nano-learning modules are difficult if not impossible. Perhaps, due to such challenges, most of the current approaches (mostly for 7-12 graders) to explain nanotechnology are limited to animations and web-based explanations. Some examples are 'Too small to see' [29], 'Nanoze' [30], 'Nanokids' [31], 'Exploring the Nanoworld' [32], 'Nanomaterials and Nanoworld' [33], 'NanoLeap' [34], "Nanozone' [35], Powerof10' [36], 'Molecularium' [37], 'NanoManipulator' [38], 'Nanobio'[39], 'Soft lithography for nano' [40], and 'Nano Camp' [41]. However, among the limited hands-on efforts, one effort to explain crystal structure, polymers and photonic materials using Lego® bricks stands out [42][43][44][45][46][47].

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A unique feature of the TASEM program is that it, encompassing a number of inquiry based ideas, focuses on current and future technologies using a hands-on approach, including nanotechnology. It is based on the notion that if macro/micro technologies and mini-robots are used as enabling technologies to explain nano concepts in a fun way, both the formal and informal learners can be engaged providing a continuous challenge. For example, in a study conducted during 2005-07 on over 300 undergraduate and K-12 students, it was found that as the learners watched the skin of soap bubbles changing their color a few times before they break, their excitement and fascination became evident from their observed level of interest. While the undergraduate students graduated and no data could be collected, approximately 50 % of the K-12 children returned to the sessions in 2006-07. The real strength of the TASEM nano-education modules is the fact that they can start with something as simple as a Lego model of a microchip (an integrated circuit) and take the learner on a journey into the world of carbon nanotubes and nano-sensors. This paper reveals the use of Lego creations and programmable robots for nanotechnology education for the first time using the TASEM concept.

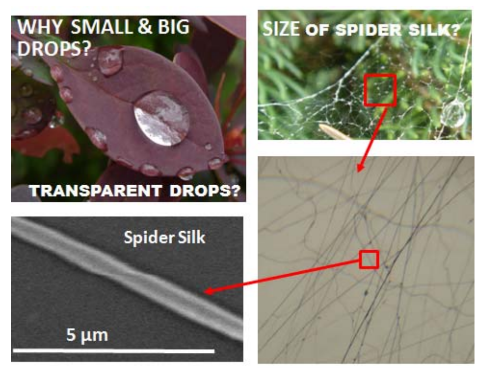

Fig 2 Observation of everyday items can be used for introducing the size concept.

Concept of Dimensions

The concept of dimensions can be realized by observing everyday items such as those shown in Fig. 2. The spider silk thread that one can see with a naked eye is usually a combination of more than one strand. A single strand of silk is approximately one micrometer in diameter (Fig. 2). How small is a micrometer? As shown in Fig. 3, there are 1000 micrometers in a millimeter, there are 1000 nanometers in a

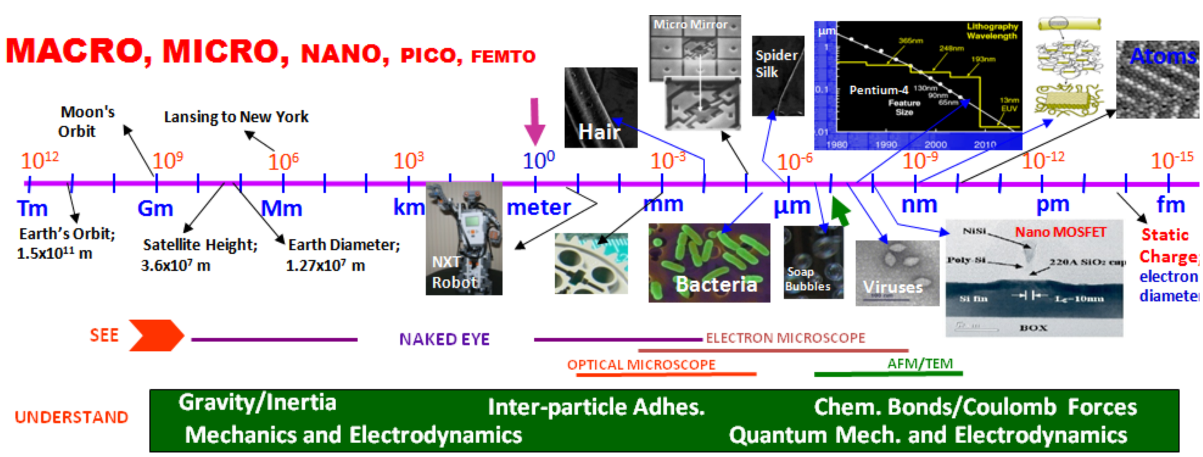

Fig 3 Dimensions of different objects, microscopes needed to see them, and science needed to under them.

