**CHAPTER 1**

**Nanotechnology and Chemistry: The Unseen Size with Magnificent Impact**

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**1.1. Introduction**

*“There’s Plenty of Room at the Bottom.”*

This was the title of physicist Richard Feynman’s talk on December 29, 1959, at the Annual Meeting of the American Physical Society at The California Institute of Technology (Caltech). In that talk, Feynman asked many questions widely believed to be illogical at the time. Feynman believed that if we were able to control matter at the atomic or molecular scale, we could achieve many practical advances that could revolutionize technology and production processes.1

Feynman posed many questions related to very small-scale systems and their enormous usefulness. For example, he discussed how the small size of living cells aids in executing important functions for living organisms. Feynman proposed an idea that if we could have the ability to manipulate things as small as atoms and molecules, that these manipulations could be used in a limitless range of technological applications. He imagined that if we could control small-scale substances, we could create materials with new chemical and physical properties for new applications. Essentially, Feynman focused his talk on the idea of nanoscience and nanotechnology, but he never explicitly stated it.1

* + 1. **What Is Nano and Why Is It Important?**

Linguistically, the word “nano” is derived from the Greek word pertaining to dwarf, which refers to very small things. One nanometer (nm) is equal to one billionth of a meter (0.000 000 001 m). Here are some relative comparisons which describe the nanometer scale:

* If a one mm section on a ruler is divided into one million equal parts, this is one nanometer in length.
* The average diameter of human hair is about 60 000 to 100 000 nanometers.
* A sheet of paper is about 100 000 nanometers thick.
* Ten hydrogen atoms lined up is equal to one nanometer.

Nanoscience and nanotechnology are multidisciplinary scientific fields that deal with the preparation, processing and application of materials, devices, and systems at the nanometer scale. These fields have attracted great interest among scientists and researchers, which has led to many developments that are used in our daily life.2

Nanomaterials are materials that have at least one dimension in the nanometer scale. Scientists discovered that nanoscale-sized materials demonstrate different physical and chemical properties. For example, gold (Au) displays known, familiar properties of being: i) a gold-colored, soft, and shiny metal; ii) a good conductor of heat and electricity; iii) chemically inert (making it widely used in the jewellery industry); and iv) its melting point is 1064 0C. These properties are present in gold, in dimensions larger than the nanometer range. Reducing the size of gold to the nanometer scale causes drastic changes in its characteristic properties. For example, nanometer-sized gold is not characterized as gold in color. In the nanometer size range, it also becomes a semiconductor, good catalyst, and its melting point reduces to 300 0C (Table 1.1).Many materials at the nanoscale exhibit unique optical, electrical, magnetic, and chemical properties which their larger counterparts do not possess. These unique nanoscale properties have a great impact in technology and medicine. Nanomaterials have become basic components of everyday, modern technologies, and major players in twenty-first century technological advances. 3,4

[Table 1.1 near here]

* 1. **Why Do Properties of Materials Change at the Nanoscale?**

Two main effects are responsible for the differences of material properties when sized in nanoscale.

* + 1. **Surface Area-Volume Ratio**

Material reactivity properties are strongly related to the number of particles that are exposed to the surrounding environment. This means that the material surface area is the central feature which affects reactivity. Subdividing materials into smaller parts maintains an item’s volumetric size but its collective surface area increases. For example, a cube with dimensions of 1 cm × 1 cm × 1 cm has a volume of 1 cm3, and the area of its six surfaces equals 6 cm2. By dividing the cube into one million smaller cubes of 0.1 mm × 0.1 mm × 0.1 mm, the whole cube maintains its total volume, but simple calculations reveal that after this division, the collective total surface area of the cubes becomes 100-fold larger than that of the original cube. If the cube is divided further into smaller, non-visible cubes with dimensions of 1 nm × 1 nm × 1 nm, its surface area increases by 10 million.

Nanoscale-sized materials possess greater surface areas than their larger-sized counterparts of the same material. This is because the number of atoms and molecules that were previously inside the materials are exposed and become surfaces. This presents a particularly unique and interesting phenomenon at the nanoscale: nanomaterials with extremely high surface area to volume ratios will interact with the surrounding environment more intensively. Nanomaterials exhibiting large surface areas influence innate properties, such as the melting point, density, solubility, mechanical properties, electrical conductivity, surface tension, catalytic activity, and spectroscopic properties.5-11

[Figure 1.1 near here]

* + 1. **Quantum Confinement Effect**

The quantum confinement effect is observed when a material size affects its electronic and optical properties.

That is, when a semiconductor material absorbs a photon with an energy equal to or higher than its bandgap, it promotes an electron from the valence to the conduction band. This event leaves a hole in the valence band and an exciton is then formed. An exciton is an electron-hole pair associated with coulomb electrostatic interactions between the hole and the promoted electron. According to the rules of quantum mechanics, the distance between the hole and the promoted electron is the Bohr exciton radius. A typical semiconductor material is larger than the radius of the Bohr exciton when the electron motion is not confined or restricted. On the other hand, when reducing the size of a material to the nanoscale, the material size will lessen to be smaller than the radius of the Bohr exciton. This leads to confinement of electron motion and a congested arrangement of electron holes, resulting in quantum confinement of the electron hole pairs. Consequently, the bandgap increases, and discrete energy levels appear. This increased bandgap creates differing optical and electrical properties. As a result, nanoscale-sized materials could appear to be different colors not normally associated with larger-sized materials of the same type (Figure 1.2).5, 12-17

[Figure 1.2 near here]

* 1. **Types of Nanostructured Materials**

The most common method to classify nanostructured materials is based on the number of dimensions that are not at the nanoscale range. Accordingly, four categories of nanomaterials are classified as the following:

1. Zero-dimensional (0D) nanomaterials range from 1 to 100 nm in each spatial dimension. This is described as electron confinement that occurs in all x, y, and z directions.
2. One-dimensional (1D) structures are nanoscale in two dimensions, and one dimension is on the macroscale. Electron confinement occurs in two dimensions, and in one dimension the electrons are free to move along it.
3. Two-dimensional (2D) structures consist of one dimension confined to the nanoscale and two dimensions in the macroscale. Electron confinement exists in one dimension, while in the other two macroscale dimensions the electrons are free to move.
4. Three-dimensional (3D) structures do not have dimensions in nanoscale. Therefore, they do not have electron confinement in the nanorange and electrons move freely along all three x, y, and z directions. Figure 1.3 illustrates the four types of nanostructured materials according to their number of nanoscale dimensions.18

[Figure 1.3 near here]

Each category of nanomaterials consists of differing types of nanostructures which are categorized according to their shape, morphology, characteristics, and application. The most common representation of 0D nanomaterials are nanoparticles and quantum dots (QD). Nanoparticles are defined as small nanostructured materials with sizes ranging from 1 to 100 nm. The properties of nanoparticles are directly related to their size. Nanomaterial properties change when their size approaches the nanoscale as this increases the ratio of atoms on their surfaces. At times the exciting properties of nanoparticles are unexpected due to their high surface area that outperforms the contributions of their interiors.

Metal nanoparticles, such as gold and silver particles, are distinguished from other nanomaterials by their unique optical properties that arise from the quantum confinement effect. In addition, a unique feature of metal nanoparticles stems from a phenomenon called surface plasmon resonance (SPR). SPR refers to when metal nanoparticles are irradiated with electromagnetic radiation and the wavelength of the light becomes much longer than the size of the nanoparticles, inducing oscillation of conduction electrons when interacting with the light. This oscillation around the surface of the nanoparticles causes a dipole to oscillate along the direction of the electric field of light. The amplitude of the oscillation reaches its maximum at a specific frequency, thereby denoted as SPR. The SPR induces strong absorption of incident light, which can be measured with ultraviolet-visible absorption spectroscopy (UV-Vis). This phenomenon is responsible for the unique, unfamiliar colors of the different metallic nanoparticles, illustrated in Figure 1.4.

[Figure 1.4 near here]

The SPR phenomenon is affected by the size and shape of metal nanoparticles. For example, gold nanoparticles have fascinated scientists because of their ability to display a variety of colors, due to the collective oscillation of the electrons at the surface of the nanoparticles. Optical absorption is also strongly dependent on the size of gold nanoparticles. Consequently, gold nanoparticles can appear red, orange, purple, and even blue. To produce glossy sheens, nineteenth century artists exploited the colorful range of metallic nanoparticles by applying them onto vessel surfaces or producing stained glass.

Quantum dots are nanostructured particles made of semiconductor materials. In comparison to nanoparticles, the size of quantum dots ranges from 1 to 10 nm, less than the size of nanoparticles. Quantum dots are strongly characterized by the electron confinement effect and this is reflected by their unique array of colors.19

One of the molecular allotropes of carbon is fullerene C60. Fullerene exists asa 0D nanoparticle consisting of six sp2 hybrid carbon rings and is widely used in electronics, biology, and medicine.

Nanowires and nanotubes are 1D nanostructures and are characterized by diameters between 1 and 100 nm. Their lengths are much larger than their diameter range. A nanowire is defined as any solid material in the form of a wire with the diameter in the nanoscale range. The ratio between the length of nanowire and its nanoscale diameter is called the aspect ratio. Typical nanowires have aspect ratios of 1000 or more, which signifies that its length is at least 1000 times longer that its diameter. Differing types of nanowires include metallic, semiconductor, and molecular nanowires. All nanowire types are composed of repeating molecular units of organic or inorganic materials. Two nanowire dimensions are affected by quantum confinement due to their sizes being in nanoscale. The length of nanowire is not in nanoscale and therefore the quantum confinement effect does not take place. This imparts distinct electrical and optical properties.

Nanotubes are hollow nanowires with a cylindrical shape. The most well-known nanotubes are called single-walled carbon nanotubes (SWCNT) and they consist of rolled up graphene sheets. One of the allotropic structures of carbon is graphene. Graphene is a single layer of graphite that is made up of carbon atoms organized into hexagonal shapes. Each graphene carbon atom bonds to three other carbon atoms and leaves one electron in free motion, thus causing high electrical conductivity.

Carbon nanotubes are cylindrical structures made up of graphene sheets with diameters in the nanoscale and lengths in the macroscale. Carbon nanotubes are known for their strength and rigidity, stemming from the strong covalent bonds formed between their carbon atoms. Another form of carbon nanotube is the multiple-walled carbon nanotube (MWCNT), composed of multiple layers of graphene. Each nanotube in a MWCNT is considered a single molecule consisting of millions of carbon atoms. They have tremendous electrical, thermal, and mechanical properties that make them attractive candidates in the development of novel materials and applications, including biomedical applications, biosensors, and energy storage. A schematic representation of nanowires and nanotubes is shown in Figure 1.5.20

[Figure 1.5 near here]

Thin layer structures or nanosheets are typical examples of 2D nanostructures, as the thickness of a nanosheet is in nanoscale. The most well-known nanosheet is graphene. As shown in Figure 1.6, graphene sheets are composed of carbon atoms where each atom is bonded to three other ones and packed into a sequence of hexagonal shapes.21

[Figure 1.6 near here]

Three-dimensional nanostructures are not confined to the nanometer scale in any dimension. This means all three dimensions are at the macroscale and the electrons are free to move in all three dimensions. Three-dimensional nanostructures can be composed of dispersed nanoparticles, nanowires, and nanotubes.22 In nature, many examples of 3D nanostructures exist, including the blue, iridescent-colored wings of the morpho butterfly (*Morpho achilles*). It was discovered that the unique, blue-colored wings of the morpho butterfly are composed of multilayered 3D nanostructures.

[Figure 1.7 near here]

* 1. **History of Nanomaterials**

Recent studies have shown that the use of nanostructured materials began in antiquity, without user intent or awareness of the ideas of nanoscience and nanotechnology.23 Five thousand years ago, Egyptian civilization was known to produce a unique, bright blue dye called Egyptian blue. In that period, the dye was used frequently throughout the Middle East for painting statues, tombs, and more. This dye was characterized by its unparalleled blue color that resulted from copper being one of its main components. It ranged in color from light to dark blue, depending upon its composition. Recent studies have proven that this unique blue dye is composed of a mixture of cuprorivaite (CaCuSi4O10), or calcium copper tetrasilicate, and silicon dioxide (SiO2) nanoparticles. These compounds are heated to high temperatures ranging between 800-900 °C in order to produce they dye’s characteristic range of blue colors. After the end of the Roman era, the Egyptian blue dye became in limbo with their components and creation. 24-26

[Figure 1.8 near here]

The production of colored stain glass was a notable trend in the years of 1200-1000 BC, the late Bronze Age. During this period, red glass discovered in the Italian locale of Frattesina di Rovigo was found to be composed of copper nanoparticles. Similarly, red Celtic enamel from 400-100 BC was also found to be composed of copper nanoparticles.27

[Figure 1.9 near here]

In the fourth or fifth century AD, Romans used gold and silver nanoparticles to create the famous Lycurgus Cup. The cup appears to be one of two different colors, depending on the direction of light passing through it. When light passes from the front, the cup appears green. When light passes through from behind, the cup appears red. Studies attributed this dichroism (two colors) phenomenon to the unique effects produced by the cup’s gold and silver nanoparticles.28

The Damascus Sword was produced some time between the eighth and seventeenth centuries and was characterized by its unique combination of flexibility and strength. Although swords are known to be made of steel, the rigidity of the steel depends on its carbon and iron concentrations and ratios. The French and Russians attempted to duplicate the strong and flexible features of the Damascus Sword in the early eighteenth century. However, their attempts were proven unsuccessful and they were unable to discover the secret behind its production. In 2006, scientists were able to reveal the production secret behind the sword’s unique features. The Damascus Sword contained carbon nanotubes, one of the most durable and flexible materials known to this day. 29

[Figure 1.10 near here]

Metal nanoparticles are characterized by their distinctive colors that differ from their familiar color when they are at the macroscale. In Europe during the Middle Ages, in order to color medieval stained glass, glass windows in churches were painted with distinctive metal nanoparticle colors. It was discovered in later years that these colors consisted of solutions of nanoparticles of silver, gold and copper.30, 31

[Figure 1.11 near here]

In 1857, nanoscience and nanotechnologies were first introduced to the scientific arena by an English scientist named Michael Farady. He developed the first scientific procedure to produce the ruby color of gold nanoparticles dispersed in an aqueous solution. In 1908, Mie described that the appearance of different metal colors at the nanoscale was due to the theory of quantum size effects.32 In 1940, silicon dioxide SiO2 nanoparticles were first produced and used as additives for black carbon in rubber reinforcement.33

Later, in 1959, Richard Feynman famously lectured at the meeting of the American Physical Society under the title of: "There is Plenty of Room at the Bottom". Here he postulated, "what would scientists be able to do if they could control the material at the atom and molecular scale and rearrange it as they want?". He also described a new field of science dealing with individual atoms and molecules to make materials and machines with distinctive properties. This was the first known mention of a new field later termed nanotechnology.1

The year 1974 was the first time the term “nanotechnology” was used to describe different methods to produce very small particles.34 In 1976, the Palestinian-American particle physicist Munir Nayfeh renewed a laser technique to detect and measure individual atoms with the highest levels of accuracy and control. He mentioned that one atom of million ones and could revealed its identity for the first time in history, his method was based on excitation of atoms by laser beams.35 Based on Munir Nayfeh’s discovery, the Swiss researchers Gerd Ping and Henrik Rohr invented the scanning tunnelling microscope in 1981.36 For the first time in history, this microscope allowed scientists to directly image and manipulate atoms and molecules in order to create nanoparticles. In 1991, the Japanese researcher Sumio Lijima invented carbon nanotubes. With their unique mechanical and electronic properties, the creation of carbon nanotubes enabled the manufacturing of distinctive nanostructures.37 In 1992, the scientist Munir Naifeh wrote the smallest words in history (P♥) using a scanning tunnelling microscope.

* 1. **From Optical to Electron Microscope: Seeing at the Nanoscale**

Many scientific applications in biology, chemistry, and physics require observing and viewing extremely small sample sizes that are invisible to the naked eye. In the middle of the nineteenth century, optical microscopy was invented as a tool for magnifying and observing very small objects. An optical microscope’s technology is based on the use of visible light rays and different lens types in order to magnify a sample. The magnification process depends on shining a light directly onto the sample in a two-lens system. From there, the optical microscope is able to enlarge objects about 2000 times. This assists the user in being able to view microorganisms and cells in the micrometer size range. However, the limited magnification power of the light microscope was not ideal for all scientists and researchers whose research required viewing and analyzing objects in size ranges smaller than the microscale.38

[Figure 1.12 near here]

In 1931 the electron microscope was invented by German engineers Ernst Ruska and Max Knoll. The principal adaptation to microscopic technology used in the electron microscope was to use rays of electrons instead of visible light. Wave properties of electrons were discovered in a cathode ray experiment performed by J.J Thomson in 1897. Einstein first proposed that light consists of discrete units of energy known as photons: this dual nature of light became known as the wave-particle duality. Louis de Broglie extended the wave-particle duality principle to electrons. He argued that electrons have both particle and wave natures and proposed an equation that expresses the wavelength of an electron beam as: 39

λ = h/p (1)

where λ is the de Broglie wavelength of electron,h is the Planck’s constant, and p is the electron momentum. When comparing the wavelength of electron waves to the wavelength of a visible light beam that is used in optical microscopes, the wavelength associated with the electron is much shorter than the wavelength of visible light. The average wavelength of visible light is equivalent to 5000Å, while the wavelength of electron rays only reaches 1Å. The discovery of the wave property of electrons is considered a new starting point for the invention of microscopes that rely on electron waves, instead of using visible light rays. This led to much larger magnification power, due to the very short wavelength of electron waves. The magnification power of electron microscopes can reach up to 2.5 million times enhanced magnification of a sample which enables viewing at the atomic or molecular level. The invention of electron microscopes created an important and useful tool for studying and analyzing very small particles in the nanoscale. Mentioned below are some of the electron microscope types that are widely used in studies of nanoscale materials and structures.39,40

[Figure 1.13 near here]

**1.5.1 Transmission Electron Microscope**

The development of magnification devices which rely on the use of electron waves instead of visible light rays have had a great impact on the development of nanoscience and nanotechnology. A transmission electronic microscope (TEM) is one of the most important magnification devices used in this field. It is a form of microscope that magnifies via the interaction of electron beams passing through a sample. From there, an image can be obtained on a fluorescent screen or by using a CCD camera. The ability of a TEM to magnify with high accuracy is due to the short wavelength of electrons. This made the device a very important analytical tool used in nanomaterial research. The first TEM was built in 1938 and contained an internal vacuum system and electromagnetic lenses. The TEM vacuum system enabled electron rays to reach the sample without colliding with gas molecules while the electromagnetic lenses made of magnets directed the electron path.40

[Figure 1.14 near here]

**1.5.2 Scanning Electron Microscope**

A scanning electron microscope (SEM) is a device which can obtain three-dimensional images for analyzing morphology and shape. The SEM shines electron rays onto a sample and a three-dimensional scan of the sample is obtained via mapping detailed information from the sample cavities, scratches, and cracks. A magnetic field is used to control the movement of the electron beam over the sample. The electron beam carries large amounts of kinetic energy, but this energy disperses as a variety of signals generated by electron-sample interactions when the electrons are slowed in the solid sample.40

[Figure 1.15 near here]

* 1. **Nanoparticle Behavior in Colloid Solutions**

Chemically, substances are divided into two main categories: (i) pure substances, which includes elements and compounds; and (ii) mixtures. Mixtures can be homogeneous or heterogeneous. In general, solutions which are defined as homogeneous mixtures are uniform in composition. Figure 1.16 presents three solutions that seemingly look the same. Solution “a” is a solution of a red food dye dissolved in water. Solution “b” is a solution of gold nanoparticles dispersed in water. Solution “c” is an emulsion of oil droplets suspended in the water phase when the water is colored red. At first glance, all these solutions appear similarly red in color. However, scientifically, these solutions are categorized into three different types: true solutions, colloid solutions, and suspensions. The main difference between these three types of solutions is attributed to the size of dissolved substances.

