Advances in Social Science, Education and Humanities Research, volume 157
International Conference on Education Innovation and Social Science (ICEISS 2017)

Divergent Thinking during the Electrospraying Processes for Implementing Engineering Teaching in Higher Education

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***Abstract*—Knowing how to do divergent thinking is very important for cultivating the creativity of college students in high education. In this paper, an advanced technique--electrospraying was exploited as an example to explain how to foster the undergraduate students' divergent thinking. From the preparation of a working solution, the implementation of electrospraying process, the characterization of electrosprayed microparticles, and also the final potential applications of the mediated microproducts. Each of the above-mentioned steps comprises good materials for promoting the students to think divergently, learn actively, judge and make a decision using convergent thinking. It is suggested for high education that advanced technologies can be utilized as useful tools for cultivating the students' divergent thinking and innovation capability.**

Keywords—Divergent thinking; Higher education; Advanced techniques; Creativity

I. INTRODUCTION

Today, innovation and creativity are very important for our knowledge society [1]. How to foster the college students' creativity is always a big concern for their teachers. A fundamental cognitive component of creativity that has been extensively studied since 1950s is the concept of "divergent thinking" which involves generating novel associations [2]. Divergent thinking is a thought process that can be exploited to generate creative ideas by exploring many possible solutions. It is often used in conjunction with convergent thinking, which follows a particular set of logical steps to arrive at one solution.

Often, a topic can be first broken down into several components for achieving insight about its different aspects [3]. Later, the detailed information can be organized through convergent thinking [4]. In high school, it is a common sense that creativity has a close relationship with the working processes, which is very useful for fostering the students' cooperating and cognitive ability [5]. Thus, higher education should provide more trainings for the students to grow from "active learning" to "passive learning".

Based on this idea, more curricula about advanced technologies should be opened to the students for them to experience an innovative and creative environment. These curricula should very useful for cultivating innovations for both teaching and also learning.

In the present job, an example is showed how to implement the students' divergent thinking training exercises with an advanced technology ----electrospraying as an example tool [6-7]. Taking the advantages of electrospraying practices, the teachers have successfully trained the students' capability of divergent thinking, provided opportunities for them to contact modern technologies and to do more exercises in the scientific laboratories, and to promote them thinking in a creative way.

II. ELECTROSPRAYING

Electrospraying, (or sometimes, improperly, electrohydrodynamic atomization (EHDA)), has been growing in popularity owing to its ability to easily fabricate particles and thin films. Electrospraying and electrospinning are the two main EHDA techniques, and comprise unique processes in that they produce fibers and particles at the micro- and nano scale by exploiting electric forces [8-15]. A significant feature of electrospraying is its ability to generate particles with a mean diameter that can be varied between hundreds of micrometers and tens of nanometers. This is achieved by carefully controlling processing parameters such as flow rate, needle diameter, and applied voltage, as well as the chemical composition and concentration of the solution.

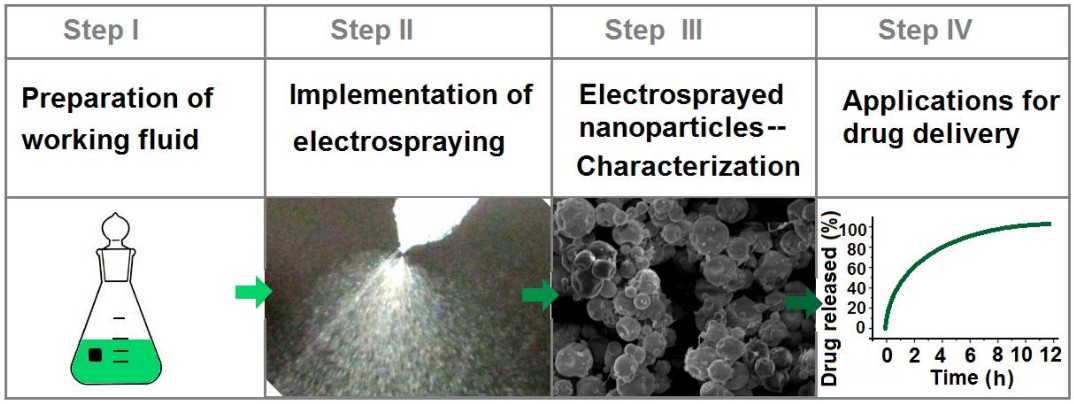

Fig. 1. A schematic diagram of the electrospraying process for fabricating medicated microparticles

During an electrospraying process, a solution is pumped into a capillary. At the end of the capillary, a droplet can be formed. When an electrical field is added on the working solution, the droplet will change its morphology from round shape to a conical shape, which is the famous Taylor cone. At the tip of the Taylor cone, a liquid jet is formed before it is broken into small droplets.

Electrospraying first generates near-monodisperse droplets whose size can be varied between a few to hundreds of micrometers. Later, the droplets rapidly shrink due to the fast evaporation of solvents resulting from the Coulombic explosion. The huge surface areas of the micro-droplets provide the possibility for complete of the solvents and the solidification of products. The facile interactions of electrons with fluid solvents accelerate their evaporation. If the solvent in the droplets does not evaporate effectively, they will form thin films on the collector. If the solvent evaporates well, the droplets shrink, and finally solid particles are formed.

Although a very simple and straight forward process for nanofabrication, it is a fine tool for training the college students' divergent thinking and also convergent thinking capabilities. An electrospraying process that was exploited to prepare medicated microparticles for drug sustained release is shown in Figure 1. It consists of three inter-related steps for fabrication and characterization, i.e. preparation of working solution (Step I), implementation of the electrospraying process (Step II) and characterization of the electrosprayed particles. Later, the functional performance of medicated microparticles can be tested for evaluating their potential applications in drug controlled release.