micrometer, and there are 1000 picometers in a nanometer. Atomic force microscope (AFM) and tunneling electron microscope (TEM) are used to see nanometer and picometer dimensions. Referring to length in Fig. 3, it is found that the structures with dimensions below approximately 100 nm are not only difficult to see but hard to understand and explain. The properties of materials at such small dimensions can only be understood by using quantum mechanics. Some important questions are: How small the length scale needs to be to qualify as nanostructure? How many atoms are there in a nanostructure? Are the physical properties of nanostructures different from those of bulk materials?

Definition of Nano

As there two approaches of study of nanostructures, the top-down and bottom-up, the definition of what is considered nano may differ depending upon the approach. In the bottom-up approach the study of molecules can lead to self-assembly of molecules into nanostructures or ligaments with properties different from those of bulk materials. In the top-down approach, the nanostructures are produced by reducing the dimensions to below approximately 100 nm. As the material properties (melting point, band gap, etc.) change if the dimensions are decreased below 100 nm, the structures below 100 nm are called nanostructures [48]. When the particle size becomes much smaller than 100 nm the surface properties may dominate to the extent that surface modifications by foreign atoms may substantially affect the nanostructure properties.

It is interesting to look at a broader definition of small structures with unusual properties. While the minimum conductive lengths in transistors in the latest Pentium microprocessors are at 45 nm level, these lengths in future processors are expected to be at 10 nm level (Fig. 4). Can such lengths get smaller than 1 nm? Is it possible to define physical properties for particles at 1 nm or smaller? At such small length scales it is also important to consider the number of atoms as shown in Fig. 4. For the calculation of density of atoms in a particle of cubic shape, it is assumed that there is one atom in the cube if its dimension is 100 pm. As one needs a certain minimum number of atoms in a particle to calculate its physical properties, an important question is: At what smallest level, length or number of atoms, it becomes impossible to define the physical properties? It is found that if the particle size is less than approximately 1-2 nm or 1000 – 2000 pm, the physical properties cannot be defined [49]. Based on number of atoms in a particle, the structures with dimensions around 1000 pm or less (Fig. 4) can be defined as picostructures and the technology needed to fabricate them as picotechnology.

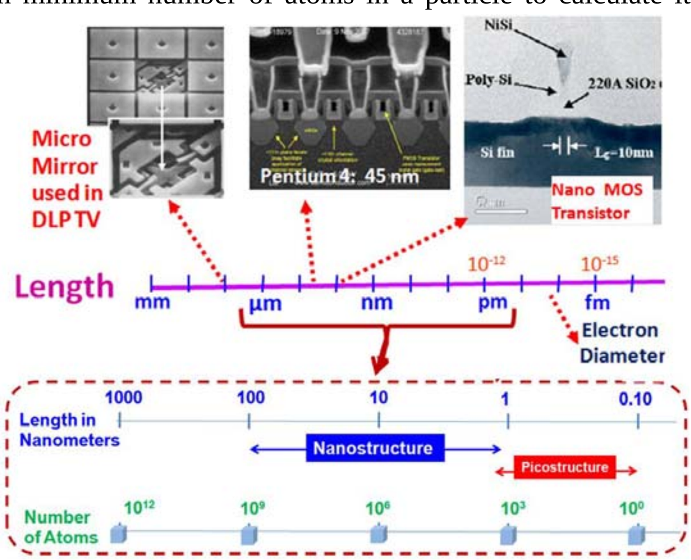

Fig 4 Dimensions and definitions of nano- and pico-structures.

Experiments on Nano

Although both animations and videos can be effective for learning, hands-on nanotechnology experiments can generate more excitement for the learner. Top-down approach is used in this paper to conduct nano-experiments. As the modules range from very basic to very advanced, their description and related learning are categorized (according to their degree of difficulty) for different audience levels; **L** (Lay audiences), **K** (K-12 audiences), **C** (College audiences), and **P** (Professional, undergraduate & graduate audiences).

L, K, C & P: The concept of dimensions can be explained by showing videos of robots of different sizes; bigger robots are used in car manufacturing while small size robots can be used to probe the human body.