[Figure 1.16 near here]

A true solution is a homogenous mixture composed of one or more solutes dissolved in a solvent. The size of solute particles in a true solution is below 1 nm. A suspension is a heterogenous solution where the size of solute particles ranges from 10 to 1000 µm. In a suspension, the solute particles are large enough that gravity forces cause them to settle downwards unless the mixture is constantly stirred or shaken. Solutions of nanoscale materials are considered colloid solutions. A colloid solution is a heterogenous composition of two phases, a dispersed phase and a dispersion medium. The dispersed phase is composed of nanoscale particles that are evenly dispersed throughout the dispersion medium. The medium can be a solid, liquid, or a gas. The size of dispersed phase particles in colloid solutions ranges from 1 to 1000 nm. The word “colloid” is of Greek origin meaning “glue” and was first mentioned by Thomas Graham in 1861. Graham created a "pseudo solution" with a very small diffusion rate. This phenomenon indicated to him that the reason could be due to the presence of "huge" particles in the solution.41

The main difference between the three types of solutions is attributed to the size of solute particles. Colloid solutions are composed of nanoscale solute particle sizes between those found in the true solutions and suspensions. Figure 1.17 illustrates the types of solutions categorized according to their solute particle size ranges.42,43

[Figure 1.17 near here]

**1.6.1 Types of Colloid Solutions**

Colloid solutions are defined as heterogenous mixtures of intermediate sized “solute” particles between 1 to 1000 nm that do not settle out. Colloid solutions are composed of two phases – a dispersion medium and a dispersed phase of nanoscale particles. Each component of the colloidal solution can exist in three states of matter: gas, liquid and solid. Consequently, different combinations of dispersion mediums and dispersed phases of different states lead to four main types of colloidal solutions. For example, sol is the term used when referring to solid nanoparticles dispersed in liquid dispersion medium. If the dispersion medium is an aqueous solution, it is called hydrosol. If the dispersion medium is an organic solvent, the nanoparticle solution is considered an organosol. When nanoparticles are in the gas state and are dispersed in a solid or liquid dispersion medium, it is called a foam. An emulsion is produced by the dispersion of liquid nanostructures in a liquid dispersion medium. An aerosolis the term usedwhen liquid or solid nanoparticles are dispersed in a gas phase. Table 1.2 presents several types of possible colloid solutions, depending on the dispersion medium and dispersed phase.

[Table 1.2 near here]

Colloidal solutions are differentiated from other types of solutions due to Brownian motion and Tyndall effect properties.44,45 Brownian motion is a random movement or zigzag-like motion of nanoparticles in colloidal solutions that results from collisions between the nanoparticles and the molecules of the dispersion medium. Figure 1.18 illustrates the random Brownian motion of a nanoparticle in solution.

[Figure 1.18 near here]

The Tyndall effect is an optical property that arises from passing a beam of light through colloidal solutions. When a light beam passes through a colloid solution, the light collides with the nanoparticles inside and this results in light scattering in all directions. This phenomenon is represented by seeing a beam of light inside the solution. The light scattering is attributed to the size of particles in the solution. In comparison, true solutions have solute particles with sizes below 1 nm. This size is too small to lead to light scattering, and therefore no beam of light is detected. Figure 1.19 illustrates these two solutions, a solution of silver ions and a colloid solution of silver nanoparticles. In image/part X, a shiny line inside the colloid solution is visible after a laser beam passes through it. In image/part X nothing is detected when a laser beam passes through the true solution.

[Figure 1.19 near here]

**1.6.2 Stability of Colloidal Solutions**

Technological and medical applications of materials at the nanoscale are mainly based on using stable colloidal solutions. Random Brownian motion of nanomaterials in colloidal solutions increases the possibility of collision between the nanoparticles. Colloid stability depends on the interactions between them when they collide. Van der Waals forces are considered a main attractive force between nanoparticles in solutions. Van der Waals forces are divided into three main types:46

1. Permanent dipole-permanent dipole forces (Keesom)
2. Permanent dipole-induced dipole (Debije)
3. Transitory dipole-transitory dipole (London and/or VDWL)

There has been increasing attention put upon the particle-particle interactions in nanomaterials due to their large surface area. If attractive forces between nanoparticles exceed repulsive forces, then the nanoparticles tend to cluster together and aggregate into larger-sized particles that eventually precipitate under the influence of gravitational forces. The aggregation process of nanoparticles is represented by several stages as follows and depicted in Figure 1.20.46

1. Flocculation, where the aggregation process is reversible
2. Coagulation, where the formation of large, aggregated particles becomes an irreversible process
3. Sedimentation, where the aggregated nanoparticle precipitation is caused by the force of gravity

[Figure 1.20 near here]

To prevent the process of aggregation between the nanoparticles and to obtain a stable colloidal solution, the repulsive forces must overcome the forces of attraction between them. The main attraction forces between nanoparticles in colloidal solutions are Van der Waals forces. These forces have great effects on colloid stability and can lead to aggregation, which destroys the structure of the colloid solution. In order to prevent nanoparticle aggregation, three stabilization methods exist and are described in the following section 1.6.2.1.47

**1.6.2.1 Electrostatic Stabilization**

The most effective way to balance the attractive forces between nanoparticles in solution is to create electrical repulsion forces between them. This is done by dispersing positive or negative charges onto the nanoparticle surface. Surface electrical charges could be created by one or more of the following mechanisms:

* Ionization of functional groups – Examples include organic molecules in the formulas of RCOOH, which ionize to RCOO- in aqueous solutions; amines, RNH2, which ionize to RNH3+; and SiOH, which ionizes to SiO- in aqueous solutions. This mechanism depends on the chemical nature of the nanoparticles.
* Physical or chemical adsorption of electrically charged materials applied to the nanoparticle surface – There are different types of electrically charged materials that could adsorb to the surface of nanoparticles including simple ions, polymers, or surfactants.42

**1.6.2.1.1 Electrical Double Layer**

The stabilization of a colloid solution via generating electrically charged nanoparticles results in the formation of an electrical double layer. This electrical double layer consists of parallel layers of coions and counterions which surround the nanoparticle. The electrical double layer is created mainly from the different attraction and repulsion forces between the ions in the colloidal solution. According to this theory, the presence of electric charges on the colloidal particle surface area affects the dispersion of ions in solution. Counterions are ions with opposite charges that stay close to the particle surface, due to the electrostatic attraction between them. Coions are ions with similar electric charges distributed within the solution. The specific electrical charge distributions around the surface of the particles and the effects of Brownian motion cause the formation of the electrical double layer.

An electrical double layer consists of two main regions, the Stern layer and the diffuse layer. The inner region is the Stern layer, which is an electrically charged surface of nanoparticles. The diffuse layer is the outer region, composed of dispersed, oppositely charged ions in solution, which distance themselves from the particle surface. In 1994, the scientist Stern developed a model in which the inner and outer regions of the electrical double layer were separated by an imaginary plane called the Stern plane. The outer part of the double layer was characterized by Gouy in 1910 and Chapman in 1913. They assumed that the dispersion of ions is based on a Boltzman distribution. Figure 1.21 portrays the structure of an electrical double layer with a negatively charged particle incorporated into a distribution curve. Figure 1.21 illustrates the change of electrical potential generated as a function of the distance from the surface of the nanoparticle.46

[Figure 1.21 near here]

Experimentally, the electrical potential of charged colloidal particles can be measured only at a certain distance from its surface. As shown in Figure 1.21, the distance that exists behind the Stern plane and at the edge of the diffusion region indicates the charges associated with the particle’s charge and its stability. This phenomenon is called the zeta potential and is represented by the Greek letter zeta (ζ). In principle, the numerical value of the electrical potential decays as one moves away from the particle surface, but the zeta potential can still attest to the surface charge. The measured magnitude of the zeta potential is an indication of the stability of a colloid solution. Lower zeta potential values specify that the electrical charge is not sufficient to prevent attraction between nanoparticles. Higher zeta potential values indicate that the electrostatic repulsion forces between the nanoparticles in colloid solution could exceed the attractive forces. Higher zeta potential values imply that the colloid solution is stable and that the nanoparticles will not aggregate. Table 1.3 presents different possible zeta potential values and their relationship to the stability or instability of the colloidal solution.46

[Table 1.3 near here]

A colloid solution stabilized by electrostatic mechanisms are greatly affected by the addition of different electrolytes. This is related to the simple interaction between electrically charged species. The addition of electrolytes with electrical charges opposite to the charge of the nanoparticles (counterions) could gradually lead to naturalization. This affects the colloid solution stability and could lead to destroying the stabilization mechanisms and creating nanoparticle aggregation.

Critical coagulation concentration (CCC) isdefined as the minimum electrolyte concentration required to coagulate colloidal particles. Adding counterions to a stable colloid solution causes the outer part of the electrical double layer around the charged nanoparticle to compress. From this, an energy barrier is created which is expressed by connecting the particles to distances where Van der Waals forces will be significant. This results in nanoparticle coagulation which precipitates under the influence of gravity. Figure 1.22 shows how adding counterions into a solution leads to precipitation of the aggregated nanoparticles from a stable dispersion.

[Figure 1.22 near here]

This process is accompanied by a gradual decrease of zeta potential value. For example, if the nanoparticles are stabilized by acquiring negative electrical charges, the addition of positively charged ions leads to minimizing its negative charge, and this is expressed by a lower zeta potential value. In most cases this results in complete naturalization, reflected by a zeta potential value of zero. The zeta potential value of zero is called the isoelectric point.46

In an aqueous colloidal solution, the pH value affects the zeta potential and the stability of the solution. If we assume a colloidal solution of negatively charged nanoparticles, the addition of an alkali leads to increasing the negative charges and this results in higher zeta potential values. If the pH of the solution is lowered by adding an acid, the zeta potential will decrease. The negative charges of the nanoparticles reduce and thereby the solution reaches its isoelectric point. It is very important to note that adding more acidic molecules could lead to positively charged nanoparticles and this restabilizes it by acquiring opposite electrical charges. Figure 1.23 presents the possible curve of the zeta potential value as a function of pH.

[Figure 1.23 near here]

**1.6.2.1.1 DLVO Theory**

In 1940, the scientists Derjaguin, Verwey, Landan, and Overbeek (DLVO) developed a quantitative theory of colloidal system stabilization. According to this theory, the stability of particles within a solution depends on the potential energy, VT, of the particles. This energy results from a balance between competitive attraction and repulsion forces between the nanoparticles that are created by the double electrical layer when:

VT = VA + VR + VS (2)

where VA is due to attraction forces and is expressed by:

VA= -A/(12π D2) (3)

and A is the Hamaker constant that depends on the nature of material and D is the distance between the nanoparticles. VR is due to repulsive forces represented by the equation below:

VR= 2πƐaΨd2e-KH (4)

where Ɛ is the dielectric constant of the dispersion phase, a is the radius of the nanoparticle, Ψd is the electric potential on the Stern plane of the electric double layer, 1/k is the double electric layer thickness, and VS is the potential energy derived from the solvent. VS does not significantly contribute to the final balance of the forces existing between the particles.

According to the DLVO theory, the stability of a colloidal solution is a function of the attractive and repulsive forces that are created by the double electric layer when particles collide during Brownian motion. The electrostatic repulsive forces create an energetic barrier that prevents the particles from approaching too closely to one other. However, when the attractive forces between the particles overcome the energetic barrier, aggregation takes place and the colloidal solution is destroyed.48 Figure 1.24 illustrates the total potential energy versus the distance between nanoparticles in solution.

[Figure 1.24 near here]

**1.6.2.2 Steric Stabilization**

Steric stabilization of colloidal solution occurs by the physical or chemical adsorption of macromolecules onto the nanoparticle surface. Via this process the macromolecules create a steric barrier against aggregation. Such macromolecules belong to families of polymers, copolymers, amines, and thioethers, as well as solvents such as THF and THF/MeOH, and alcohols with long hydrocarbon chains and surfactants. In general, hydrophobic molecules are used in an organic dispersion medium and the colloid solution is called an organosol. When hydrophilic molecules are used in an aqueous dispersion medium the colloidal solution is called a hydrosol.46

**1.6.2.2.1 Mechanism of Steric Repulsion**

When there are two nanoparticles with long chains attached to their surface, the interaction between them will be significant as they approach a distance equal to at least twice the thickness of each layer. Quantitatively, the degree of stabilization is described by the energetic change caused as a result of the interaction between the two layers of the macromolecules around each nanoparticle. The change in free energy that occurs as a result of the interaction between the macromolecules layers is called the Gibbs energy and is defined in the following equation:

ΔG= ΔH-TΔS (5)

where ΔG is the Gibbs energy, ΔH is enthalpy, T is temperature, and ΔS is entropy. If the free energy is negative due to the interaction, then the nanoparticles will be unstable and undergo aggregation. However, positive free energy causes a stable dispersion of the nanoparticles. In isothermal conditions, the degree of stabilization is a function of the enthalpy and entropy change of the system.

Over the years, several theories have been developed to explain the steric stabilization mechanism. These theories attempt to mathematically calculate the energetic change due to the overlap between two long chains around each nanoparticle as they approach one another. All theories describe the stabilization process as the entropy stabilization theory. These theories assume that there is no penetration of one chain layer within the other as two particles approach one other. Thus, when two nanoparticles approach each other at a certain distance, the long chains around their surfaces are compressed and the chain segments lose their entropic configuration. This is when the chain segments have fewer configurations in the compressed state compared to the uncompressed state. This decrease in entropy causes an increase in free energy, repulsion between the nanoparticles, and prevention of aggregation. According to this theory, the enthalpy change between the adsorbed long chains is negligible and therefore it can be assumed that:46

ΔG= -TΔS (6)

In general, a polar surface of a nanoparticle is defined as an area with acidic or basic sites. Polymer polar functional groups are usually acidic or basic groups in the molecular structure of the polymer. The adsorption of polymers onto the surface of different particles is a function of the chemical structure of its functional groups and the surface of the particle. For example, it has been found that polyamides and polydimethyl siloxane can adsorb to highly polar nanoparticles but not to particles with low polarity. The scientists Ullman and Ellerstein proved that the presence of highly polar groups embedded in the polymer molecular structure causes adsorption onto the particles. This phenomenon is a result of the interaction of the functional groups with the basic or acidic sites on the particle surface.49

In some cases, in addition to the presence of the polymers in the solution, the dispersing medium molecules are very important due to their potential to also adsorb onto the particle surfaces. The competition between the dispersion medium molecules and the polymers is determined by the chemical nature of the particle surfaces. For example, poly(methyl methacrylate) weakly adsorbs onto silica particles when dioxane is the dispersion medium, because this basic solvent "acquires" the acidic surface of the particles and prevents the polymer from adsorbing.

Steric stabilization has several advantages when compared with electrostatic stabilization and are described as follows:

1. Steric stabilization is not affected by the presence of electrolytes in solution.
2. Steric stabilization can be applied to both hydrosols and organosols
3. In electrostatic stabilization, the flocculation process is due to the addition of counterions and this process is usually irreversible. The flocculation process of steric stabilized nanoparticles is reversible.

**1.6.2.3 Depletion Stabilization**

Depletion stabilization is a mechanism which occurs in the presence of long chain polymers in colloidal solution when not adsorbed onto the surface of the particles, as shown in Figure 1.25. The large dimensions of these chains can compete with VDWL attractive forces among the nanometer particles. The prevention of particle aggregation is due to the presence of these molecules in solution freely, i.e., there is no interaction between the polymer and the particle.46

[Figure 1.25 near here]

**1.6.3** **Ferrofluids**

To prepare magnetic materials in liquid state, solid iron must be melted and maintained at a high temperature in order to maintain the magnetic material’s liquid state. Nanoscience has revolutionized the production of solutions with magnetic properties without the need to heat materials to high temperatures. These solutions are called ferrofluids. Ferrofluids are colloid solutions of magnetic nanoparticles dispersed in either an aqueous or organic dispersion medium. Creating a stable dispersion of magnetic nanoparticles is considered a significant challenge due to the magnetic attractive forces between the particles and the Van der Waals attractive forces. In order to prevent aggregation of the magnetic particles in solution, they must be provided with sufficiently strong enough repulsive forces in order to overcome these strong attractive forces. The stabilization of these solutions is determined by the balance between these strong attractive forces and the repulsive forces caused by steric or electrostatic stabilization. Common solutions of this type are ferrofluids composed on nanoparticles of magnetite (Fe3O4), cobalt, and nickel.

Ferrofluids are widely used and in recent decades many chemists and physicists have attempted to synthesize these solutions. Papell was the first scientist to succeed in stabilizing magnetic nanoparticles in 1965. Afterwards, many scientists began to study and synthesize them. The widespread use of these systems is attributed to their unique features as described below.

1. Nanoparticles in solution are strongly attracted towards the direction of an external magnetic field
2. They absorb electromagnetic energy at a certain frequency and heat up
3. When exposed to an external magnetic field, their physical properties can change

These unique features of ferrofluids make them attractive candidates for various applications in the fields of technology, biology, and medicine.50 Figure 1.26 presents a schematic of the reaction of ferrofluids when exposed to magnets.

[Figure 1.26 near here]

**1.6.4** **Preparation of Nanomaterials**

Over the years various methods of preparing nanomaterials have been developed. In general, these methods have been divided into two main categories, top-down and bottom-up. As illustrated in Figure 1.27, top-down methods are based on breaking down macroscale materials to nanoscale dimensions by applying different energy sources. The bottom-up approach is based on chemical methods where atoms, molecules, and ions are built up to nanoscale dimensions.42

[Figure 1.27 near here]

**1.6.4.1 Top-Down Methods**

**1.6.4.1.1 Mechanical Grinding**

Mechanical milling is a method that has attracted great interest due to its simplicity and low cost. This method is based a milling technique where strong mechanical shear forces are used to grind down macroscale bulk materials to nanoparticles in nanoscale dimensions. For example, this method is used to fabricate metal nanoparticles ground from high-energy steel ball milling.

