What conductive polymers have taught us about the meaning of education: education before innovation

Kazuaki Hiroki
Tsuyama National College of Technology
Numa 624-1, Tsuyama, Okayama 708-8509, Japan
E-mail: hiroki@tsuyama-ct.ac.jp

Abstract. There are many scientists and engineers who made a great discovery or a breakthrough invention. What is common to them? It is that they had a chance to experience a deep impression of science and technology in their childhood. Science shows and experiment classes are extremely effective methods to help students learn the excitement of Chemistry. In this paper, I discuss the importance of education in chemistry by presenting an illustration about the development and implementation of experiment classes on conductive polymers.

1. Introduction
Several years ago, I produced exhibitions and experiment labs as a member of National Museum of Emerging Science and Innovation in Tokyo (the Miraikan) [1]. As soon as I arrived to the Miraikan, I joined the renovation team for the exhibitions. There were exhibitions about nanotechnology originally, which had a problem of becoming obsolete quickly because of the fast change in this area. So our team decided to make an exhibit about how breakthrough inventions, discovery and technological innovations happen. We named the exhibitions "The driving forces of innovations". Through the research for this exhibition, I met many scientists and engineers, and I wondered: What is a driving force of innovation that brings a revolutionary inventions and discoveries? What is common to the Japanese Nobel Prize in Chemistry winners since 2000? I found the answers to these questions. What is common to the great scientists is that they became familiar with nature, and had impressive experiences with nature in their childhood. They were impressed to watch flowers in full glory, trees of beautiful green, stars glittering, blue of the sky, the depth of the sea, red fiery autumn leaves, and so on [2]. Or they were strongly impressed by exciting scientific experiments. Some were excited by chemical reactions, which caused sudden color changes, emissions, or sometimes explosions. It goes without saying that they never forgot the excitement, and went on to learn chemistry, became scientists or engineers, and then engaged in creative research and innovation. In some instances, the importance of Serendipity is acknowledged, such as in the invention of conductive polymers by Prof. Hideki Shirakawa [3].

Therefore "impression" is one the keywords. So, what is an impressive method to tell people about the wonderfulness of chemistry? An answer is a science show or experiment class. These are...
extremely effective methods to help students experience the excitement of chemistry. Below, as examples of good experiment classes, I present two experiment classes on conductive polymers.

2. Result and discussion

2.1. Experiment class in Conductive polymers for general people

Prof. Hideki Shirakawa was awarded the Nobel Prize in Chemistry for the discovery of conductive polymers in 2000. But even before that auspicious year, he was carrying the fear that the opportunity for chemical experiments in schools was decreasing. Unfortunately, this seemed to cause a "hate science" attitude among students in Japan. So Prof. Shirakawa and the Miraikan planned and carried out the science workshop on the theme of conductive polymers at the pace of almost one a month [1]. Because it is the "mirai"="future" science museum, we have to exhibit advanced science, and the experimental classes were not an exception.

In the workshops, Prof. Shirakawa directly teaches the participants. The target audience are all fifth-grade elementary school students, as well as higher grade students and adults. As a Shirakawa-Kijima laboratory graduate and also as a science communicator for the Miraikan, I was responsible for the development and implementation of the experimental classes. And I had noticed that conductive polymers have immeasurable possibilities as a teaching material [4].

Experiments with conductive polymers may seem to be too difficult for general people. However, conductive polymers actually possess various characteristics that can make chemical experimental workshops very attractive. These characteristics are:

1. They can be relatively easily synthesized.
2. Doping conditions induce drastic changes in their colors and characteristics.
3. Doping induces various physical properties, such as electrical conductivity, electrochromism, and electroluminescence.
4. Their characteristics are all linked directly to various applications.

In addition, experiments using conductive polymers allow people to experience the synthesis and application of the polymers at the same time. They are rare materials that can contribute to learning the wonder of the entire spectrum of science, in addition to chemistry. Below, I demonstrate the use of conductive polymers for scientific education.

2.2. Experiment Classes in Conductive Polymers(1)

Using PEDOT to fabricate a transparent film speaker. Poly(3,4-ethylenedioxythiophene) (PEDOT) is an important conductive polymer, which has attracted attention for its unique properties [4]. Its excellent doping performance, high stability and conductivity make PEDOT useful for a variety of applications, including organic electroluminescence devices (OLEDs), photovoltaic cells, sensors, etc [5] [6]. One of the most interesting applications is a transparent film speaker, which has already been commercialized by the Korean company “Fils” [7].