For example, one can show videos of how (a) a robotic arm interfaced to human brain can be so useful for those who have lost their arms, (b) a millimeter size robotic pill can go on a journey inside the intestinal track, take pictures and wirelessly transmit them outside the human body, and (c) future micro and nano robots can explore other parts of human body including blood and DNA. The size concept can also be explained using information posted on a number of websites [36]. After the learners watch the Java animation on the websites, one can ask them to answer questions related to dimensions (10^{23} – 10^{-16} meters):

What is the size of?

Oak tree leaf ....; Plant cell ....; Chromatin in leaf cell ....;DNA Strands ....
DNA Nucleotide ....; Carbon Atom ....; Atomic Nucleus ....; Quarks ....
Identify objects that are 100 nm or less.

K, C & P: For the first hands-on experiment, a digital caliper is used. The learners are asked to (a) measure sizes of Lego pegs, gear tooth, paper, and plastic sheets, (b) record the data in a table, and (c) answer the following questions: *What is the smallest size you can measure using the digital caliper? What is the error in the measurements for different sizes of objects? Can you measure the difference in size of identical Lego blocks?*

Fig. 5 A digital caliper with micrometer accuracy.

For smaller objects the learners use Intel microscope and inexpensive conventional microscopes. A number of objects are provided but the learners are encouraged to explore other objects, and explore the following questions: *What is the smallest size you can measure using the Intel microscope? What is the smallest size you can measure using the high magnification microscope? Can you see the spider silk?*

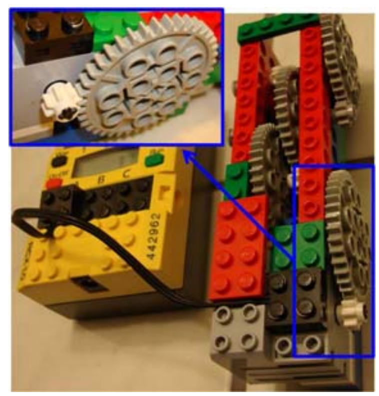

Fig. 6 A gear combination to slow down motion.

K, C & P: For the next experiment, the learners build a Lego gear system to slow the movement of a gear by a large factor. For example, in the system shown in Fig. 6 the gear ratio for single stage is 5, and if 10 stages are used the slowest gear is moving at a speed that is approximately 10^7 times slower that the fastest gear. This means that if the tooth of the fastest gear moves through 1 mm the tooth of the slowest gear moves through 10^{-7} mm or 10^{-4} µm or 10^{-1} nm or 100 pm. The motor driving the fastest gear can be programmed by a Lego robot to run at different speeds. While the learner can measure the speed of fastest gear using a rotation sensor attached the gear and interfaced with the robot, a microscope can be used to track the movement of slower gears. This simple machine can help explore nano dimensions in length and time. The learner can explore a number of questions: *What is the smallest movement you can measure for the slowest gear using the Intel microscope? The slowest gear seems to be stopped while the fastest has a large kinetic energy. Where does the kinetic energy go as it gets to the slowest gear?*

L, K, C & P: The next experiment explores the nanometer size objects using a robotic bubble maker machine. The soap bubbles are made of very thin soap film and can attract the attention of everyone including small children as seen in Fig. 7. The learners build a programmable Lego bubble maker to study the effect of fan and carrousel speeds on the size of bubbles. First the learners explore the programming of the robotics invention system (RIS). Then, they produce the soap bubbles and watch their changing color before they burst. They shine lights of different colors and see if certain colors are not seen or eliminated.

C & P: Knowledge of physics can be used to show that the skin of a soap bubble is approximately 200 nm. Since each traversal of the film incurs a phase shift proportional to the thickness of the film and inversely proportional to the wavelength, the result of the interference depends on these two quantities. Thus, at a given thickness, interference is constructive for some wavelengths and destructive for others, so that white light impinging on the film is reflected with a hue that changes with thickness. As shown in Fig. 8, the light is reflected from the top and bottom surfaces of skin of the bubble. Just before the bubble bursts in the air due to evaporation, it usually shows destructive interference for visible light of shorter wavelengths. For example, as shown in Fig. 8, upper skin of a large bubble is thinner leading to constructive interference of yellow color. Depending upon the angle of incidence, the skin thickness in upper part may be in the range of 200 nm.