**1.6.4.1.2 Laser Ablation**

Another top-down nanomaterial fabrication approach is based on laser ablation of macroscale bulk metal immersed in liquid solution. The metal is placed at the bottom of a glass vessel inside the solution and laser irradiation is directed towards the metal, thereby causing it to break down into smaller pieces. Color changes of the solution gives an indication that nanoparticle formation is taking place. In order to prevent the aggregation of the metal nanoparticles being produced, different kinds of materials are dissolved into the solution prior to the laser ablation. The materials which prevent nanoparticle aggregation can include polymers or surfactants, in order to achieve steric or electrostatic stabilization as displayed in Figure 1.28.51

[Figure 1.28 near here]

**1.6.4.2 Bottom-Up Methods**

**1.6.4.2.1 Reduction**

Reduction is a bottom-up method of creating nanoparticles in a solution by reducing metal atoms and ions which are below 1 nm in size. The creation of nanoparticles is based on self-assembly and the clustering together of reduced metal ions into larger sized scales that become nanoscale particles.42 Oxidation-reduction reactions are based on the transfer of electrons from a reducer material to metal ions in solution to form zero valent metal atoms. They are considered nucleation seeds for growing metal nanoparticles. The reaction is described as follows: 43

mMe+n + nRed mMe0 + nOx

The driving force of this reaction is the difference between the oxidation-reduction potentials of the two half reactions, ∆E. ∆E determines the equilibrium constant of the reaction, Ke, according to the Nernst equation:

lnke = nFΔE/ RT

where F is the Faraday constant, R is the gas constant, and T is temperature. Thermodynamically, the reaction occurs when ∆E is positive, which indicates that the oxidation-reduction potential of the reducer must be more negative than that of the metal ions. This difference must be greater than 0.3 - 0.4 V. Therefore, electronegative metals with E0 < - 0.2 V require the use of strong reducers, and in many cases, they must be applied under specific conditions of pressure and temperature. However, metals with E0 > 0.7 V, such as Au, Rh, Ag, Pd, and Pt, rapidly react with weaker reducers and under normal conditions.

Many metal colloid solutions can be prepared by the reduction of metal ions in solution using different reducers under appropriate conditions. Table 1.4 presents various metal ions, reducers, and appropriate reaction conditions.43

[Table 1.4 near here]

The three main steps described below present the process of forming metal nanoparticles. The steps include the reduction method, reduction of metal ions to zero valent metal atoms, nucleation, and growth of metal nanoparticles.

* Step 1: Reduction – Metal atoms form as a result of an oxidation-reduction reaction and the transfer of electrons from a reducer to metal ions, as described by the formula:

mMe+n +nRed mMe0 + nOx

* Step 2: Nucleation – Metal atoms produced from the reduction reaction become insoluble in solution. Therefore, they gradually aggregate to become larger groups called "embryos" as described in the formula:

xMe0 ↔ (Mex0)em

As more zero valent metal atoms are formed in solution, the embryos reach a critical size and separate from the solution to become solid particles {nucleus, (Me0n) nucl} and this process is defined as:

(Me0x)em +yMe0 (Me0x)nucl

The number of nuclei and their size depend on several parameters: the concentration of metal ions, oxidation-reduction potential of the reaction, temperature, and solvent viscosity.

* Step 3: Growth – As additional metal atoms continue to form in solution, the nucleus continues to grow, and the first particles are produced:

These first particles are unstable due to their high free energy. Therefore, they gradually aggregate to become colloidal metallic nanoparticles (Me0p):

Figure 1.29 illustrates the mechanism for the formation of colloidal metal particles by the reduction method.

[Figure 1.29 near here]

Various studies have demonstrated the possibility of producing metallic nanoparticles by using a variety of plant extracts. These extracts have two main functions: (i) to reduce metal ions, and (ii) to act as stabilizing agents in order to prevent the aggregation of nanoparticles. These reactions are very desirable because of their environmentally friendly properties. Silver and gold nanoparticles have been prepared by this method when their ions were mixed with various plant extracts in aqueous solution.23

**1.6.4.2.2 Electrochemical Method to Produce Metal Nanoparticles**

Electrochemical cells are widely used to produce various types of metal nanoparticles. The idea is based on using an anode made of the same metal. The anode is prepared from nanoparticles immersed in an aqueous solution of metal salt. The general process of electrochemical synthesis is described as follows:

The main processes to form metal nanoparticles in electrochemical cells are described below:

1. Oxidation of metal anode
2. Direct the flow of metal ions produced in the anode towards the cathode
3. Reduce metal ions in the cathode to zero valent metal atoms
4. Primary nuclei form in order to grow nanoparticles
5. Grow nuclei to nanoscale particles
6. Stabilize nanoparticles to prevent aggregation via introducing materials that act as stabilizers
7. Precipitate metal nanoparticles

The electrochemical method is illustrated in Figure 1.30.

[Figure 1.30 near here]

An important advantage of the electrochemical method is the ability to control particle sizing. This can be done via adjusting experimental parameters such as changing the distance between the electrodes along with altering reaction times and temperatures.42, 52

**1.6.4.2.3 Preparation of Nanometals in Gas Phase**

The main principle behind the preparation of metal particles in a gas phase is to rapidly cool metal atoms in the gas state using a cold, inert gas. This process involves placing gaseous metal atoms into a furnace of very high temperature. Within microseconds the atoms move towards high temperature gradient per centimeter space and are cooled by an inert gas. As shown in Figure 1.31, the formation of metal nanoparticles takes place between two ends of extremely different temperatures. The first one exhibits a high gradient of temperatures whereas the second one is performed under very low temperatures. In this extreme passage many embryos of nuclei are formed. These nuclei embryos aggregate together and establish the nucleation phase. The nuclei continue to grow until they expand beyond the growing zone, an area where there are no more atoms or nuclei. Finally, the nanoparticles formed are obtained at room temperature by cooling in a gas flow.53

[Figure 1.31 near here]

**1.6.4.2.4 Ultrasound for the Preparation of Nanomaterials**

Sound is defined as wave vibrations transmitted through an elastic medium. The use of sound waves began more than a century ago by the scientist Galton who attempted to measure the hearing threshold of humans and animals. To this end he developed a whistle capable of producing sound waves at different frequencies. Using this whistle, he discovered that an adult human’s hearing range is between 16 Hz – 18 KHz. Ultrasound is defined as a sound frequency of 20 KHz and higher and is considered beyond human hearing.54

Sonochemistry is a field that defines and characterizes chemical reactions under ultrasound irradiation. It has been found that ultrasonic irradiation of liquids leads to the occurrence of chemical reactions that consume high energy. The enormous energy obtained in sonochemistry stems from a physical phenomenon called acoustic cavitation. Acoustic cavitation is the formation of gas bubbles inside a reaction solution. The process of acoustic cavitation includes three steps:

1. The formation of gas bubbles inside an irradiated solution
2. Growing bubbles to a critical size
3. Bubble collapse

According to the hot spot theory, bubble collapse creates extreme conditions of pressure and temperature that breaks chemical bonds. Significant thermal energy is then released which creates localized, high temperature areas called hot spots. When the heating process is adiabatic, there is no transfer or loss of heat to the environment and therefore the hot spots catalyze other chemical reactions. The collapse of gas bubbles is adiabatic and takes place in the very short timespan of a nanosecond. Many experiments have shown that upon bubble collapse the temperature can reach up to 5000 K, the pressure up to 1000 atm, and the cooling rate above 109 ºC min-1. These parameters illustrate the enormous effects ultrasound irradiation can have when applied to a liquid and explain the occurrences of chemical reactions.55-57

**Sonochemistry in aqueous solutions**

Sonochemistry is a process based on the creation and collapse of bubbles. Generally, there are two regions of importance: the region within the bubble and the immediate vicinity surrounding the bubble. The cavitation bubble contains vapor from the solvent or other volatile reagent(s) in the solution. When under extreme conditions of temperature and pressure generated upon bubble collapse, gas molecules break down into radical molecules which are ions that have unpaired valence electrons. Water molecules in aqueous solutions undergo decomposition to become radical molecules as illustrated in Figure 1.32, below.58

[Figure 1.32 near here]

Various metal and metal oxide nanoparticles can be prepared via sonochemistry. For example, silver nanoparticles can be produced via ultrasound irradiation of an aqueous solution consisting of AgNO3 and starch. In this process the starch is cleaved due to the extreme conditions of the reaction and as a result, it reduces the silver ions and prevents them from aggregating. In addition, various ferrofluids have been prepared by sonication including magnetite nanoparticles (Fe3O4), nickel, and cobalt nanoparticles.59-62

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**CHAPTER 2**

**Nanochemistry as a Relevant Concept in Teaching Chemistry**

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**2.1 Introduction**

According to Gilbert~~1~~, an expert in XYZ, to teach science one must deal with several issues:1

* Over loaded content – Generally required from the teaching curriculum
* Isolated facts – Approaches are taught without student understanding on how to draw connections between different facts
* Isolated facts overload – Too many isolated facts do not fit the formation of the mental scheme. Students cannot make sense of what they are learning. This may lead to low class participation and forgetting memorized, isolated facts afterwards.
* Lack of transfer – Students can solve problems presented to them in ways they have learned and encountered previously. These same students may fail to solve problems using the previously learned concepts when presented to them in different ways, due to the lack of transfer of what is learned for daily life. Therefore, many students choose not to pursue chemistry studies because they do not see the relevance to what they have learned.2,3

One way to deal with these challenges is to create context through teaching techniques that address the social and cultural environment where the student exists.1 Teaching in context is characterized by employing social, technical, or scientific frameworks to develop an understanding of chemistry and creation. Chemistry then becomes more relevant to the daily lives of the students.4 Gilbert suggested theories based on context-based learning and concluded that the role of teaching in context is to enable students to be provided with meaning and experience. Through meaningful learning experiences, the student connects the concepts relevant to aspects of their lives.

Nanoscience and its respective applications are good candidates for teaching in the context of science education because they have clear connections to student daily life, they have industrial aspects, and all represent a rich environment involving research, society, and industry.4 Nanotechnology education programs have evolved in many places in the world.5 Studies have shown that the NANOLEAP program, which combines basic concepts in science (such as intermolecular forces) with concepts in nanoscience, enhances student understanding of basic concepts in nanotechnology. This program also improves student understanding of basic scientific concepts and supports research-based learning. Context-based science education with nanotechnological applications may assist a student in developing a better understanding of basic scientific concepts.6 Other research supports this type of studying as effective, useful, and relevant to daily life. Via emphasizing the forefront of science and applying a pedagogical technique where the student is at the center can cause an increase in interest and enhanced motivation among students.7 Elster indicates that context teaching of biology makes biological concepts more interesting and the students become more motivated.8

According to the studies presented, applications of nanotechnology represent scientific concepts that can make science more relevant, interesting, and meaningful to students and their daily lives. Context teaching by applying nanoscientific aspects and applications provide students with an opportunity to learn how modern science works and can encourage students to think about a career in science.5

Roco (2002) described the essence of nanotechnology in the following quote: 9

“*The essence of nanotechnology is the ability to work at the atomic, molecular and supramolecular levels, in the length scale of about 1 to 100 nm range, in order to create, manipulate and use materials, devices and systems with fundamentally new properties and functions because of their small structures. It includes understanding of phenomena and processes at the nanoscale, and integration of nanostructures along larger scales.”*

The uniqueness of nanoscience and nanotechnology is that it is a multidisciplinary scientific field which includes concepts in chemistry, biology, physics, engineering, and computer science. These concepts greatly influence various applications of materials, systems, and devices at the nanoscale, as illustrated in Figure 2.1.10

[Figure 2.1 near here]

The applications of nanotechnology can be considered a technological and medical revolution that serves humanity in various fields including energy, food, environment, medicine, and others. CThis is attributed to two main effects. The first is their high surface to volume ratioand the second is the quantum confinement effectthat influences their optical properties.11-22 This manipulation of material properties leads to various nanomaterial applications that are regularly used in modern daily life.

In their research, Blonder and Sakhnini identified seven essential concepts that must be taught in school science.23These concepts are:

1. Size dependent properties
2. Innovation and applications of nanotechnology
3. Size and scale
4. Characterization methods
5. Functionality
6. Classification of materials
7. Approaches of nanomaterials

In later research, they continued to focus on the second essential concept, innovations and applications of nanotechnology. These nanomaterial concepts affect our modern daily life, mimic nature, and they are adapted for several applications.24 The most relevant part of this concept involves nanotechnological applications that could be taught in context at high schools. According to Blonder and Sakhnini’s findings, they recommend five nanotechnological applications and are described below.

– The applications of nanoscale

1. structures and materials in medicine are divided into two categories: for medical treatment and diagnosis. Diagnostic applications are based on the change of nanomaterial properties upon binding to the targeted disease site. Medical treatments use nanostructured materials for drug delivery purposes. For example, liposomes and micellar nanostructures act as drug vehicles.
2. Nanoelectronics – Nanostructured materials are used in manufacturing electronic devices. For example, carbon nanotubes are used in electronic devices to transfer electrons from one side of the device to the other. This subset of nanotechnological applications is highly connected to daily student life because most students in industrialized areas regularly utilize computers, cellular phones, and LED-based appliances.
3. Photovoltaic cells – This concept relies on…. Students can connect to this topic by learning about the concept of surface area and its importance in increasing the material reactivity and structures at the nanoscale. For example, to increase the efficiency of solar cells, nanomaterials such as titanium oxide are used because of this material’s large surface area.
4. Nanobots – This technology relates to the design of nanoscale robots made of nanomaterials and nanostructures that are considered a challenge for future developments.
5. Self-cleaning – This nanotechnological application is closely related to the topic of green environment that is highly relevant to modern daily life. The useful properties of nanoscale materials and their high surface area is exploited for use in different kinds of self-cleaning. For example, one can fabricate superhydrophobic surfaces by using films made of TiO2 nanoparticles to produce a photocatalytic effect. This can be done by allowing sunlight to create oxygen species on the surface of TiO2 films which can attack organic contaminants. This prevents pollutants from sticking to the surface.

The following sections present examples of phenomena, applications, and activities of nanostructures and nanomaterials that are frequently used in daily life.

**2.2 Relevant Aspects in Teaching Nanotechnology**

**2.2.1 Nanoscience and Nanotechnology Teaching Module**

A teaching module was designed by Blonder for ninth grade students to teach chemistry.25 The teaching module consists of several teaching methods that aim to engage students and make the learned concepts more interesting and motivational. The module includes game-based learning, visualization and multimedia,learning with movies, learning with simulations, and learning with models.26-33 Blonder’s teaching module aims to teach two basic nanotechnology concepts. It incorporates different teaching methods where students can learn about (i) size and scale and (ii) surface area to volume ratio.

The proposed teaching module can be useful for middle school teachers in order to expose students to basic aspects of nanoscience and nanotechnology. The various teaching methods in this module keep students engaged. The final stage of the module consists of teaching the relevance of nanostructured materials to our daily life. According to Blonder, the following topics are addressed.

* Introduction to nanotechnology
* Introduction to the nanoscale
* The significance of nanotechnology
* Different nanomaterial types and shapes
* Nanotubes, nanoparticles, and their applications
* Surface area to volume ratio
* Applications of nanotechnology and its relevance to daily life.

In accordance with the proposed module designed by Blonder, the following activities are highly recommended to address the subject of nanoscience and nanotechnology to middle and high school students.

Activity 1: Nano scraps(game-based learning) – In this activity students are asked to cut the smallest possible piece of paper and write on it, according to their own knowledge, the name of an object that is in the nanoscale. The aim of this activity is to investigate the preliminary knowledge base students have regarding nanoscience and nanotechnology.26

Activity 2: Size and scale –This activity is based on the strategy of learning through visualization. Student are exposed to the relative size of different, familiar objects. This activity allows students to investigate how small the nanoscale is and to correct misconceptions about nanometer size and scale. Figure 2.2 presents how this activity can be executed via portraying how students can compare different objects from differing size scales.

[Figure 2.2 near here]

Activity 3: Cutting down to nanoscale – This activity employs a game-based learning approach.26 Students are asked to try and cut a piece of paper to smaller pieces using scissors. First, they are asked to cut the paper in half and then to continue to cut the paper into the smallest piece they can achieve. They will not succeed in cutting the paper to reach the nanometer scale. However, in this activity students experience visually how the paper exponentially decreases in size. To make this game-based activity more interesting and engaging, students can compete for who can cut the smallest piece of paper. This activity demonstrates to students how nanoscale objects are much smaller than the smallest visible objects. It is highly recommended to give examples of small, invisible objects that can have large impacts, such as the coronavirus.

Activity 4: What is nanotechnology? – This activity is based on the strategy of learning with the aid of videos and movies.30-31 Students watch a video where two children explain what nanotechnology is.34 In the video, human hair is enlarged to model how small nanoscale objects are in size. This activity exposes students to the nanoscale and nanotechnology in a friendly, relatable way in order to explain the amazing world of nanotechnology.

Activity 5: Significance of nanotechnology – This activity is also based on the strategy of learning with the aid of videos and movies. 30-31 This activity employs the use of short movies to demonstrate to students the variety of uses nanotechnological applications have in industry, technology, and their importance to daily life. An appropriate movie selection will actively engage students and introduce them to unusual or lesser-known nanotechnology applications.35, 36

Activity 6: Learning with dice – This activity uses modelsto demonstrate the main effects that surface area to volume ratios have on materials and structures at the nanoscale.33 The students use dice, cubes, and Hungarian cubes (known as the Rubik’s Cube) as tangible models to understand the concept of surface area per volume.

Activity 7: Material Polystyrene Model – This activity is based on learning with models. The students build a cube from polystyrene balls and each ball represents an atom. From this, students can realize the importance that surface area plays in different physical and chemical properties of materials. They will obtain a better understanding of how atom arrangements on the surface differ when they are surrounded by fewer atoms and exposed to the environment. They are surrounded by fewer atoms in comparison to atoms and molecules inside the material.

Activity 8: Models and phenomena from daily life – This activity connects phenomena and models from our daily life to concepts of surface area per volume ratios. For example, the wrinkles in elephant skin increases its surface area. As a result, heat is spread out over a larger surface area to keep the animal cool. Some heat radiators are designed similarly, where the radiators which are divided into rectangles enhance the surface area, and then the heat dissipates more.

Activity 9: Building different types of nanostructured materials – The activity is based on models and game-based learning strategies. Students use models to build fullerene and carbon nanotubes to assemble different types and shapes of nanostructured materials. This activity can also be accompanied with presenting different three-dimensional images of nanomaterials.

Activity 10: Nanotechnology applications – In this activity students are exposed to different kinds of nanotechnology applications that are familiar to them, for example, technological gadgets like iPhones. Electrodes of iPhones are coated with nanoparticles in order to increase the available electrode/battery surface area. As a result, this increase in surface area enhances the power available to the battery and lessens the time required for battery recharge.

**2.2.2 The Self-Cleaning of Lotus Leaves: Superhydrophobic Surfaces**

The leaves of lotus plants fascinate many scientists due to their ability to repel dirt and clean themselves. Large amounts of research have been dedicated to elucidating the structure of lotus leaves and the mystery behind their ability to self-clean.37-38This unique property was thought to be due to their superhydrophobic surfaces with roughness caused by microfilaments.39 Recent studies reported that the surface of a lotus leaf consists of micro- and nanoscale hierarchical structures, or branch-like nanostructures on the top of micro-papillae.40 Figure 2.3 presents an image of a water bubble on a lotus leaf. The shape of the water droplet does not spread across the surface of the leaf, thereby indicating that the lotus leaf possesses hydrophobic and water-repellent properties.