Prof. Shirakawa and the Miraikan Science Work Shop (Miraikan SWS) planned and performed the experiment classes using PEDOT transparent film speakers. In this section, I explain the method and contents of these classes.
3,4-Ethlenedioxythiophene (EDOT) is polymerized on the both sides of piezoelectric film using Fe$^{3+}$ catalyst (Scheme 1). We usually use Fe$^{3+}$ catalyst, such as an ethanol solution of iron (III) p-tolu-nesulfonate (Figure 1). Extra monomer and catalyst are removed by rinsing with ethanol (Figure 2). Thin PEDOT electrodes are re-doped with the polymer dopant poly (vinylsulfonic acid), or PVS, by applying a solution of PVS (Figure 3). When we attach copper foils as auxiliary terminals, the transparent film speaker is completed, with its thin and mysterious blue colored PEDOT/PVS electrodes (Figure 4). When the electrodes are connected to an audio player (Figure 5), the flexible piezoelectric film vibrates according to the audio signals (Figure 6).

**Scheme 1.** Oxidative polymerization of EDOT using catalyst.

**Figure 1.** The steps to form a thin PEDOT electrode on a piezoelectric film by applying a solution of EDOT and catalyst.

**Figure 2.** The steps to removed extra monomer and catalyst by rinsing with ethanol.
Figure 3. The steps to re-dope thin PEDOT electrodes with the polymer dopant PVS, by applying a solution of PVS.

Figure 4. The steps to attach copper foils as auxiliary terminals, and complete the transparent film speaker.

Figure 5. The steps to connect copper foil terminals to an audio player.

Figure 6. Mechanism of the flexible transparent film speaker.
This means that PEDOT plays the role of a transparent thin film electrode, converting the vibration audio voltage, which is the trick to make the sounds come out. When lovely music flows from the film speakers, everyone will smile.

2.3. Experiment Classes in Conductive Polymers

A HANDMADE Polymeric Organic Electroluminescent Device [OLED]. As seen in the experiment above, PEDOT is a useful conductive polymer. It can be considered one of the ideal molecular structures of conductive polymers. Another important conductive polymer is Poly [2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene](MEH-PPV), which applied for a light-emitting layer of polymeric OLEDs.

Prof. Shirakawa and the Miraikan SWS also planned the experiment “fabrication of HANDMADE polymeric OLEDs.” In this section, I explain the method and contents of the experiment classes of fabricating a polymeric OLED using PEDOT and MEH-PPV (Figure 7).

What do I mean by “HANDMADE”? The use of evaporator and spin coater is difficult for children, and in the first place takes an unreasonable amount of time.

So we make PEDOT layer on top of the ITO glass by the electro-chemical polymerization of EDOT (Scheme 2, Figure 8), and dip coating the toluene solution of MEH-PPV layer on it (Figure 9). Next, the solvent is removed by drying with a hair dryer. On another ITO glass, we place the Ga-In eutectic (Figure 10). Finally we stick them together with double-sided tape with a hole (Figure 11), and the HANDMADE polymer organic EL device is completed (Figure 12) [8].
Figure 8. The steps to synthesize a PEDOT as the hole injection layer on an ITO glass by electro-chemical polymerization.

Figure 9. The steps to dip coat the toluene solution of MEH-PPV on the ITO glass with thin PEDOT layer.

Figure 10. The steps to put the Ga-In eutectic as the electron injection layer on another ITO glass.

Figure 11. The steps to stick together two ITO glasses with double-side tape.
The construction of this HANDMADE polymeric OLED is described in Figure 13. It is a typical multi-layer structure, ITO (electrodes), PEDOT (a hole injection/transport layer), MEH-PPV (a light-emitting layer), and Ga-In eutectic (an electron injection/transport layer).

Thus, we developed methods to fabricate a HANDMADE polymer OLED without either a spin coater or a vacuum deposition machine. When the electrodes are connected to a power supply, the handmade polymeric OLED emits light orange (Figure 14). When the OLED lights up, with its warm orange light, everyone is sure to be impressed.

Figure 12. Completed “HANDMADE” polymeric OLED.

Figure 13. Construction of a HANDMADE polymeric OLED.

Figure 14. Light emitting the HANDMADE polymeric OLED, in the experiment class at Nagoya University (2012).
3. Summary
We have developed interesting and exciting experiment classes on conductive polymers. The experiments to fabricate devices are simplified as much as possible; so that the participants can succeed easily, especially the children. From one point of view, these experiments can be regarded as simplified industrial processes of making devices, and may help students understand any featured processes, such as roll-to-roll processing, printable electronics, etc.

On the other hand, from educational point of view, we have succeeded in developing attractive experiment classes on advanced materials. When I see the smiles and excitement of the participants, I am always happy. The purpose of the experiment classes is to give knowledge and carry out the experiment itself, but both of these are secondary. The true purpose of the experiment is demonstrating the excitement of conductive polymers. Even if students fail the experiment, it is still exciting. This can be the magic that inspires students. The experience of being excited by chemistry provides a chance to aspire greater heights in science and engineering. It is no wonder that the scientists and engineers who stir up the innovation for the future begin with curiosity and wonder.

The true meaning of education is having the students watch, listen, be surprised, and experience the pleasure of understanding, rather than giving the knowledge unilaterally. We will continue to develop a new experiment classes on conductive polymers in the future. We will continue to verify the effectiveness of both the scientific process and the educational effect.

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