Questions: *Can our eyes see a film of 200 nm? How can you explain the reflections of light from the top and bottom surface of the film? Does the light reflected from the bottom surface travels a longer path? Are the bubbles attracted to static charges created on plastic sheet by the process of rubbing?*

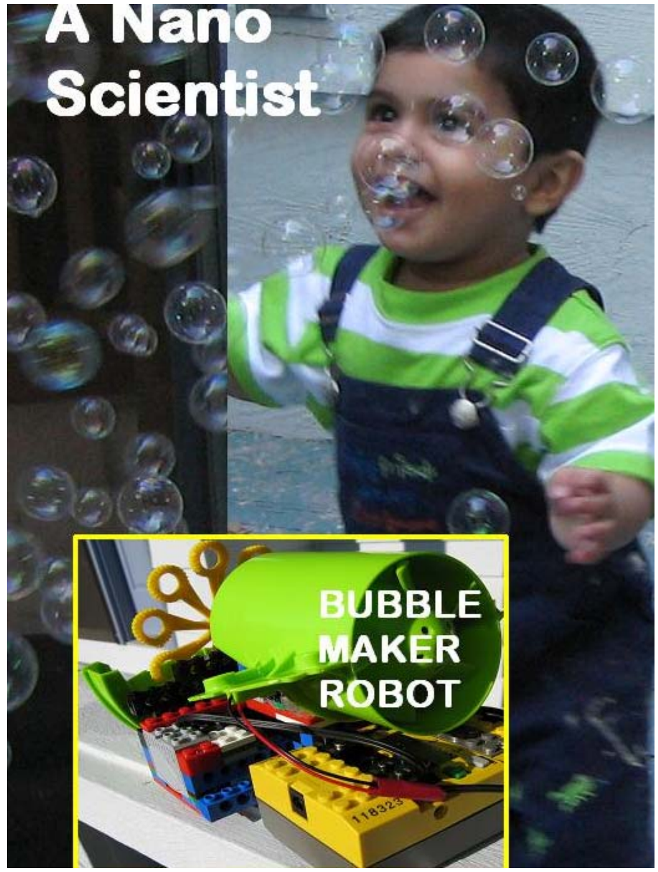

Fig. 7 The eyes of this two-year old boy mirror a level of excitement that can only be indebted to the 200 nm thick skin of the bubbles.

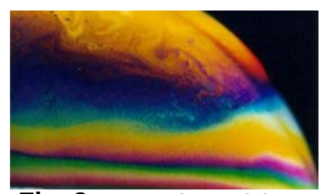

Fig. 8 Top surface of the bubble is yellow.

K, C & P: In the previous experiment, programmable robots were used to generate bubbles with nanometer size bubble-skin. Such robots are used in automation and other industries. The heart of such robotic systems is a microchip called a microcontroller, which is a single chip computer. The brain of a microcontroller is an electronic device called a transistor. A transistor is like a switch. A mechanical switch is controlled by (meaning it can be switched by) mechanical energy. A transistor switch can be controlled by electrostatic energy. In other words, it can be switched on and off by static charges. In this experiment, the learners will be able to explain the operation of a transistor switch by a positive charge at its gate.

An interesting question is; why does the transistor require a positive or negative voltage at its gate for switching it? While in a water valve mechanical energy is applied to control the water flow flowing between source and drain. In a similar way, in a transistor, the charge flow between source and drain is controlled by applying positive or negative voltage at its control electrode call 'Gate' (Fig. 9). Depending upon the type of Si used in the fabrication of MOS (Metal Oxide Semiconductor) transistors, it is called NMOS (negative charge flows through the transistor) or PMOS (positive charge flows through the transistor). A CMOS (complementary MOS) contains both NMOS and PMOS, and is used computers..

In the keyboard used in a computer, every key is assigned a code using the language of zeros and ones (0 & 1), the so-called digital or ASCII (American Standard Code for Information Interchange)

Characters [50]. This is because the micro-processors understand the language of Zero and Ones. Fig. 9 shows an interesting explanation of a transistor, used as a switch to generate Zeros and Ones, and its Lego models (both micro and nano). The Lego-based transistors are fully functional replicas of real transistors and are used to demonstrate the structure and the operation of MOS transistor switches in a fun way.