[Figure 2.3 near here]

The remarkable ability of lotus leaves to repel dirt has been an inspiration for developing disinfection and self-cleaning technologies. The discovery of rough-surfaced lotus leaves containing branch-like nanostructures played role in the fabrication of superhydrophobic surfaces based on hydrophobic nanostructures. Yuyang et al. fabricated artificial lotus leaf structures by assembling carbon nanotubes onto the cotton surfaces. Inspired by the natural lotus leaf structure, the authors attempted to convert water absorbent cotton fabrics to display superhydrophobic surfaces.41

Recently, Muharjan et al. applied self-cleaning, hydrophobic nanocoating onto glass substrates.42 They began the process by roughing flat glass surfaces with micro and nanoscale particles of diamonds to increase surface area. This was an idea inspired by the natural surfaces of lotus leaves. This step was followed by the deposition of the hydrophobic trichloro(1H,1H,2H,2H-perfluorooctyl) silane as illustrated in Figure 2.4.

[Figure 2.4 near here]

Another study created lotus-like superhydrophobic copper substrates without chemically modification. This process was based on roughing copper plates via the electroplating method.43-44

The application of superhydrophobic surfaces are widely used in modern daily life as well as for uses in industrial processes such as textiles, cleaning, and corrosion protection.45-47 The natural structure of lotus leaves with its nanoscale effects became an inspiration for forming superhydrophobic surfaces for several purposes.

**2.2.2.1 Converting a Copper Plate Surface to a Hydrophobic One - Lab Experiment**

Lotus plant leaves and their superhydrophobic, rough surfaces based on branch-like nanostructures can be introduced as a laboratory activity. Here students convert hydrophilic copper plates to become hydrophobic in order to imitate lotus leaf structures.44 The experiment consists of two steps. In the first step copper plates are roughed and the second step involves coating the surface of the copper plate with hydrophobic material. During this activity, students can compare the wettability of the copper plate in three different situations: before roughing the copper plate; after roughing; and after coating with hydrophobic material. The experimental procedure is described below.

Experimental procedure

Materials: Copper plates (2 × 2 cm2), aqueous solution of 2.0 M NaOH, aqueous solution of 1.0 M K2S2O8, 5 mM ethanol solution of dodecanoic acid, and acetone.

Step 1: Roughing the copper plate surface – Immerse copper plates into an aqueous solution of 2.0 M NaOH and 0.1 M K2S2O8 at room temperature for 20 minutes. Take the copper plates from the solution and rinse them thoroughly with water. Air dry. This process roughens the copper plate surface by creating copper hydroxide nanowires with interconnected architectures that cover the copper surface.

Step 2: Coating the surface of the copper plate with hydrophobic material – Immerse the copper plate from step one into 5 mM ethanol solution of dodecanoic acid for another 20 minutes. This process creates/applies a self-assembled monolayer of copper carboxylate. Rinse the copper plates with acetone. Air dry.

**2.2.3 Coating with Nano:The Magic Sand**

When teaching chemistry, materials can be categorized according to their hydrophobic properties as being either hydrophilic or hydrophobic. Hydrophilic materials are defined as materials that attract water. Hydrophobic materials repel water molecules. The differing chemical structures are what determine if a material is hydrophilic or hydrophibic

The Magic Sand activity can demonstrate examples of hydrophilic and hydrophobic materials along with

how nanoscale materials affect surface properties. Standard sand types are made of hydrophilic materials that are strongly attracted to water molecules. This phenomenon is clearly observed at the beach when sand becomes wet with sea water and it turns into mud. Scientists can use nanotechnological means to coat natural sand grains with silicon-based compounds. This silicon-based compound can possess a hydrophilic end on one side and a nanoscale-sized hydrophobic end on the other. The hydrophilic end would attract the sand grains. The hydrophobic layer over the other end of the sand grain would repel water. This layer would convert standard sand from strongly attracting water molecules to strongly repelling them.49

Magic sand can be used as a simple experiment to demonstrate how “unseen” nanoscale layers can dramatically affect the chemical behavior of materials. By coating the sand with specific nanomaterials, students can compare between regular sand and magic sand and how the sand interacts with water. The magic sand activity is very simple, with the materials needed being only natural sand, magic sand, and water. Water is poured

into two beakers or cups: one cup contains natural sand and the other cup contains a certain quantity of magic sand. Students can then witness each respective cup of sand’s interaction with water. The students will observe that magic sand remains dry while natural sand becomes wet, as illustrated in Figure 2.5.

[Figure 2.5 near here]

**2.2.4 Teaching Nanotechnology Concepts to Elementary Students - Surface Area**

When teaching about nanoscience and nanotechnology, it is very important to address two basic phenomena that are responsible for the principal changes of the physical and chemical properties of materials when they are at the nanoscale. As described in Chapter One, a large surface area to volume ratio is a principal feature of nanoscale sized materials.

Teaching nanotechnology needs to be based on understanding its basic aspects and its importance in daily life.50 In research performed by Nandiyanto, he/she and his/her team performed a very interesting experiment that could be considered as a simple starting point to expose students to basic aspects of nanotechnology.51 The suggested experimental demonstration is based on the correlation between the size of solute particles and their dissolution into water, a phenomenon that is highly relevant to modern daily life. This experiment puts the surface area aspect of nanoscale materials into context. For elementary students, dissolution is explained plainly, without mentioning more complicated chemistry concepts such as ion formation, concentration of solution, and chemical bonds, among others. Nandiyanto and his/her team relied on the definition that dissolution could be explained by homogenously distributing solute particles in the solvent phase. Solute particle size significantly affects the dissolution ability of the particles, as smaller particles dissolve more easily than larger ones. In order to explain this in a simple and clear way, a cube is presented, and a comparison is shown between the obtained surface area and the total surface area after cutting it into several smaller cubes, as shown in Figure 2.6.

[Figure 2.6 near here]

Two kinds of solutes were used, sugar and table salt. Both solute types were of differing sizes as shown in Figure 2.7.

[Figure 2.7 near here]

This experiment can be useful for learning about the effects of surface area on the reactivity of materials. Surface area size is one of the basic factors that affect the properties of materials at the nanoscale. It is highly recommended to expand the scope of this experiment by relating other phenomena from modern daily life that are influenced by the relationship between surface area and material properties. For example, students could compare between burning a piece of iron versus a piece of iron wool, as illustrated in Figure 2.8. Another example could include melting ice cubes versus melting ice cubes of the same volume after grinding them into very small pieces. This process is due to the evaporation of a known volume of water versus the evaporation of the same volume after dividing it into small quantities. (Riam, in press).

[Figure 2.8 near here]

**2.2.5 From Optical Properties of Gold Nanoparticles to Colorimetric Sensors**

Metal nanoparticles are characterized by the unique colors they exhibit that are different from their known color when sized in the macroscale. As described in Chapter 1, colloidal solutions of metal nanoparticles are characterized by surface plasmon resonance (SPR). Briefly, the small size of metal nanoparticles is consistent with the wavelength of visible light. Therefore, an interaction between the light and the metal nanoparticles occurs which produces an oscillation of the metal nanoparticle free electrons. This phenomenon results in the absorption and emission of UV-visible light that produces a spectrum of visible colors in metal nanoparticle solutions.

The optical properties of metallic nanoparticles are known for their unusual and beautifully bright colors. Thus, metallic nanoparticles are used for developing sensors that are based on visualizing color changes.52-55 SPR is strongly affected by both the size and shape of metal nanoparticles. As a result, different sizes of metal nanoparticles could exhibit differing colors.

As described in Chapter 1, the effect of the larger surfaces area per volume of materials at the nanoscale causes Van der Waals attraction forces to be great influencers, which may lead to nanomaterial aggregation. In order to prevent this from happening, different stabilization methods have been developed. Electrostatic stabilization is one such method that is based on bestowing an electric charge to the nanoparticles in order to overcome the attraction forces between the nanoparticles.56

McFarland and his colleagues proposed a lab activity that introduces students to the unique optical properties of gold nanoparticles.57 In this activity, students prepare aqueous colloidal solutions of gold nanoparticles via applying the reduction method. The reducing agent acts as both a reducer and stabilizer by adsorbing onto gold nanoparticle surfaces and thereby creating a negative electrical charge. Next, students explore the applicability of using gold nanoparticles to act as an electrolyte sensor. This is done by adding electrolyte solutions which induce gold nanoparticle aggregation by enhancing nanoparticle electrical attractive forces. This process produces color changes in the colloidal solution that is attributed to the nanoparticle size changes induced by the added reagents.

**2.2.5.1 Developing Electrolyte Sensors from Gold Nanoparticles**

Another suggested lab activity can be to prepare an aqueous colloidal solution which acts as a sensor for the detection of gold nanoparticles in the solution. The preparation method is based on the reduction of gold ions by trisodium citrate (Na3C6H5O7(aq)).58 The preparation procedure is described schematically in Figure 2.9. In this figure, an aqueous solution of HAuCl4 is heated to boiling temperatures while continually stirred. After the solution begins to boil a trisodium citrate solution is added. Stirring and heating are continued until the solution turns red in color, which indicates the presence of gold nanoparticles.57

[Figure 2.9 near here]

In Figure 2.9, trisodium citrate reduces gold ions to gold atoms that accumulate to produce gold nanoparticles. In an aqueous solution, sodium citrate has a negative charge. The excess XYZ in the solution adsorbs to the gold nanoparticle surfaces, conferring upon them an overall negative electrical charge.

Gold nanoparticle solutions are characterized by their differing color displays that depend on the size and shape of the gold nanoparticles. Differently sized nanoparticles determine how they interact with light and this is visually reflected by the produced color. In fact, red-colored solutions of gold nanoparticles turn to purple when the nanoparticle sizes increase. The unique feature of size-dependent color makes negatively charged gold nanoparticles a form of a selective chemical sensor.

In one example, an experiment can be performed to differentiate between a table salt solution and a sugar solution. The two solutions appear to look the same, but chemically, table salt (NaCl) is an ionic compound and sugar is a molecule. Therefore, their dissolution modalities in water are different. No ions are available in the sugar solution, whereas, the solution of table salt contains positive and negative ions. Based on these facts, the addition of sugar solution to the solution of red colored colloids made of gold nanoparticles will not lead to any color change. In comparison, adding the salt solution to the gold nanoparticle solution will lead to the gradual transition of its colors to turn from red to purple. Precipitation of XYZ may also happen at this time. This color change occurs due to the presence of positively charged sodium ions that reduce the intensity of the negative charges of the gold nanoparticles and the attraction between them. This leads to increasing the gold nanoparticle sizes and this is what causes the color change, as displayed in Figure 10.2.

[Figure 2.10 near here]

**2.2.6 Preparation of Magnetic Liquids in Low Temperatures**

Conventional methods to create liquified magnetic material require extreme conditions of high temperatures to measure a highly magnetic solid-like iron. There are two principle challenges that conventional methods present in order to accomplish this goal. The first challenge is that in order to keep magnetic material in a liquid state, a high temperature must be applied at all times. This makes it difficult to use for different purposes. The second challenge is that solid magnetic materials can lose degrees of magnetism upon melting. This happens because the material magnetic properties are strongly affected by temperature. Each magnetic material has a specific Curie temperature (TC), a property that is attributed to magnetic materials where thermal energy overwhelms the tendency of electrons to align in a magnetic domain. In most cases, TC is lower than the melting point.59-60

The development of nanoscience and nanotechnology has contributed to many changes that are reflected in our daily life. The production of different nanoscale materials has had a great impact in many fields. As mentioned in Chapter 1, ferrofluids are differing colloidal solutions made of magnetic nanoparticles. Interestingly, the production of ferrofluids overcomes the obstacles mentioned above.

Ferrofluids are liquid magnetic solutions that are stored at room temperature and can be controlled by an external magnetic field. Ferrofluids have a wide range of applications both for technological and medical purposes. The American National Aeronautics and Space Administration (NASA) developed the first ferrofluid in 1960 and used it for rotating shaft seals in satellites. Nowadays, ferrofluids perform a significant role in a variety of machines ranging from centrifuges to computer hard drives.61 Controlling ferrofluids using external magnetic fields makes them useful materials for various medical applications. For example, an actuator made with ferrofluids is used for an implantable artificial heart. The actuator can be controlled by simply applying an external magnetic field.59

Aqueous magnetic fluids have also been successfully used as drug vehicles. Drugs are attached to the surface of magnetic nanoparticles and via applying a magnetic field, the drug can be directed to a specific desired site in the body.62 Makhluf et al. successfully loaded magnetite nanoparticles into sperm cells. After this process the sperm cells kept their mobility and ability to fertilize an egg.63-64 This process made sperm cells acquire a magnetic property that enabled the management of their movement by applying an external magnetic field. In principle, magnetic nanoparticles of ferrofluids can be bonded to various structures and biomaterials in order to control their motion and activity for different purposes.

In the United States, one can identify an authentic dollar bill by its attraction to a strong magnet. Ferrofluids are used as magnetic ink in the ink jet printers used to manufacture the bills and therefore magnets can verify their authenticity, as displayed in Figure 2.11. 65

[Figure 2.11 near here]

Berger and his colleagues proposed a lab experiment that describes the preparation and characterization of ferrofluids.65 The experiment can be performed with high school students or undergraduate students. In this experiment, magnetite Fe3O4 nanoparticles are synthesized and then stably dispersed in an aqueous solution. A magnetite crystallized structure is composed of both Fe(II) and Fe(III) ions as shown in Figure 2.12. The preparation is based on the reaction between both iron ions in an aqueous ammonia solution, as described in the following reaction:

The reaction

[Figure 2.12 near here]

The process of preparing colloidal solutions involves two important factors. The first factor involves finding the appropriate preparation method for the nanoscale material. The second factor is attributed to the process of stabilization. This means it is an important to find a stabilizing agent which can provide enough repulsive forces between the nanoparticles so that the nanoparticles are not attracted to one another.

The preparation of a stable dispersion of magnetite (Fe3O4) nanoparticles in an aqueous solution is considered a larger challenge because of the magnetite’s innate magnetic properties. As described in Chapter 1, the large surface area of materials at the nanoscale makes Van der Waals attraction forces more powerful. Therefore, a stabilization mechanism should be applied in order to overcome these stronger attraction forces. In addition to Van der Waals forces, strong magnetic attraction forces exist that makes the stabilization process of magnetite more difficult.66-69 The suggested preparation method of Berger and his colleagues can be summarized in the following schematic diagram in Figure 2.13.

[Figure 2.13 near here]

**2.2.6.1 Preparation of Ferrofluid-Lab Experiment**

Materials types and their respective quantities needed to prepare a ferrofluid experiment are described in Table 2.1.

[Table 2.1 near here]

1. In an Erlenmeyer flask, combine 1 ml of FeCl2 and FeCl3 solutions and stir vigorously using a magnetic stirrer.
2. Slowly drip 50 ml of NH3 solution into .
3. After five to ten minutes, a black precipitate will settle down into the flask. This black precipitate indicates the formation of aggregated magnetite nanoparticles.
4. The next step involves the preparation of unstable magnetite nanoparticles. Here the nanoparticles are stabilized against aggregation, and this is when ferrofluid is produced.
5. Separate out the magnetite precipitate and the solution above, preferably by centrifugation.
6. Disperse the magnetite precipitate into a solution of tetramethylammonium hydroxide (CH3)4NOH via stirring.
7. In order to remove excess ammonia from the solution, stir the solution using a magnetic stirrer and place under a vacuum aspirator for 30 minutes.

An aqueous solution of tetramethylammonium hydroxide (CH3)4NOH consists of hydroxyl ions (OH-), and tetramethylammonium ions N(CH3)4+. The stabilization of magnetite nanoparticles can be achieved in two successive steps. In the first step, hydroxyl ions surround magnetite nanoparticles by adsorbing onto the nanoparticle surfaces. This adsorption occurs because magnetite nanoparticles are composed of both Fe+3 and Fe+2 ions. In addition, tetramethylammonium cations adsorb to the surface of magnetite nanoparticles via attractive forces between positive and negative charges. As illustrated in Figure 2.14, the stabilization process of magnetite nanoparticles results from electric reduction forces that arise from the positively charged tetramethylammonium ions.65

[Figure 2.14 near here]

The importance of ferrofluids and their numerous applications for technology and biomedicine are related to their unique physical property of being able to be physically manipulated from an external magnetic field. The preparation of a magnetite ferrofluid could also be followed by a simple visual illustration of the effect of an external magnet.

**2.2.7 Nanoscale Structure-based Light Emitting Diode (LED)**

Blonder designed a teaching module for high school students based on teaching the topic of a light emitting diode (LED), its working principals, and the role LEDs play in the development of nanotechnology. 7 LED is a light source composed of semiconductor materials. Unlike conventional light sources that are based on converting electrical energy into heat and then into light, LED is based on converting electrical energy directly into light. Semiconductor materials are characterized by their band gap energy. By applying electrical energy, electrons move from the higher energy conduction band to the lower energy valence band. In this transition across energy bands, they emit wavelengths of light from the ultraviolet, visible, and infrared spectrums. As illustrated in Figure 2.15, the wavelength of the emitted light is based on the energy difference between the conduction and the valence energy states which leads to different colors of light emitted.

[Figure 2.15 near here]

As described in Chapter 1, one type of zero-dimensional nanostructure is quantum dots. Quantum dots are very small nanostructures made of semiconductor materials. They are characterized by the phenomenon of quantum confinement, or a higher band gap energy in comparison to microscale semiconductor materials.70 In addition, quantum dots that are made of the same material could possess a different band gap energy depending on the dot morphology and size on the nanoscale. Smaller sizes of quantum dots possess greater band gap energies. A unique feature of quantum dots is related to the fact that their band gap energy is consistent with the energy of light that is in the visible region. When applying an energy, electrons in the valence band “jump” to a higher energy level. When it returns, they emit an energy with a wavelength in the visible light spectrum. The color of emitted light from this occurrence depends on its energy band gap. According to the quantum confinement effect, smaller sized quantum dots emit shorter wavelengths of light because of their higher energy band gap. It is not uncommon to see blue light produced, while red-colored light has been more frequently seen from the emission of smaller sized quantum dots. As shown in Figure 2.16, quantum dots with intermediate-sized, green-colored light can appear.

[Figure 2.16 near here]

Blonder adapted the student-centered pedagogy as a teaching strategy for incorporating nanotechnology concepts when teaching chemistry.7,71 According to her study, increasing student motivation to study chemistry could be achieved by bridging the gap between modern technological developments that affect our daily life and current high school learning platforms. Nanotechnology concepts can be an interesting candidate for teaching about modern life.

**2.2.7.1 Learning Module: LED as a Well-Known Nanotechnology Application**

This module consists of three different activities which aim to gradually build basic knowledge and highlight features of LED as a modern nanotechnological application.7

Activity 1: Diodes as components in an electrical circuit

This activity is composed of two stages. In the first stage, students measure the conductivity of different components and materials and examine the direction of the conductivity. The aim of this activity is to expose the students to different types of materials, insulators, semiconductors, and conductors. In addition, students gain the knowledge that a diode is an electrical circuit component which allows electricity to flow in one direction. By performing these experiments, the students are able to ask questions related to how electrical circuits function. In the next stage of the activity, students are given adapted scientific texts about electrical circuits and their components. For example, they can be given information about silicon as a semiconductor material, its properties, and its behavior.

Activity 2: Color mixing versus light mixing

This activity attempts to introduce the topic of light as one type of electromagnetic wave and that light color depends on its energy. During this activity students are asked to mix gouache paints and create different colors. Then students are asked to try and to create the same colors by mixing different colored light beams. Students discover that mixing different-colored light beams does not always replicate the same colors as the gouache paints can do. This activity can trigger a student’s curiosity regarding the concepts of light and color. This is a chance to explain that the light’s source of color depends on the electronic structure and energy levels of different materials. In the second part of this activity the instructor can demonstrate an experiment of burning differing metal salts to create different colors in a fire flame. This activity can be followed by another demonstration where students can build an electrical circuit. In this activity, students can compare between a conventional diode that converts electricity to heat and a LED that converts electricity directly into light.

In a third activity, students can compare the efficiencies of standard lamp and a LED lamp via illuminating an object within a black box. At the end of these three activities, students can receive a concluding assignment that includes a scientific text about LED from an article titled: “Weaving with Light”. 72

According to Blonder, this module designed for high school students can expose them to one of the more well-known, advanced applications in nanotechnology – LED. The role of LEDs in electronic devices is based on the unique properties of nanostructured materials, specifically their large surface area and distinctive optical properties.

**2.2.8 Carbon Nanotubes: Unseen Structures of Carbon Atoms**

“*Coal and diamonds, sand and computer chips, cancer and healthy tissue: throughout history, variations in the arrangement of atoms have distinguished the cheap from the cherished, the diseased from the healthy. Arranged one way, atoms make up soil, air, and water; arranged another, they make up ripe strawberries. Arranged one way, they make up homes and fresh air; arranged another they make up ash and smoke*."

*-Eric Drexler*

Carbon atoms are distinguished by their possibility to bond each other in different ways. This results in the formation of different structures called carbon allotropes. The most common structures of carbon are diamond and graphite. Diamonds are used in jewelry production. Pencil tips are made of graphite. In fact, diamond and graphite are not the only allotropic structures of carbon, they exist as invisible structures with nanoscale dimensions. These structures have distinctive characteristics that make them suitable candidates for many uses. As mentioned in Chapter 1, it was discovered that the Damascene sword, known for its durability and flexibility, contains nanotube structures made of carbon atoms.

Graphite, graphene, buckyballs, and carbon nanotubes are allotropic structures of carbon that are nanoscale at least in one of their dimensions. The carbon atoms in these structures share some things in common: each carbon atom is bonded to three other carbon atoms in the x-y plane, and from this they form hexagonal, geometric molecular structures. The carbon atom’s fourth electron located in the outer valence shell remains free to move and it is responsible for phenomenal electronic properties. Graphite is a multi-layered, single sheet of graphene. Buckyballs and carbon nanotubes are spherical and cylindrical structures of graphene, respectively. These different structures exhibit differing arrangements of graphene sheets and, consequently, distinctive electronic, thermal, and mechanical properties that are responsible for various applications in batteries, fabrics, and electronic devices.

Carbon nanotubes are cylindrical and hollow molecular structures made of carbon atoms, and are equivalent to a graphene sheet rolled into tube-like structures. The carbon atom arrangement in the carbon nanotubes are responsible for the “honeycomb” shape in a rolled graphene sheet. Carbon nanotube diameters are in the nanoscale whereas their length ranges from nano- to micro- and even to millimeter scale. Two types of carbon nanotubes exist – single-walled carbon nanotubes (SWNT) and multi-walled carbon nanotubes (MWNT). SWNTs consist of one graphene sheet and MWNTs are composed of several graphene sheets rolled up to form a cylindrical structure. The diameters of MWNTs range from several nanometers to 100 nanometers. The distinguishing properties of carbon nanotubes make them suitable candidates for many applications including electronic devices, sensors, and electrodes.

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**CHAPTER 3**

**Nanoliposomes as a Model for Teaching Nanochemistry**

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**3.1 Introduction**

Water is an essential component of life and the most abundant compound on earth. It occupies about 75% of the earth`s surface and over 60% of human body. More than two thousand years ago, Aristotle considered water as one of the main components of materials.1

Chemically, the structure of a water molecule exhibits unique features that make it a very common and effective solvent. Each molecule of water contains two hydrogen atoms bound covalently to one oxygen atom. The covalent bonds between hydrogen and oxygen atoms are formed by sharing a pair of electrons, one electron from the hydrogen atom and the other from the oxygen atom. The electronegativity difference between oxygen and hydrogen is 1.4. This indicates that the covalent bond between them is unequally shared with the electron bond. Therefore, the oxygen atom possesses a higher tendency to attract electrons in comparison to the hydrogen atom. This in turn leads to polar covalent bonds between them. Consequently, in water the hydrogen atoms end up with a partial positive charge and the oxygen atom a partial negative charge.2

As two water molecules approach one another their polar forces attract each water molecule to the other. The oxygen atom of one water molecule binds to several hydrogen atoms of the other water molecules. These bonds are called hydrogen bonds. Generally, hydrogen bonding exists in molecules with a hydrogen atom that is covalently bonded to a very electronegative atom such as oxygen, nitrogen, and fluorine. In comparison to covalent bonds, intermolecular hydrogen bonds are weaker, but they are strong enough to attract water molecules together and thereby confer onto water its unique properties. Figure 3.1 illustrates the bonding phenomenon in water. 2

[Figure 3.1 near here]

Water’s molecular polarity and intermolecular hydrogen bonds make it known as the “universal solvent.” This is due to its ability to dissolve various materials such as ionic compounds and other polar molecules by forming electrostatic interactions. Conversely, nonpolar molecules like fats and oils dissolve weakly in water.1,2

When comparing interactions of water molecules with other substances and characterizing its chemical structure, substances are categorized into two types – hydrophilic and hydrophobic materials. The linguistic roots of hydrophilic translates to “water loving”, meaning that when substances interact with water molecules that these substances are polar molecules. Hydrophobic is translated to “water fearing” and these substances do not easily interact with water molecules because of their nonpolar chemical structure. Oils and fats are said to be hydrophobic materials.Candles are made of paraffin wax which is an example of a hydrophobic material. Chemically, it consists of a mixture of different hydrocarbon chains.4

Other types of waxes consist of ester groups formed by binding fatty acid carboxylic groups and hydroxyl groups from long chain alcohols. Its long hydrocarbon chains give it its hydrophobic property. Table sugar, also known as sucrose, is highly soluble in water and it is known to be hydrophilic. The chemical formula of sucrose is C12H22O11. Each molecule consists of 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms. Sucrose is a polar molecule that consists of multiple hydroxyl groups and it interacts with water molecules by forming hydrogen bonds.4

Why is soap used for cleaning? The answer is related to its chemical structure as soap belongs to a family of materials called surfactants, surface-active agents, or amphiphilic substances. As shown in Figure 3.2, these types of materials have two different sides in their chemical structure. One side is hydrophilic and consists of ionic or polar groups. The other side is hydrophobic and consists of nonpolar groups, usually a hydrocarbon chain. The amphiphilic structure of surfactants like soaps gives them the ability to solubilize both hydrophobic and hydrophilic materials. The polar structure of water molecules prevents them from dissolving oily compounds and keeps oily dirt away from surfaces.3

[Figure 3.2 near here]

When mixed with water, surfactant molecules tend to cluster together in such a way that keeps their hydrophobic sides away from water molecules. At the same time, the hydrophilic side of surfactants are attracted towards the water molecules. Consequently, these dual hydrophobic and hydrophilic interactions of water and surfactant molecules create unique shapes called micelles.2-3

Owing to their chemical structure, water and oil do not mix. Two separate phases are produced when they come in contact with each other. There is no interaction between polar water molecules and the long hydrophobic chains of oil. However, scientists succeeded in mixing oil and water by using surfactant molecules. The unique chemical structure of surfactants enables them to disperse oil in water by creating so-called oil-in-water micelles (O/W). The is where oil molecules are surrounded by the hydrophobic sides of the surfactant molecules. Or, inversely, when dispersing water in oil and creating water-in-oil micelles (W/O) these solutions are called emulsions as illustrated in Figure 3.3.2

[Figure 3.3 near here]

When the size of micelles is at the nanoscale, emulsions are said to be a kind of colloid solution where nanoparticles of materials are dispersed stably in a dispersion medium. In this case, the water phase acts as the dispersion medium. Various studies have demonstrated the great importance of micelles at the nanoscale, especially for medical applications. For example, O/W micelles have been demonstrated to deliver hydrophobic drugs.5-8

**3.2 Teaching Module: From the Cell Membrane to Drug Delivery Based on Nanostructures**

A biological cell is the smallest, basic unit of life that is responsible for all of life`s processes. In principle, each cell contains a fluid called the cytoplasm, which is surrounded by a membrane. In the cytoplasm there also exists many biomolecules such as proteins, nucleic acids, and fats. In addition, cellular structures called cell organelles are also suspended in the cytoplasm.9

Cells are made up of multiple cellular organelles that perform specialized functions to carry out life processes. Each organelle has a specific structure. The genetic material of organisms is also present in living cells.

Each cell that can sustain life executes the following processes.9

* Metabolism – This process includes absorption of substances; assembly and decomposition of materials; and excretion of waste.
* Sensitivity and response to stimuli
* Growth and development
* Reproduction and transmission of genetic traits

The basic organelles of biological cells include:

* Cytoplasm – Cytoplasm fills the cell volume and contains enzymes that perform metabolic processes. Cytoplasm is where the first stage of cellular respiration takes place. In addition, the cytoplasm carries substances from one place to another inside the cell.
* Cell nucleus – The center place which contains and transfers cell genetic materials.
* Mitochondria – An organelle where energy is produced in the process of cellular respiration.
* Ribosomes – Organelles found in the cytoplasm where proteins are created according to DNA instructions.
* DNA – Genetic material located in the cytoplasm in prokaryotic cells (cells without a nucleus) or DNA is surrounded by a cell membrane if located in a eukaryotic cell.

**3.2.1 Cell Membrane**

All cells are surrounded by a layer called the cell membrane. It consists of a lipid bilayer and various proteins. The cell membrane separates the cytoplasm from the extracellular environment and allows only some substances to pass in and out. In this way, the membrane allows the cell to maintain different conditions inside versus outside it and it allows the cell to function as an independent unit. The cell membrane has a liquid character and it is usually asymmetrical: These properties are crucial for the full functioning of the cell. The cell membrane plays an essential role for cell existence and these roles are described further in the following points.

• It creates a cell boundary from the external environment.

• It regulates the movement of materials between the cell and its surrounding environment.

• It communicates between the cell and other cells.

• It differentiates between the cell self and a stranger cell.9-11

**3.2.1.1 Cell Membrane Chemical Structure**

The cell membrane is composed mainly of lipids into which proteins are incorporated. Most cell membrane lipids are phospholipids. Phospholipids are a type of surfactant that have a hydrophilic head and two hydrophobic fatty acid tails. An illustration of the cell membrane is shown in Figure 3.4. The phospholipids in a cell membrane are arranged in a double layer “sandwich model." One of the sandwich phospholipid heads faces inwards, towards the inner cell cytoplasm and the other phospholipid heads face outwards, towards the outer extracellular fluid environment. Both phospholipid tails face inwards towards the inner part of the membrane. This structure of the cell membrane forms a hydrophobic region between the two aqueous solutions of the cell interior and the cell exterior environment. This allows for selective passage of substances through the membrane as well as maintaining the cell shape despite its fluidity. The two-layer structure minimizes the exposure of the hydrophobic groups to water, so the membrane structure is energetically desirable. A hole created in the membrane that exposes hydrophobic groups to the surrounding water is soon sealed.12

[Figure 3.4 near here]

**3.2.1.2 Chemical Structure and Biological Function of Lipids and Phospholipids**13

Lipids are organic compounds. Each biological molecule that is soluble in oil is a lipid. Oils, fats, vitamins, and cholesterol are all lipids. In living organisms, lipids are one of the basic cell membrane components. The chemical structure of lipids is categorized into several groups. The main categories of them are described below.

* Fatty acids – They are a type of carboxylic acid than consists of up to 36 carbon atoms. They contain carboxylic groups (-COOH) and long hydrocarbon chains. Fatty acids are divided into two main groups, saturated fatty acids and unsaturated fatty acids. Saturated fatty acids have singular covalent bonds between carbon atoms and they are saturated with hydrogen atoms. Unsaturated fatty acids have at least one double bond between the carbon atoms.
* Glycerides – Glycerides are chemical structures that are composed of glycerol (an alcohol) bonded to fatty acids. Glycerol is viscous, colourless, and water-soluble liquid. When glycerol is bonded to one fatty acid it is considered a monoglyceride. When it is bonded to two fatty acids it is called a diglyceride. A triglyceride is formed when glycerol is bonded to three fatty acid molecules. The glycerol molecule is composed of a chain of three carbon atoms. Each carbon atom is bonded to a hydrogen atom (one or two) and a hydroxyl group (-OH). This is why glycerol belongs to the family of alcohols.
* Phospholipids – These are diglycerides with a hydrophilic group consisting of phosphate and a polar group. The phosphate group is a derivative of phosphoric acid and this group is negatively charged with a physiological pH of 7 as displayed in Figure 3.5.

[Figure 3.5 near here]

A phospholipid molecule is formed when two hydroxyl groups in glycerol bond to the carboxylic group of fatty acid. The third hydroxyl group of glycerol bonds to a phosphorus group. The resulting molecule is called phosphatide. The phosphorus group in phosphatide is bonded with the hydroxyl group of one of the following molecules: serine, ethanolamine, choline, inositol or glycerol (Figure 3.6).

[Figure 3.6 near here]

Phospholipids are lipids that contain phosphorus. Phospholipids contain four basic components: fatty acids, glycerol, a phosphorus group and another chemical group. In nature, the fatty acid hydrocarbon chains in phosphoglycerates usually contain an even number of carbon atoms – usually between 14 to 24. Figure 3.7 illustrates the chemical structure of phospholipid molecule.

[Figure 3.7 near here]

The most well-known type of phospholipid is phosphatidylcholine. It is a type of phospholipid composed of choline in the head group and two fatty acyl groups as the tail groups. It is the main component of biological membranes and via using a hexane extraction method it can easily be obtained from a variety of sources such as egg yolk, mustard, sunflower, and soybeans.2

Phosphatidylcholine is a precursor molecule in producing acetylcholine in the body. It is also considered a brain activity stimulator. Medical studies have shown that eating food supplements containing phosphatidylcholine significantly improves memory, concentration, and learning. In addition, it has been found that it improves disorders related to depression and stress. It was also found that the phosphatidylcholine molecule could significantly improve the quality of life of patients with senility and Alzheimer's Disease. Important advantages of using phosphatidylcholine is that it is considered safe, and it does not have reported side effects.14

Phospholipid molecules are of paramount importance in nature as they are a major component in all living organism cell membranes. In the human body they constitute the membrane that surrounds the cells and the membrane that surrounds the various organelles in the cell. The unique properties of the biological membrane are due to the phospholipid chemical composition. For example, membrane fluidity depends on the length and degree of fatty acid saturation in the phospholipid molecules. In fact, the phosphatidylcholine molecule is the most common phospholipid molecule in the membrane of our body cells.

All types of phospholipids that make up the cell membrane have a common basic structure that categorize them as amphipathic molecules (surfactants). Amphipathic molecules contain two different regions: Two fatty acid tails with a hydrophobic chain and a hydrophilic head of a phosphate group. Fatty acids are long chains composed mainly of hydrogen and carbon. Phosphate groups are composed of a phosphorus molecule with four attached oxygen molecules. These two components of the phospholipid are connected by a third molecule, glycerol (Figure 3.8).

[Figure 3.8 near here]

The bilayer structure of a cell membrane is based on the chemical nature of the different components in the human body. Blood is an aqueous solution of different ionic and polar molecules. Blood consists of phospholipids that allow the cell membrane to be organized in such a way that their hydrophilic part is oriented towards the exterior part of the cell, towards the blood system. The hydrophobic part of blood cell membranes is oriented towards the interior part of the cell.

Phospholipids are widely available in natural components. For example, phosphatidylcholine can be easily extracted from egg yolks or soybean.

**3.2.2 Liposome Structures**

The chemical structure of a phospholipid molecule consists of two different parts: The hydrophilic head group and two hydrophobic tails of long hydrocarbon chains. The dissolution mode of phospholipids in water mimics the structure of a cell membrane. It is organized in such a way that phospholipid hydrophobic tails are oriented far from water molecules, whereas, the hydrophilic head is oriented towards the water molecule. This results in the formation of bi-layer structures called liposomes. Liposomes can be defined as microscopic vesicles wherein their aqueous volume is surrounded by phospholipid molecules. The name liposome is derived from two Greek words, “lipos” meaning fat, and “soma” meaning body.15

* + - 1. **Liposomes Mimic Cell Membrane Structure**

Comparing between the cell membrane structure and the structure of liposomes reveals great similarities. Liposomes consist of an aqueous core surrounded by a lipid bilayer. Similarly, cell membranes separate a cell’s inner aqueous core from the bulk outside. Liposomes resemble the circular structures of the cell membrane.

The unique resemblance between the natural structure of cell membranes and liposomes created a breakthrough for medical uses of liposomes such as their use as drug carrier candidates.16-18 Drug delivery is a method or technological process where drug compounds are intended to act upon a target site under defined conditions. This is in order to achieve an effective therapeutic effect in humans or animals while reducing side effects. The main goal of a drug delivery system is to direct the drug to the appropriate target and thus optimize the drug's interaction with the diseased tissue.

Traditional drug delivery, such as oral drug administration or intravenous injection, is based on the drug's absorption into all body tissues so that only a small portion of the drug reaches the target organ. The drug delivery method is based on targeted and timed drug release at the target site. Liposomes are the most frequently used carrier to dispense drugs. Liposomes can be synthetically produced and consist of a double, fatty layer of phospholipids that enclose into a circle and form a spherical shape. The liposome can store the drug in the hydrophobic envelope or inside the hydrophilic inner region depending on the properties of the drug being delivered. When the liposome reaches the target site it will join onto the cell membrane and transfer its contents specifically into the cytoplasm of the target cell. In addition to their use as drug carriers, they have multiple uses in cosmetics and food manufacturers for encapsulating unstable compounds such as antimicrobials, antioxidants, and flavorings. Liposomes can carry both hydrophilic and hydrophobic compounds. They are characterized by their biocompatibility, biodegradability, low toxicity, and the ability to capture hydrophobic and hydrophilic drugs. Due to their versatile properties, there has been enhanced interest and research into liposomal structures and their use as drug carriers.19-21

**3.2.2.2 Nanoliposomes as a Drug Carrier**

The combination of nanotechnology and medicine paved the way for the beginning of a new field called nanomedicine. Nanomedicine includes a wide range of nanotechnological applications, such as drug delivery systems, sensors, fluorescent markers for imaging purposes, and more.22,23 The nano-revolution in medicine has advanced the development of nano-systems that can carry drug molecules in our body. Due to their tiny size, nano-carrying systems can localize to a specific area in the body. Nano-systems for carrying drugs consist mainly of a carrier material and an active substance. The carrier material serves as the body of the nanoparticle and the active substance targets molecules that allow the particle to find certain cells in the body. There are now a wide variety of nanoscale carrying systems that differ from each other in various respects. They differ in the materials of which they are composed, in their size, and by the amount of material they can carry.