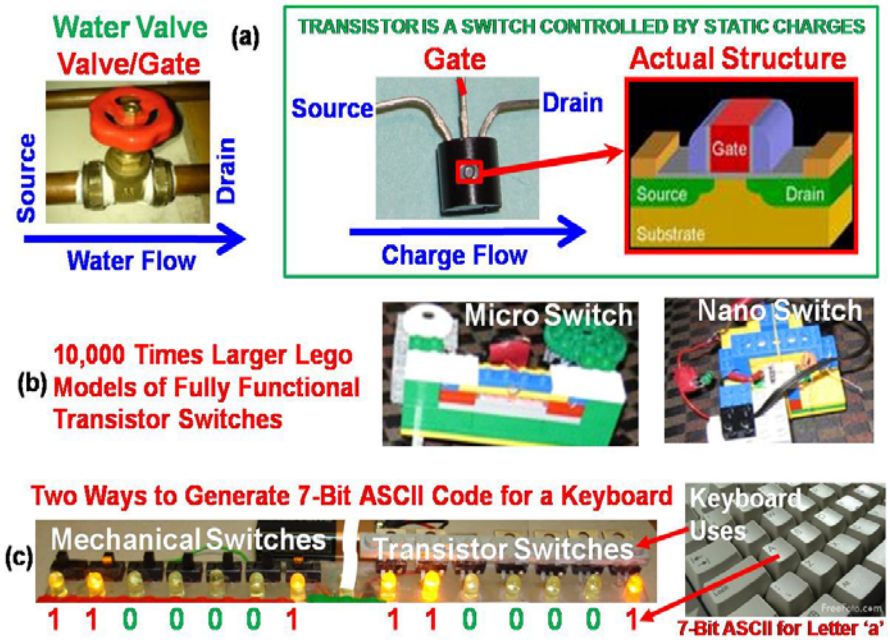

Fig. 9 (a) The transistor switch is comparable to water valve, (b) Lego models of micro and nano transistors, and (c) switch demos and code for letter 'a' in a computer keyboard using 7-Bit ASCII Code [50].

C & P: Fig. 9 (c) shows and explains how a 7-bit ASCII code generates the letter 'a' in a computer keyboard. In this demo, any combination of LEDs can be switched on by using mechanical switches or by using static charges applied to the MOS switch. This is an interesting way to demonstrate the generation of any letter (lower or upper case) or number on the keyboard using the ASCII tables provided in [50].

Expected Impact

Table 1 shows the possible impact on different audiences in different settings and environments. The efficacy of the program discussed in this paper is based on teaching at the undergraduate/graduate (formal) and K-12 (informal) levels. It may be pointed out that no formal education research was conducted to generate the Table 1. Thus, the data provided here is qualitative and is based on the assessment of instructors, parents and other professional observers (one of the observers had a doctorate in education).

Table 1 Learning level (Basic, Intermediate, Advance), underlying STEMS areas (S, T, E, M), expected impact (Low, Normal, High), learner interest (Low, Normal, High), possible audience types (Families, Children, Adults, College Students, Teachers, Professionals, Underserved, Retired, Boy Scouts, Hobbyists and Explorers), and possible locations (Museum, Science & Technology Center, Community Center, Mall and Shopping Center, Library, Websites, After-School Locations).

Gen. Area	Sub Areas	Learning Level: B, I, A	STEM Areas	Expected Impact: L, M, H	Learner Interest : L, M, H	Audience Types: F, C, A, S, T, P, U, R , B, E	Possible Location: M, T, C, S, L, W, A	Unique Aspect
Nanotechnology	*Concept of Dimensions*	B, I	S, T, E, M	H	H	All	All	Everyday items/experience
	Nano & Pico Dimensions	B, I	S, T, E	H	M	All	M, T, C, S, A	Hands-on Nano
	Program. Robots	B, I	S, T, E, M	H	H	All	M, T, C, S, A	Explain STEM with fun
	*Fun with Static Charges**	B, I, A	S, T, E	H	H	All	M, T, C, S, L, A	Explain switches/gates
	Com. Switches & Sensors	I, A	S, T, E	M	M, H	All	M, T, C, S, L, A	Legos, VDG generators

Conclusions and Future Plans

Focusing on technology innovations, rather than education research, this paper reveals for the first time Lego-based hands-on nano-educational modules field-tested on approximately 200 K-12, undergraduate and graduate students. As most of the educators in engineering in the US have doctoral degrees in research areas related to engineering fields, their knowledge and focus on education research is limited. On the other hand most of those who have doctoral degrees in education research are less focused on the use of latest micro and nanotechnologies in their everyday research work. Consequently, it has become difficult to develop research partnerships with education researchers particularly in the areas of latest micro and nano technologies. Nevertheless the future plans of the nano research reported in this paper include the development of active collaborations with education researchers for the formal conduction of education research.

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