Nanoliposomes are very attractive as drug delivery vehicles. Like the cells found in our body, nanoliposomes are nanoscale-sized, spherical structures that consist of a circular membrane of phospholipids and are filled with fluid. The liposome acts as a form of nanoscale container that can carry the drug inside it and bring it to its destination. A great example of the use of liposomes as a carrier system is the drug Doxil®, which uses a liposome carrier system to treat breast cancer. The active substance in Doxil® is doxorubicin. Doxorubicin is located inside the liposome. It is carried towards the tumor in a targeted fashion so that its distribution into the rest of the body and its side effects are significantly reduced. Figure 3.9 illustrates a drug loaded nanoliposome when it penetrates the cell membrane.24-26

[Figure 3.9 near here]

**3.3 Lab Activity: Nanoliposomes as a Drug Vehicle**

The lab activity presented here aims to expose students to one of the main medical applications of nanostructured materials. It is intended to be taught to secondary school students and undergraduates. The activity consists of presenting several consecutive steps, starting from introducing the cell membrane chemical structure to using nanoliposomes as a drug vehicle.2,27

Science teaching curriculums for secondary students around the world includes subjects on cell structure and its function. Students learn extensively about the cell and its different organelles, including the cell membrane. The main purpose of this study is to optimize the study material so that students learn and understand much more complex organic processes and systems. Various studies over the years indicate that many teaching hours with diverse teaching strategies are devoted to the subject of the cell. However, students continue to have difficulty answering questions in biology and they also fail biology tests that deal with these topics.28

The accepted model for the structure of cell membrane is the bi-layer model of lipids and proteins.29 According to this model, the membrane separates the extracellular environment from the intracellular one. The aim of the presented lab activity is to have students fabricate artificial cell membranes (nanoliposomes) that can mimic the structure of cellular membranes using natural phosphatidylcholine. During the lab activity the students complete the following tasks.

* They produce liposomal structures using the surfactant phosphatidylcholine. Phosphatidylcholine is a natural type of phospholipid which can be extracted from egg yolks or soybean oil.
* They will investigate the ideas of hydrophilicity and hydrophobicity by exploring the dissolution mode of hydrophilic and hydrophobic food colors in liposomal structures.
* They will form a demonstrative model of drug loaded liposomal structures.
* They will reduce the liposome size from microscale to nanoscale.

**3.3.1 From Cell Membrane Structure to Drug Nano-Vehicles**

**3.3.1.1 Experiment One: The Amphiphilic Structure of Phosphatidylcholine**

Phosphatidylcholine is a surfactant which has both hydrophilic and hydrophobic regions in its molecular structure. It dissolves and forms liposomal structures in water. It achieves this by arranging its polar regions towards the water molecules and its non-polar tails towards the interior, away from the aqueous phase (Figure 3.10).2

[Figure 3.10 near here]

In this experiment, students explore the dissolution mode of phosphatidylcholine in three environments: pure water, oil in water emulsion, and water in oil emulsion.2 This experiment could be suitable for secondary school students and undergraduates, accordingly, and two experimental descriptions for each age group are described below.

Materials Needed:

* Phosphatidylcholine
* Double distilled water
* Vegetable oil
* Iso-Propanol

Experimental Instructions for Undergraduate Students2

1. In a 50 ml round bottom flask and while continually stirring, add 0.5 g of phosphatidylcholine into 25 ml of iso-propanol.
2. Stir for about two minutes in order to dissolve the phosphatidylcholine.
3. Evaporate the solution under vacuum at 500 C in order to remove the solvent and to allow the lipids to form a film onto the surface of the flask.
4. Finally, dissolve the lipid film into 100 ml of double-distilled water via stirring with a magnetic stir bar for one hour.

Experimental Instructions for Secondary School Students

1. insert a small amount of phosphatidylcholine into a plastic tube.
2. Add double-distilled water into the tube.
3. Shake the tube vigorously using a test tube vortex shaker.

In these experimental set-ups, students can witness the organizational mode of phospholipid molecules in water and they can view the liposome structures under an optical microscope. Figure 3.11shows how students will be able to differentiate between the inner hydrophilic region of liposomes and the hydrophobic ring that separates the interior and exterior hydrophilic regions. When dissolving phosphatidylcholine in water, it organizes itself in such a way as to keep its hydrophobic chains away from the water phase. According to Riam et al. microscale liposome structures are formed.2,27 In addition, students can compare between a cell membrane and liposomal structures and discover that liposomes are considered a circular structure of a cell membrane.

[Figure 3.11 near here]

Water and oil do not dissolve into each other because of their different chemical structures. Van der Waals interactions are a type of intermolecular interactions between oil molecules while water molecules interact with each other via hydrogen bonding. Therefore, oil and water are insoluble within each other and are called immiscible liquids. Consequently, when trying to mix them together, two separate phases are formed. The addition of phosphatidylcholine causes the two phases of oil and water to be mixed into one phase, called an emulsion. When using an optical microscope, the students can view the spherical structures called micelles. They can further explore the role of phosphatidylcholine upon mixing two immiscible liquids.

When attempting to dissolve oil into water, the emulsion produced is called an O/W emulsion. Upon adding phosphatidylcholine into an O/W emulsion, it self-organizes in such a way that the phosphatidylcholine hydrophobic chains become tightly packed to avoid the water molecules. Oil molecules can then be entrapped inside the hydrophobic region of the micelles. In contrast, when trying to dissolve water into oil, the phosphatidylcholine organizes in a reverse fashion. Its hydrophobic chains orient towards the oil molecules and its hydrophilic heads trap the water molecules to keep them away from the oil molecules.

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**3.3.1.2 Experiment Two: Preparation of an O/W Emulsion using Phosphatidylcholine**

1. In a chemical beaker add 1.5 g vegetable oil, 0.3 g phosphatidylcholine, and 30 ml double-distilled water.
2. Mix the solution using a magnetic stirrer for one hour.

**3.3.1.3 Experiment Three: Preparation of a W/O Emulsion using Phosphatidylcholine**

1. In a chemical beaker, add 1.5 ml double-distilled water, 0.3 g phosphatidylcholine, and 30 ml vegetable oil.
2. Mix the solution using magnetic stirrer for one hour (Figure 3.12).

[Figure 3.12 near here]

* + - * 1. **Identification of Hydrophilic and Hydrophobic Regions**

According to a study by Riam et al., the authors propose a lab activity which enables students to differentiate between the hydrophobic and hydrophilic regions of micro-scale micelles and liposomal structures that are formed.2 The lab experiment is based on simply using hydrophilic and hydrophobic food dyes during the preparation of both micelles and liposomes. For this purpose, it is recommended that students be asked to prepare six solutions with the following compositions as displayed in Table 3.1.

[Table 3.1 near here]

In solution number one, the students explore the dissolution mode of phosphatidylcholine in an aqueous solution of hydrophilic food dye. As described in the previous section XX, liposomal structures are produced in this case. In solution number two, students produce liposomal structures in water with the addition of hydrophobic food dye. In the rest of the solutions (solutions number three through six), the students prepare emulsions with different compositions. In the third and fourth solutions they prepare oil-in-water liposomes with hydrophilic and hydrophobic food dyes, respectively. In the fifth and sixth solutions, water-in-oil emulsions are created with hydrophilic and hydrophobic food dyes, respectively.

The following materials are needed for the proposed lab experiments described below.

* Phosphatidylcholine
* Double distilled water
* Vegetable oil
* Iso-propanol
* Hydrophilic red food dye
* Hydrophobic red food dye

**3.3.1.4.1 Dissolving Phosphatidylcholine in an Aqueous Solution of Hydrophilic Food Dye (Solution 1 in Table 3.1)**

Experimental Instructions for Undergraduate Students

1. Pour 25 ml of iso-propanol into a 50 ml round bottom flask.
2. Weigh 0.3 g of phosphatidylcholine.
3. Add phosphatidylcholine into the 25 ml of iso-propanol.
4. Stir for about two minutes in order to dissolve the phosphatidylcholine.
5. Evaporate the solution under vacuum at 500 C in order to remove the solvent and to allow the lipids to form a film onto the surface of the flask.
6. In a different flask, prepare an aqueous solution by dissolving 10 mg of hydrophilic food dye into 100 ml double-distilled water.
7. Dissolve the lipid film into the aqueous solution of hydrophilic food dye via stirring with a magnetic stir bar for one hour.

Experimental Instructions for Secondary School Students:\

1. Insert 0.3 g of phosphatidylcholine into a plastic tube.
2. Add 10 mg of hydrophilic food dye.
3. Add 100 ml double-distilled water into the tube.
4. Shake the tube vigorously using a test tube vortex shaker.

**3.3.1.4.2 Dissolving Phosphatidylcholine in Double-Distilled Water with Hydrophobic Food Dye (Solution 2 in Table 3.1)**

Experimental Instructions for Undergraduate Students

1. Pour 25 ml of iso-propanol into a 50 ml round bottom flask.
2. Weigh 0.3 g of phosphatidylcholine.
3. Add phosphatidylcholine into the 25 ml of iso-propanol.
4. Stir for about two minutes in order to dissolve the phosphatidylcholine.
5. Evaporate the solution under vacuum at 50º C in order to remove the solvent and to allow the lipids to form a film onto the surface of the flask.
6. In a different flask, prepare an aqueous solution by dissolving 10 mg of hydrophobic food dye into 100 ml double-distilled water.
7. Dissolve the lipid film into the aqueous solution of hydrophobic food dye via stirring with a magnetic stir bar for one hour.

Experimental Instructions for Secondary School Students:

1. Insert 0.3 g of phosphatidylcholine into a plastic tube.
2. Add 10 mg of hydrophobic food dye.
3. Add 100 ml double-distilled water into the tube.
4. Shake the tube vigorously using a test tube vortex shaker.

**3.3.1.4.3 Solution 3: O/W Emulsion in the Presence of Hydrophilic Food Dye**

1. In a chemical beaker add 5 ml vegetable oil, 95 ml double-distilled water, 0.3 g phosphatidylcholine, and 10 mg hydrophilic food dye.
2. Mix the solution using a magnetic stirrer for one hour.

**3.3.1.4.4 Solution 4: O/W Emulsion in the Presence of Hydrophobic Food Dye**

1. In a chemical beaker add 5 ml vegetable oil, 95 ml double-distilled water, 0.3 g phosphatidylcholine, and 10 mg hydrophobic food dye.
2. Mix the solution using a magnetic stirrer for one hour.

**3.3.1.4.5 Solution 5: W/O Emulsion in the Presence of Hydrophilic Food Dye**

1. In a chemical beaker add 95 ml vegetable oil, 5 ml double-distilled water, 0.3 g phosphatidylcholine, and 10 mg hydrophilic food dye.
2. Mix the solution using a magnetic stirrer for one hour.

**3.3.1.4.6 Solution 6: W/O Emulsion in the Presence of Hydrophobic Food Dye**

1. In a chemical beaker add 95 ml vegetable oil, 5 ml double-distilled water, 0.3 g phosphatidylcholine, and 10 mg hydrophobic food dye.
2. Mix the solution using a magnetic stirrer for one hour.

According to Riam et al.,despite their different compositions,the six solutions described above look like the same red-colored solutions.2 The students discover the differences in their composition by viewing them under an optical microscope. Figure 3.13 presents example images which can be obtained from these solutions. Image one presents liposomal structures obtained from solution number 1. In this image the students can visualize that the interior hydrophilic region of the liposomes is red-colored which is the characteristic color of the applied, red hydrophilic food dye. In addition, the liposome structures are dispersed in the red-stained aqueous solution.

When liposomes are prepared with the addition of a hydrophobic food color, no dye is detected either in the interior region of the liposomes nor in the aqueous solution. The food color is trapped in the hydrophobic ring of the liposomes, as shown in image two. Different micelles are formed in this situation, and the colored, spherical micelles that are dispersed in the non-colored solution can be detected. They can be detected with oil-in-water micelles prepared with hydrophobic dye and water-in-oil micelles prepared with hydrophilic dye. In contrast, non-colored spherical micelles dispersed in colored solutions can be detected when preparing an oil-in-water solution with a hydrophilic food color and water-in-oil solution with a hydrophobic food color.

[Figure 3.13 near here]

**3.3.1.5 Preparation of Microscale Drug Loaded Liposome Structures**

Based on the results of step two of the lab activity, students can potentially conclude that any material could penetrate different regions inside the liposomal structures. However, it depends on its chemical structure and whether it is hydrophobic or hydrophilic. These features of liposomes make them useful candidates for delivering different kinds of drugs. In addition, liposomal structural similarities to the chemical structure of cell membranes enables them to easily penetrate the cells in order to inject a drug.

During this experiment, students can choose tablets from drug types such as Optalgin®, Augmentin, or vitamin C. They must then grind them and dissolve them into double-distilled water. In order to identify the drug inside the liposomal structures, the aqueous solution is dyed with hydrophilic food dye. Liposomes are then prepared by dissolving phosphatidylcholine into the dyed, aqueous drug solution. Exact steps of this experiment are described below.

Experimental Instructions for Undergraduate Students

1. Grind one Optalgin® tablet using a griding mill.
2. Prepare a saturated solution by dissolving the ground Optalgin® into 10 ml double-distilled water.
3. Add 10 mg red hydrophilic dye to the saturated solution in order to color the solution.
4. Weigh 0.3 g of phosphatidylcholine.
5. Add phosphatidylcholine into the 25 ml of iso-propanol.
6. Stir for about two minutes in order to dissolve the phosphatidylcholine.
7. Evaporate the solution under vacuum at 50º C in order to remove the solvent and to allow the lipids to form a film onto the surface of the flask.
8. In a different flask, prepare an aqueous solution by dissolving 10 ml of the Optalgin® solution into 90 ml double-distilled water.
9. Dissolve the lipid film into the aqueous solution of Optalgin® solution prepared in step 8.

Experimental Instructions for Secondary School Students

1. Grind one Optalgin® tablet using a griding mill.
2. Prepare a saturated solution by dissolving the ground Optalgin® into 10 ml double-distilled water.
3. Add 10 mg red hydrophilic dye to the saturated solution in order to color the solution.
4. Inside a plastic tube, mix 0.3 g of phosphatidylcholine into 90 ml of double-distilled water.
5. Add the Optalgin® solution into the plastic tube.
6. Shake vigorously using a test tube vortex shaker.

In the experiments above, by using an optical microscope, students can visually explore the position of the drug inside the liposomes. Figure 3.14presents possible images that could be obtained from these experiments. During the preparation of liposomes inside an aqueous drug solution, some of the dyed drug penetrates the inner hydrophilic region of the liposomal structures. The rest of the drug remains dispersed in the aqueous solution medium.

[Figure 3.14 near here]

**3.3.1.6 Drug Loaded Liposome Structures: From Microscale to Nanoscale**

The final activity of the suggested lab experiments is designed for students to convert drug loaded liposomes from microscale to nanoscale by using an Avanti® Mini-Extruder apparatus. The Avanti® Mini-Extruder is a simple device that reduces the size of liposomal structures to nanoscale dimensions in a simple and effective way.2 The activity is based on passing the liposomal solution through a nanoscale sized, porous membrane made of polycarbonates. There are different types of membranes which differ in the size of their pores. Some range from 50 nm to 1000 nm in pore size. Figure 3.15 presents a depiction of the Avanti® Mini-Extruder.

[Figure 3.15 near here]

**3.3.1.6.1 How to Compare Between Microscale and Nanoscale Sized Liposomes**

The Tyndall effect is considered an easy, simple, and visual method for the detection of nanoscale structures in solution. The Tyndall effect is also known as “Tyndal scattering.” It is a phenomenon of light scattering by particles in a colloidal solution or suspension.Typically, this effect is used to differentiate between a true solution, colloidal solution (a solution of nanoscale particles), and a suspension (a solution of microscale particles).

Accordingly, there are two main effects that may occur when shining a beam of light through a solution. The first effect shows the beam passing through the solution in straight lines, without scattering. The second option displays how the light scatters randomly into different directions due to its collision with solute particles. Both types of effects depend on the size of the solute particles. In a true solution the solute particle sizes are generally bellow 1 nm. In this case the light passes through the solution without any interference because of the small size of solute particles and therefore no scattering occurs. However, when passing a beam of light through microscale or nanoscale sized particles, the light collides with the solute particles and scattering occurs. Visually, a beam of light is detected through the solution.

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**Chapter 4-Hugerat**

**Teachers’ and Students’ Awareness of and Attitudes toward**

**Nanoscience and Nanotechnology**

* 1. **Introduction**

Nanoscience is an interdisciplinary field that deals with materials, structures, and devices at the nanoscale. The origin of the word ‘nano’ in Greek and means ‘dwarf.’ Mathematically, one nanometer is equal to 10-9 m. At this scale, the properties of materials change dramatically from the larger, macroscale-sized materials of the same type. Most of the measurement prefixes used today are derived from Greek and Latin words used in measurements.

The prefix ‘nano’ refers to a scale of size in the metric system. ‘Nano’ is used in scientific units to denote one-billionth (0.000000001) of the base unit. For example, it takes one billion nanoseconds to make a second. In practical, everyday use, the term ‘nanosecond’ is not very useful for describing time accurately. Imagine discussing time in these terms where we would say things like: “Dinner will be ready in 300,000,000,000 nanoseconds.” Instead, the term ‘nanosecond’ is mainly used to refer to a very short time period. A nanosecond is to a second as one second is to approximately 30 years.[[1]](#endnote-2) Nanotechnology literally refers to any technology on a nanoscale that has applications in real life.[[2]](#endnote-3)

Nanotechnology involves putting to use the unique physical properties of atoms, molecules, and structures measuring roughly 1-1000 nm which have applications in real life.2 The advancement of nanoscience and nanotechnology has led to a technological revolution. These advances have had a significant qualitative impact on science and technology.[[3]](#endnote-4) Nanotechnology is a rapidly evolving science involving understanding and controlling matter. It has had profound implications on many different fields due to its interdisciplinary nature and by offering new opportunities to the nano dimension. It brings about new perspectives regarding the chemical, environmental, biomedical, electronics, automotive, and aerospace industries at the nano-scale. Nanotechnology is characterized by unique surface, catalytic, and magnetic properties that were once considered impossible.[[4]](#endnote-5)

The growth in innovative applications for nanomaterials has been accompanied by concerns about their potential health and environmental impacts due to their unique and somewhat unpredictable properties. The importance of nanoscience and nanotechnology as well as their positive effects on technological and medical developments has required us to increase our awareness and knowledge about it in order to keep up to date with the scientific advancements in these fields. We believe that schools are the first starting point. This necessitates creating future generations with sufficient scientific literacy and knowledge of leading scientific developments in this field. In 1852, John Dewey stated: “If we teach today’s students as we taught yesterday’s, we rob our children of tomorrow.” However, it is well known that often teachers teach as they were taught. As Putnam and Borko explained: “How a person learns a particular set of knowledge and skills, and the situation in which a person learns, become a fundamental part of what is learned.”[[5]](#endnote-6) To achieve this goal, a first step should examine the levels of awareness, knowledge, and attitudes toward nanoscience and nanotechnology among teachers and students. In this chapter we focused on the teaching nano-scientific concepts to the Arab sector in Israel, which represents about 20% of the Israeli population.

Teacher perception and knowledge about nanotechnology can influence their pedagogical approach to science education. Teaching styles are considered as one of the key emerging interdisciplinary fields of the 21st century. According to Abd-El-Khalick, teacher perceptions, beliefs, attitudes and knowledge base concerning emerging technologies can influence their approach to science teaching and even their teaching behaviors.[[6]](#endnote-7) Therefore, teachers as well as candidate teachers should be informed about the different aspects of nanotechnology through in-service training, seminars, model activities, and projects.[[7]](#endnote-8)

Nanotechnology education is being offered by universities around the world for bachelor’s, master’s, and doctoral studies. Generally, nanotechnology education involves a multidisciplinary natural science education with courses in nanotechnology, physics, chemistry, math and molecular biology.[[8]](#endnote-9) In addition, nanotechnology requires some basic understanding of higher educational subjects such as philosophy, values, and learning. Nanotechnology is a growing aspect of virtually every industry. It is strongly integrated within the global economy and it has a profound influence on the lives of people in the 21st century.8

### **Nanotechnology Awareness**

Several surveys have shown that the majority of the public have little to no awareness or knowledge of nanotechnology. One study conducted by Waldron, Spencer, and Batt among 1,500 participants, aged between six and 74 years-old, revealed that 60% of them had not heard of nanotechnology at all.[[9]](#endnote-10) They reported that the general public, particularly secondary school students, had very limited knowledge of nanotechnology. A study carried out by Macoubrie in 2006 was designed to gauge attitudes and opinions of American citizens regarding the development of nanotechnology.[[10]](#endnote-11) This study revealed that 95% of the participants had not heard of nanotechnology before being informed about it within the context of formal education. A survey carried out by the Australian Office of Nanotechnology showed that the general public had very high expectations for nanotechnology, their concerns were ranked as only moderately, whereas their knowledge and awareness are rather low.[[11]](#endnote-12)

Several studies reveal that the majority of the public have a low awareness or knowledge about nanotechnology. General public surveys about nanotechnology awareness have been carried out in a number of countries, *e.g*., Japan, USA, UK, Germany, Iran, Italy, and Australia. Although the surveys were carried out in different years, ranging from 2004 to 2011, all these countries have high literacy rates. Kahan in 2015 showed in a survey involving 1,850 Americans that 81% of the participants had no idea about nanotechnology.[[12]](#endnote-13) Similarly, a recent study conducted in Iran demonstrated that the majority of the Iranian population are not familiar with the concept of nanotechnology. However, those that were aware of it felt that its benefits outweighed the risks.[[13]](#endnote-14) A study performed by Ho and others suggested that the more people that know about nanotechnology, the more likely they will hold positive attitudes toward it.[[14]](#endnote-15) They found that the public perceived nanotechnology as having greater risks and fewer benefits compared to experts.

In addition, Scheufele and Lewenstein found that the participants in their study were largely unaware of emerging technologies such as nanotechnology.[[15]](#endnote-16) Furthermore, there was little evidence of knowledge increasing over time. Four in ten Americans say that they had heard nothing at all about nanotechnology, and six in ten admited to hearing nothing at all about nanotechnology used for human enhancement.

Waldron and others also found that most people have a limited understanding of nanotechnology.9 Only 60% of their research participants between the ages of 15 to 59 were familiar with the term ‘nano’ and they associated it with something small. Children under the age of 14 and adults 60 and over were the least familiar with nanotechnology. The study found that when asked to state the smallest thing they could think of, 52% of 11-year-olds stated microscopic and nanoscopic objects. More elaborate responses were obtained from participants between the ages of 14 and 17 years-old. In this group, over 40% chose answers that suggested some knowledge of the nanoscale world, including references such as ‘an atom,' ‘a proton’, or ‘a molecule.' The greatest level of awareness of nanoscopic objects was evident in young adults of 18-22 years of age. Interestingly, adults did not provide more elaborate responses than children about nanotechnology.

A 2014 study was conducted by Elmarzugi and others about the “Awareness of Libyan Students and Academic Staff Members of Nanotechnology.”[[16]](#endnote-17) The study was based on a random survey involving many campuses of Tripoli University (Alfateh), and two governmental research centers (polymer and plastic) in Tripoli over a period of about five months. They found that of the 330 participants, 156 knew about nanotechnology but 174 had no knowledge about it.16 A study conducted by Toqeer and others in Pakistan revealed that the majority of the respondents (77%) had heard about nanotechnology but only 47% had read about it.[[17]](#endnote-18) A slightly lower percentage (44.4%) had an awareness of its applications. Elki and Sahin investigated Turkish middle school student awareness, factual knowledge, opinions, and risk perceptions toward nanotechnology.4 Their results showed no significant difference between male and females. However, for some of the demographic and affective domain factors, as well as the student’s achievement in science courses, significant differences were found.

Nanoscience and nanotechnology are often presented as a new scientific revolution or a new frontier to overcome which could generate tremendous economical gains.[[18]](#endnote-19) These subjects also raise debates in society related to health and environmental issues, ethical concerns associated with modification of human beings and transhumanism, social and political issues linked to individual data security, as well as discussions about science and technology developments in democratic regimes.[[19]](#endnote-20) In this context of controversial science and technology developments, education is presented as the major mode of regulating science-society relationships.

A recent review of the literature on nanoscience education has shown four emerging domains of interest for curriculum development and science education research and they are described below.[[20]](#endnote-21)

1. Curriculum content, including approaches and purposes for nanoscience education at all levels of schooling
2. Student representations of size and scale, with particular emphasis on nanoscale
3. Specific instrumentation for nanoscience and nanotechnology teaching
4. Science instructor training approaches in nanoscience and nanotechnology – Instructor perceptions and knowledge about nanotechnology can influence their approach to science technology education and their teaching behavior.

Nanotechnology is considered as one of the key emerging interdisciplinary fields of the 21st century. Teacher perceptions, beliefs, attitudes and understandings concerning the emerging technologies can influence their approach to science teaching and even their teaching behaviors.6 In the emerging fields of technology such as nanotechnology, it is necessary to determine a teacher’s basic knowledge and opinions about these fields so that they can impart the basic required knowledge to their students.7

In today’s world, it is widely recognized that the real power does not come from the physical power but instead from intellectual power. To keep pace with the nanotechnology era we should first educate future teachers in this field. People should be knowledgeable about every aspect of nanotechnology, *e.g.,* the applications, potential risks, the benefits stemming from its applications, and its importance. While people can gain important information about some aspects of nanotechnology, this may lead to adverse effects regarding their opinions and attitudes because of insufficient knowledge about this subject. Therefore, teachers as well as candidate teachers should be informed about the different aspects of nanotechnology through in-service training, seminars, model activities, and projects. 7

Nowadays, nanotechnology is a part of every aspect of scientific life and applications of this technology are increasingly integrated into the economy, industry, trade, and medicine. Moreover, according to specialists in this field, the world will require a skilled workforce of more than two million nanotechnologists by 2015. Therefore, this kind of technology has been integrated into schools, institutes, and universities all over the world.[[21]](#endnote-22)

* 1. **The Origins of Nanotechnology**

Nanotechnology, like any other successful technology, has many founders. In fact, the field of chemistry has been associated with nanotechnology since its inception, as have the fields of materials science, condensed physics, and solid state physics. The nanoscale is not so new. However, investigating and designing things with an emphasis on the nanoscale are new and revolutionary. The term ‘nanotechnology’ can be traced back to 1974. Norio Taniguchi first used the term in a paper entitled: “On the Basic Concept of Nano-Technology.”[[22]](#endnote-23) Taniguchi described nanotechnology as the technology that engineers materials at the nanometer level. However, nanotechnology’s history predates this. Traditionally, the origins of nanotechnology can be traced back to a speech given by Richard Feynman at the California Institute of Technology in December 1959 called “There’s Plenty of Room at the Bottom.”[[23]](#endnote-24) In this talk, Feynman spoke about the principles of miniaturization and atomic-level precision and how these concepts do not violate any known law of physics. He proposed that it was possible to build a surgical nanoscale robot by developing quarter-scale manipulator hands that would build quarter-scale machine tool analogous like those found in machine shops. This could continue until the nanoscale is reached, around eight iterations later. As we see, this is not exactly the path that nanotechnology research has actually followed.

Technological development requires trained personnel. Having skilled and dedicated workers is crucial to technological advancement.[[24]](#endnote-25) To develop a capable workforce, a nation needs long-term planning to encourage interest and knowledge in advanced technology in its youngsters. Nanotechnology, an emerging field that will impact many areas of science and technology, was a catalyst for transformation.[[25]](#endnote-26)

The importance of nanotechnology (NT) has been recognized worldwide. Between 2001 and 2004, more than sixty countries established nanotechnology programs at a national level. Regardless of whether nanotechnology is incorporated into the developmental goals of a nation, the products of nanotechnology will be flooding the markets internationally. The attitude of the public toward nanotechnological products will depend on their awareness of this technology and their perceptions of how these technologies will affect their lives.[[26]](#endnote-27)

The public’s level of awareness with regard to a relatively new technology like nanotechnology will depend critically, among other factors, on: (i) the literacy rate of the population; (ii) the awareness created among different segments of the society by the scientific community through different channels of communication; and (iii) the general attitude of the public toward technical innovations. It is therefore important that periodic surveys be carried out to gauge the reaction of the public toward technology in general, and new technologies, in particular. This helps to frame rules and regulations for these technologies and to also develop policies regarding education, science, and technology.17

Nanoscience and nanotechnology are often presented as new scientific revolutions or new frontiers to overcome that could generate tremendous economical gains.18 They also raise debates in society regarding: health and environmental issues; ethical concerns associated with modification of human beings and transhumanism; social and political issues linked to individual data security as well as discussions about science and technology developments in democratic regimes.19 In such a context of controversial science and technology developments, education is presented as the major mode of regulating science-society relationships.

### **Attitudes about Nanotechnology**

Nanotechnology and nanoscience are interdisciplinary and can be taught in many relevant fields including physics, chemistry, biology, engineering, material sciences, medicine, and pharmacy. The inclusion of the main aspects of nanotechnology in a curriculum may address, for example, the physical world of material size, force, properties, and time. Furthermore, it also could address the dimensional aspects of the nanostructure, one-dimensional space such as thin film, two-dimensional space such as nanotubes, or three-dimensional space such as quantum dots.[[27]](#endnote-28)

Regarding the attitudes of students and their teachers on this technology, the influence of mass media was noted. Ho and his team relayed findings that were consistent from previous studies in that the mass media shapes public perceptions of nanotechnology.14 Scholars in the field of communication have argued that the most positive framing of nanotechology in the mass media is likely to act as cues in influencing the public’s consideration of its risks and benefits. In addition, teacher attitudes toward nanotechnology influenced whether nanotechnology was successfully introduced to K-12 students. Teachers which relayed more positive attitudes toward nanotechnology expressed a higher motivation to incorporate nanotechnology into their K-12 science programs. Therefore, enhancing positive attitudes in K-12 teachers toward nanotechnology would be a crucial issue for promoting K-12 nanotechnology education.14

### **The Need for Nanoscientists and Nanotechnologists**

A key challenge for nanotechnology development lies in the education and training of a new generation of skilled workers who are familiar with the multidisciplinary perspectives necessary for rapid progress with this new technology.18 The concepts at the nanoscale (atomic, molecular, and supramolecular levels) should penetrate the education system in the next decade in a similar manner as microscopic approaches made inroads in the educational curriculum in the last 50 years. Furthermore, interdisciplinary connections that reflect a unity in nature should be promoted. Such education and training must be introduced at all levels, from kindergarten to continuing education, and from scientists to nontechnical audiences that may later decide the use of technology and its funding. Opportunities should be created for most school-aged students (about 50 million in the U.S. alone in 2002). It is estimated that about two million nanotechnology workers will be needed worldwide by 2015.[[28]](#endnote-29)

One way to ensure a continuation of new students in the field is to promote interaction between the school system and the public at large. Several U.S. universities reported an increased number of highly qualified students moving into the physical and engineering sciences in the last two years because of public recognition of nanotechnology and research that was supported. University outreach activities should also stimulate nanotechnology innovation in industry and international interactions.

The interest in each nanotechnological research topic can be estimated based on the trends in using typical nanotechnology instrumentation.26 Such estimates show that advanced materials constitute about 30% of all research topics, semiconductors and electronics about 25%, nanobiotechnology (including pharmaceuticals, biology, and medicine) about 20%, with the remaining 25% divided among tools, optics, electrochemistry, aeronautics, and energy. Patent trends and new venture funding for 2002–2003 showed an increase in the proportion of nanobiotechnology R&D activities to about 30%. Of the 6,400 nanotechnology patents identified in 2002 at the U.S. Patent and Trademark Office, the leading numbers were for molecular biology and microbiology (roughly 1,200 patents) and for drug, bio-affecting, and body-treating compositions (about 800 patents). Together these nanotechnological subjects represented about 31% of the total patents given in that respective year.18

### **Studies about Nanotechnology Around the World**

In a 2013 study conducted by Balakrishnan, Er, and Visvanathan on “Socio-ethical Education in Nanotechnology Engineering Programs: A Case Study in Malaysia”, the responses to their student survey indicated that the attainment of the objectives of ethical instruction among students was low.[[29]](#endnote-30) The found insufficient awareness among the students about their roles and responsibilities as engineers who can make ethical decisions. The findings of this study also showed that student attitudes toward socio-ethical issues related to nanotechnology were low due to less emphases being placed by faculty on these issues in an undergraduate engineering program. It was noted from student responses that the nanotechnology engineering program’s emphasis was less on sustainable development issues. These issues focussed on where faculty members need to incorporate modules that focus on sustainability in technical subjects related to nanotechnology. From the findings of this investigation, it can be concluded that sociotechnical education has a strong influence on student knowledge, skills, and attitudes regarding socio-ethical issues related to nanotechnology. However, the students in this study were found to be unaware of the engineer’s role and responsibilities in society as a whole. This is due to socio-ethical education that is ineffective in building student knowledge, skills, and attitudes regarding socio-ethics.

Some strategies and methods for teaching socio-ethical education have been proposed in order to produce competent and holistic engineers who are capable of handling both technical and societal issues effectively. It is worthwhile for every university to examine how socio-ethical education in their current nanotechnology engineering education set-up is implemented as well as to assess student attitudes toward socio-ethical issues. Failure to focus on these aspects can delay or even prevent the benefits of nanotechnology from being reaped. This could affect the national economy, societal well-being, and environmental sustainability.

A study conducted by Elmarzugi and co-workers about the “Awareness of Libyan Students and Academic Staff Members of Nanotechnology” applied a methodology involving the distribution of a survey that was collected randomly.16 Results were collected from many campuses of Tripoli University (Alfateh), and two governmental research centers (polymer and plastic) in Tripoli over a period of about five months (March – July). The questionnaire aimed to measure public awareness about this branch of science and technology. The study sample consisted of 330 participants selected at random. Of these, 145 were employed, and the rest were students. From this study sample, 156 (47.27%) knew about nanotechnology and 174 (52.72%) did not. The first part of the questionnaire included general questions that specifed the characteristics of the study sample population such as educational degree, occupation, place of work or study, and experience.

The results from the community regarding the “Awareness of Libyan Students and Academic Staff Members of Nanotechnology” study attracted little attention. However, many displayed a favorable attitude toward nanotechnology and in the near future they dream of incorporating it into the Libyan undergraduate and postgraduate curriculum and education. Research centers, higher education authorities and university bodies should foster collaboration among themselves and work in the short term to plan strategies to create nanotechnology courses.

A study conducted by Toqeer and others in 2015 entitled: “Awareness and Attitude about Nanotechnology in Pakistan" conducted a survey to examine the level of awareness and the attitudes toward nanotechnology among the students and teachers of some higher educational institutions in Islamabad, Pakistan.17 The majority of the respondents (77%) had heard about nanotechnology but only 47% had read about it and a slightly lower percentage (44.4%) had an awareness of its applications. Considering the fact that nanotechnology has not been introduced either as a subject or as a part of the course contents of higher educational institutions that were surveyed, this number represents the percentage of students and teachers who had accessed information about nanotechnology through individual efforts. The level of awareness about nanotechnology increased significantly (p = 0.00) with the number of years of schooling. There was a gradual increase in the percentage of respondents who had read about nanotechnology from 28.8% for 12 years of schooling to 84% for 16+ years of schooling. They concluded from their survey that a higher level of awareness about nanotechnology and its applications (p = 0.00) and a higher level of education (p = 0.01) had a positive impact on the attitude of the participants toward NT. The results of this survey could help to define a framework for developing nanotechnology in the country.

An additional study conducted by Ekli and Sahin investigated awareness, factual knowledge, opinions, and risk perceptions of students from Turkish middle schools concerning nanotechnology in a very general sense.4 It was carried out on 1,396 middle school sixth, seventh, and eighth-grade students. Student perceptions and opinions about nanotechnology were elicited through a questionnaire developed by the authors. It was found that students had some awareness of nanotechnology, and that most of them had positive feelings and opinions about it. Student perceptions of nanotechnology and the influence of their demographic and affective domain factors, achievement in science courses, and science motivation regarding these perceptions were also investigated. The results showed that for gender no significant difference was observed. However, significant differences were found for some of the demographic and affective domain factors along with achievement in science courses.

* 1. **Attitudes about Nanotechnology - The Israeli Case**

A 2019 study by Abu-Much and her team investigated awareness and attitudes toward nanotechnology among teachers and students from the Arab sector in Israel.[[30]](#endnote-31) The research was based on distributing a questionnaire and a semi-structured interview. The results revealed that both teachers and students had a basic knowledge of nanotechnology. Moreover, different variables including gender, grade, years of experience, and the level of education revealed no effects. This was an interesting result because nanotechnology was not introduced as a subject in the school curriculum.

Abu-Much et al.’s study examined the awareness and attitudes of teachers and students from the Arab communities in Israel toward nanotechnology. Teacher and student knowledge and attitudes were examined as a function of different factors including gender, grade, level of education, and the number of years of experience. The participants of this research were randomly selected teachers and students from the Arab sector in Israel. The participants were asked to complete a questionnaire regarding their knowledge and attitudes toward nanotechnology. The study was adapted from the Norwegian Relevance of Science Education Project (ROSE) questionnaire except that the concepts of science and technology were replaced by nanotechnology and nanoscience.[[31]](#endnote-32) The participants were asked to answer 14 questions concerning different aspects related to nanotechnology. In this research, students and teachers were asked to write what they know about nanotechnology.

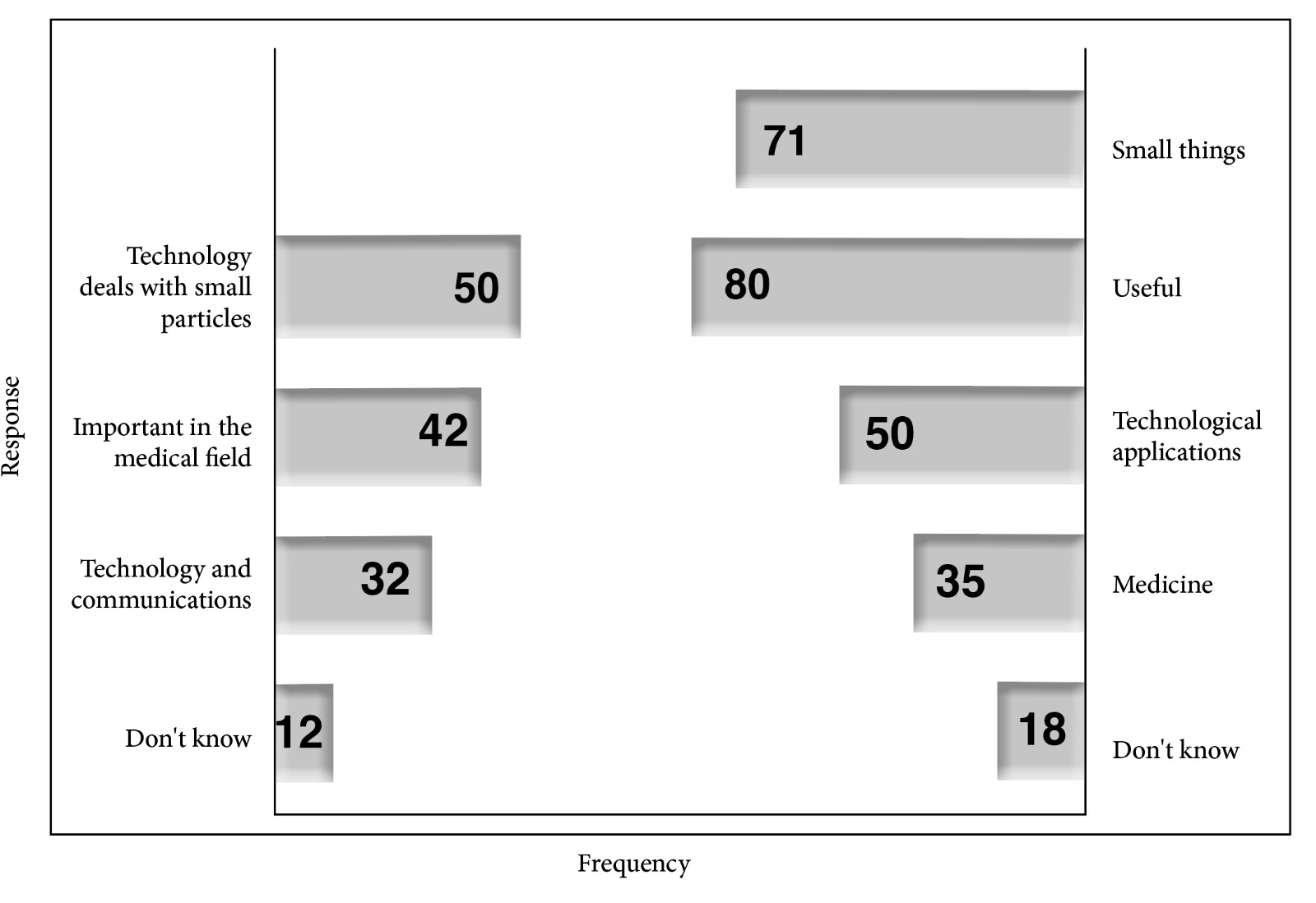


Fig. 4.1. Student (right) and teacher (left) answers regarding their knowledge of nanotechnology.

Figure 4.1 shows that the majority of the students and teachers were aware that nanotechnology deals with small things, with a frequency of 50 for teachers, and 71 for students. A high frequency also indicates its importance in medical and technological applications. The lowest frequency was found for teachers and students who had no idea about nanotechnology.

We can infer from these results that while teachers had heard about the subject of nanotechnology their knowledge base was limited. In addition, their knowledge correlated with things that are tiny or minuscule in size. This could potentially be related to the insufficient information that they had been exposed to during their undergraduate studies. Alternatively, this lack of information could have also been lacking in the curriculum or their curriculum did not contain enough information about nanotechnology or its applications. Figure 4.2 shows responses from students and teachers who were asked to describe examples of nanotechnology used in everyday life.

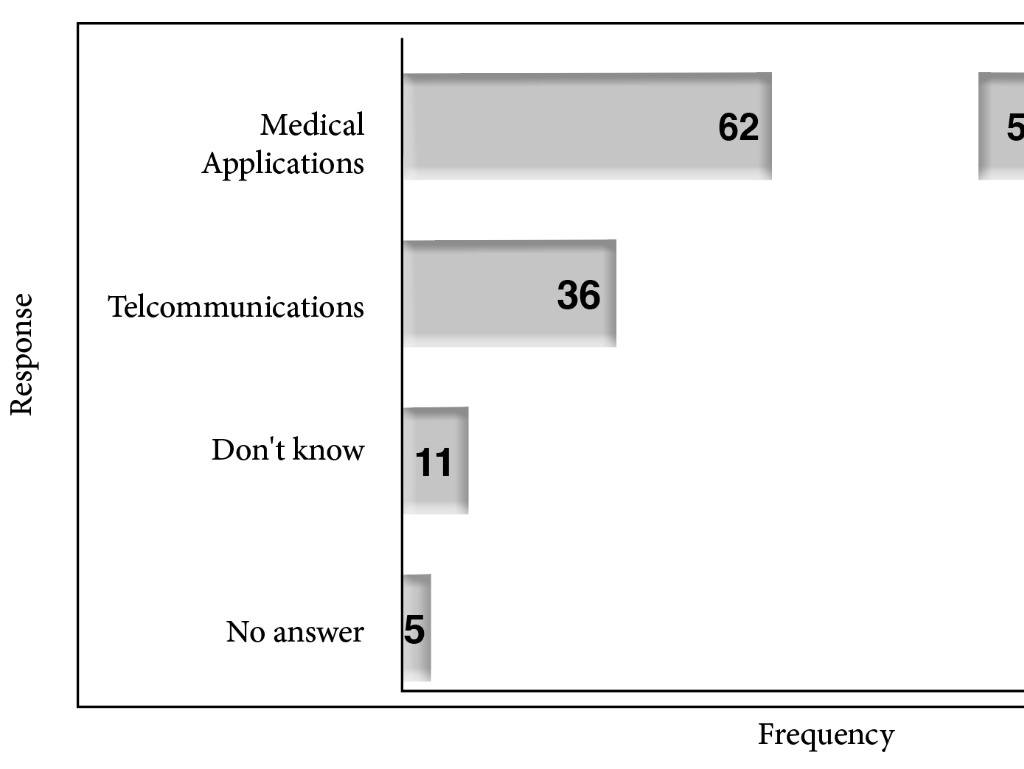
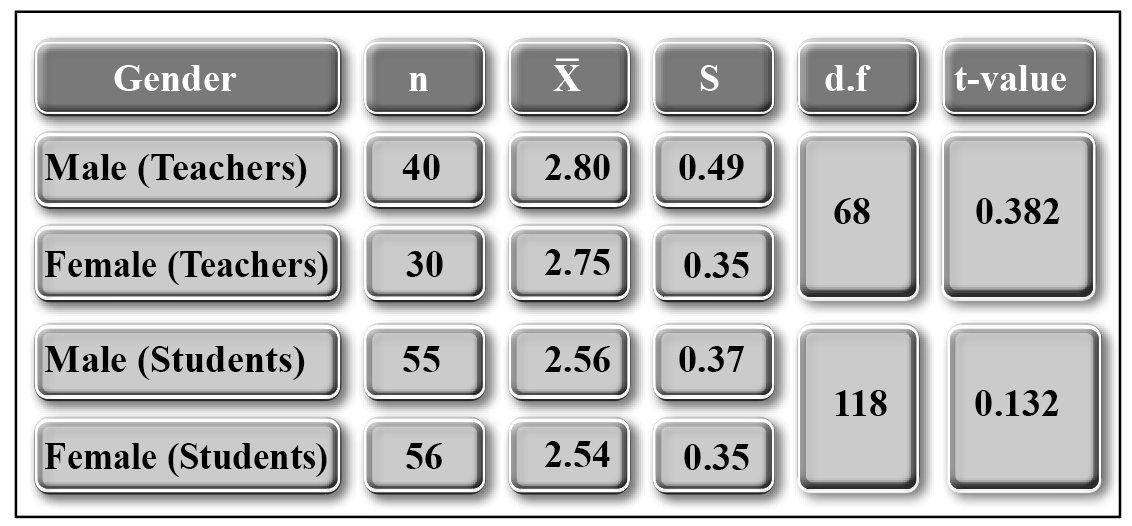


Fig. 4.2. Student (right) and teacher (left) answers regarding nanotechnology used in daily life.

Figure 4.2 shows that responses from both the teachers and students were encouraging. The majority of them were aware of the importance of nanotechnology for medical and technological applications, whereas a lower percentage did not know of its importance. The previous data indicate that students have shallow knowledge about nanotechnology and its applications. However, this shallow knowledge does not reflect their true knowledge of it. We found that students had heard of the word nanotechnology but they did not have any technical understanding of it. It is expected that these students would not have had any definitive opinion about nanotechnology. This could reflect the inferior quality of the teaching or the lack of information about nanotechnology in the curriculum.

## Concerning the attitudes of teachers and students toward nanotechnology, the results showed a similarity between their attitudes toward nanotechnology. Their knowledge could be categorized as ‘medium’ with n=70, 55.6%, x=2.78 for teachers, and n=120, 51.0%, x=2.55 for students. Concerning their responses with respect to gender, there was no difference between their attitudes toward nanotechnology (p = 0.703>0/05) (Table 4.1).30

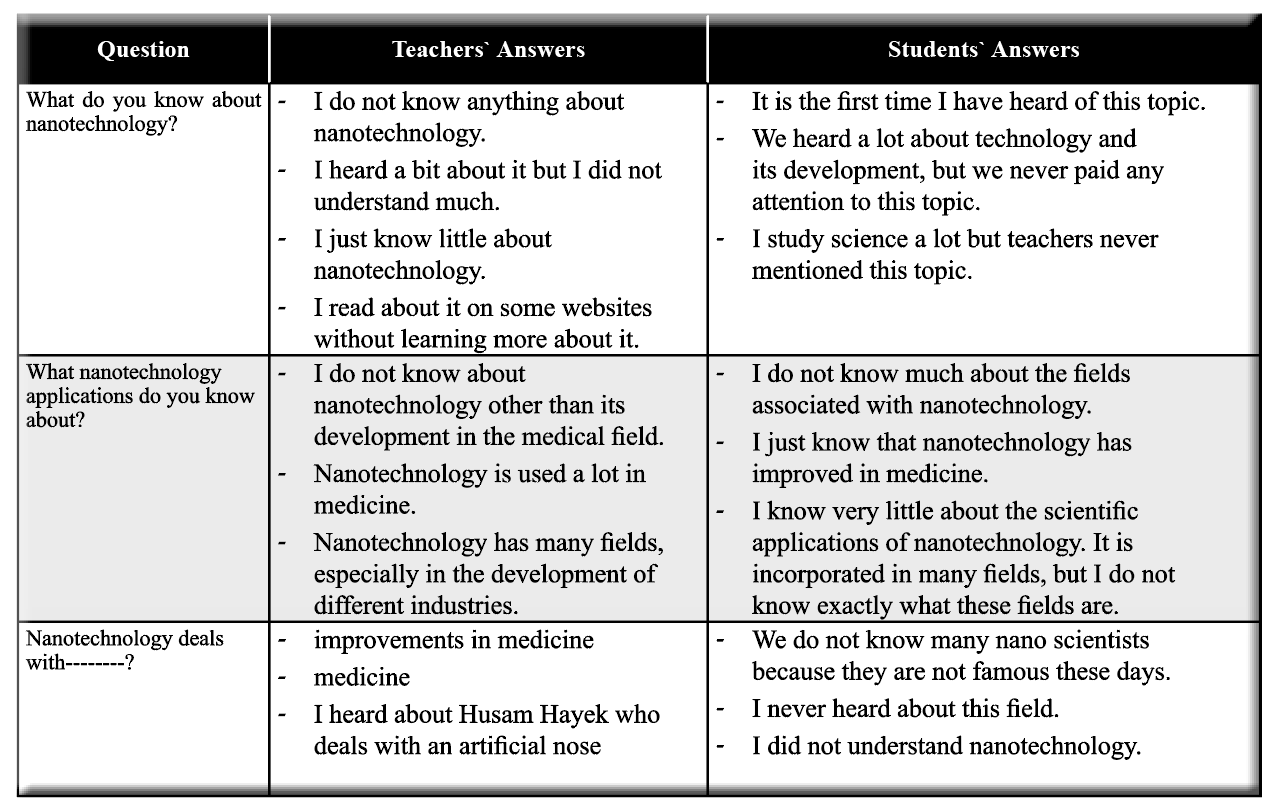
Table 4.1. Teacher and student attitudes with respect to gender.



These concerns indicate that teachers did not have enough information about nanotechnology. They did not develop stronger positive attitudes toward nanotechnology probably because this technology was considered new to them. Our results indicate that teacher attitudes were slightly more positive toward nanotechnology. Their attitudes were more positive than student attitudes and that their attitudes were considered moderately positive. The results also show that there were no differences in teacher attitudes toward nanotechnology related to gender, school, educational level, or years of experience.

In addition to the quantitative data assembled via questionnaires, a semi-structured questionnaire interview was conducted for randomly selected teachers and students. The questions and answers are presented in Table 4.2. According to the participant answers in this interview, both the teachers and students lack considerable information about the field of nanotechnology.

Table 4.2. Teacher and student answers to the semi-structured interview.



The findings from Abu-Much and her colleagues indicate that in the Israeli Arab population, both teachers and students have only a basic or insufficient knowledge base about nanotechnological concepts. Nobody specifically referred to the nano-meter scale. In investigating the attitudes of teachers and students toward nanotechnology, their responses were at a low level, which showed that they had very superficial knowledge. Moreover, none of these variables were examined: years of their teaching experience; level of education; student grades and type of school; and gender of both the teachers and students. All of these variables have a significant effect on their attitudes toward nanotechnology.

Other findings in the literature were found to be consistent with the results of the research conducted by Abu-Much and team. Toqeer and others found that most respondents had heard about nanotechnology but only 47% had read about it.17 A slightly lower percentage (44.4%) of respondents had an awareness of its applications. According to research done by Hingant and Albe, students from Turkish middle schools had some awareness of nanotechnology and most students profess positive opinions about it.20 A study conducted by Sheetz and her team showed that only 17% of respondents knew what nanotechnology was. This research found that males had a higher percentage vs. females, which is inconsistent with our results.[[32]](#endnote-33)

A research study conducted in Germany in order to examine public attitudes and awareness toward nanotechnology also revealed that the majority of the participants were not familiar with nanotechnology.[[33]](#endnote-34) Research was carried out in Singapore regarding public perceptions of nanotechnology.[[34]](#endnote-35) In Singapore, technological innovations are an established part of the country’s economy. About 80% of respondents conveyed to have "some" understanding of nanotechnology, 60% reported having heard some negative information, and 39% perceived nanotechnology as beneficial. Ekli and Sahin found that science and technology teachers in Turkey had ‘moderate’ knowledge of nanotechnology and that they learned about it mostly from their daily lives.7 Their knowledge base was found to be inadequate, whereas the survey participants had positive attitudes toward nanotechnology. Our results also agree with those of Elmarzugi and others who found that many Libyan students displayed a favorable attitude toward nanotechnology.16 This was reflected in the Libyan undergraduate and postgraduate education.

* 1. **Conclusion**

In a nutshell, teachers and students in the Arab sectors of the world have heard about nanotechnology but their knowledge has been found to generally be very basic. Furthermore, Arab survey participants primarily associated the term with things that are tiny or minuscule in size. Teacher and student attitudes toward nanotechnology were positive but teachers showed more positive attitudes toward nanotechnology than students.

Drawing upon the results of Abu-Much and her team’s study, we recommend the following implementations.

1. It is advised to make available courses and training in nanotechnology and its applications to teachers, especially science teachers.
2. Coordination between universities and research centers should be established to deal with nanotechnology and to encourage students to study it.
3. It is advised to encourage students to study nanotechnology through scholarships.
4. It is advised to conduct more studies concerning student knowledge of and attitudes toward nanotechnology.

The results showed that lack of awareness among students and their attitudes toward nanotechnology are the fault of the Department of Curriculum and Instruction about Nanotechnology. Or, this phenomenon may be because it has not been integrated into the main subjects. For student scientific literacy, they should be familiar with this topic.

The Department of Instruction has ignored this topic which has shown a lack of awareness of teacher and student needs. Also, their lack of awareness and attitudes regarding nanotechnology may be because students and teachers did not keep up to date regarding technological developments other than through computers and the internet. Acquiring information about nanotechnology was little done or extremely rarely done.

In conclusion, according to the results of our qualitative and quantitative research, we recommend the following steps.

1. First, nanotechnology should be part of the educational curriculum and the school plan. This is because it has a prominent place in different fields, several industries, and it has resulted in many important discoveries.
2. Second, research institutions and schools should hold lectures about nanotechnology to enhance the scientific literacy of students. At this time, they should present practical applications of nanotechnology from daily life.
3. Third, provide courses to teachers to enhance student understanding of this topic and its importance in daily life.

This research demonstrated that teacher and student awareness of nanotechnology is very slight. They did not know the names of some scientists who dealt with nanotechnology. They only knew about Husam Hayek and his discoveries, but they did know that all of his discoveries relied on nanotechnology. Another conclusion from this research is that teacher attitudes and their demand for information about nanotechnology are rare. Teachers and students regularly indicated that that they did not know about several industries in the field of nanotechnology, they showed a lack of knowledge, or they thought that it is a sector limited to the medical field.

The research also indicated that there are no differences among teachers and students, among males and females, and among middle school and high school students regarding knowledge of nanotechnology. This led us to the conclusion that schools are not fully aware of this problem and they do not adequately teach the students and teachers about nanotechnology despite its widespread applications in many fields. The quantitative research results were found to be similar to the qualitative research results. They both indicated a lack of knowledge and awareness in different fields for teachers and students. Lack of knowledge about nanotechnology negatively influences both teachers and students regarding general and basic information about modern nanotechnologically-based developments.

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