III. Training Divergent Thinking During the Preparation of Working Solution

Divergent thinking often appears spontaneously at the mind with a series of ideas in an emergent cognitive manner. Many possible solutions are explored in a short amount of time, and unexpected connections are drawn [16]. After the process of divergent thinking has been completed, the generated information can be melt together through convergent thinking. This process can be taken to train the college students' capability of both divergent thinking and convergent thinking.

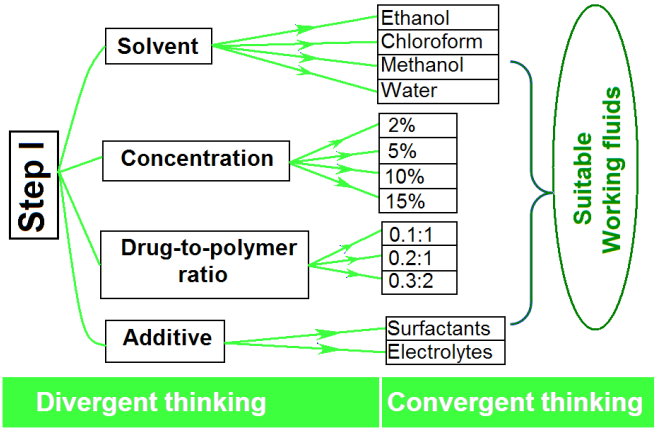

Fig. 2. Involved divergent and convergent thinking in the first step of preparing working solutions

The first problem for the students is what type of solution can be treated using electrospraying. Many answers and possible solutions are put forward by the students. Beyond imagination, one student give an unexpected connection between the working solution and an electrolyte, which means good conductivity because of its addition, and in turn would promote a smooth and stable electrospraying process to exploit the electrical energy more efficaciously. After the work of several groups students, a final solution is drawn through convergent thinking, which include using ethanol as a solvent, fixing the polymer concentration at 10%, a drug-to-polymer ratio of 0.2:1, and a tiny content of additive electrolyte. The whole training processes are shown in Figure 2.

IV. Training Divergent Thinking During the Electrospraying Process

Problem discovery is a particularly important component in the creative process because it occurs first, and because the quality of a problem may in part determine the quality of solutions. In the first step, it is relatively easy for the students because they have learned how to prepare solution previously. But for the second step, i.e. the implementation of electrospraying, it is difficult for them to put forward many questions in a divergent thinking way. However, after some pre-experiments of the process and some explanations, the question still triggers the students' creativity and they can find problems and build up new relationships between the different elements themselves.

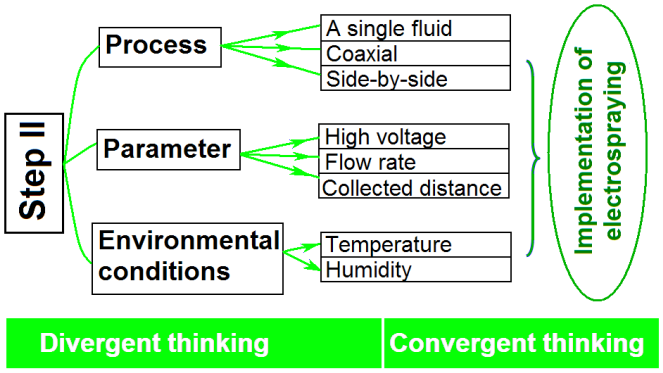

Fig. 3. Divergent and convergent thinking in the implementation of electrospraying

Sown in Figure 3, among the three important aspects for implementation of electrospraying, many students can think about why a single fluid electrospraying process is a best choice, and what the case is provided a side-by-side or a coaxial electrospraying is exploited. As for the parameters, the students can give a lot of conditions for the optimized values of the high voltage, the flow rate and the collected distance. In the step II (implementation of the electrospraying), the determination of working parameters furnishes a fine material for training the students' divergent thinking about technical processes. They can foster their imagination, develop a sense of creative awareness, and improve the ability of making a decision from the complex situation. Certainly, a series of other complicated microstructures (core-sheath, Janus and their combinations) and the related advanced multiple-fluid electrohydrodynamic atomization processes can be gradually implanted into their divergent thinking processes [17-26].

V. Training Divergent Thinking During the Characterization and Application of Microparticles

Divergent thinking – more than a mere tool – is a technique very commonly used on creative activities because it allows us to expand our brains a little bit, by looking for new opportunities and ways of getting things done [27]. This is just the case in the step III and IV (Figure 4). To characterize the electrosprayed microparticles, their morphology and inner structure, their chemical and physical properties and their functional performance should be determined. Thus a wide variety of methods may be utilized for this objective through divergent thinking.

To observe the microparticles, several methods can be conceived for this such as optical microscopy, scanning electron microscopy, atomic force microscopy and also transmission electron microscopy [28, 29]. To characterize the state of components in the nanofibers, differential scanning calorimeter, X-ray diffraction, Fourier transform infrared spectroscopy and X-ray photoelectron spectrum can be imagined and tried. As for the microparticles' performance, particularly functional one, it has been designed at the beginning of the experiments. However, it can still be used to train the students' divergent thinking through provoking their imaginations and curiosities, and to sharp up the students' thoughts for more flexible. After the processes of divergent thinking have been completed, the students should be able to analyze and evaluate their ideas, narrowing them down with convergent thinking techniques, which is also necessary to the whole activity.

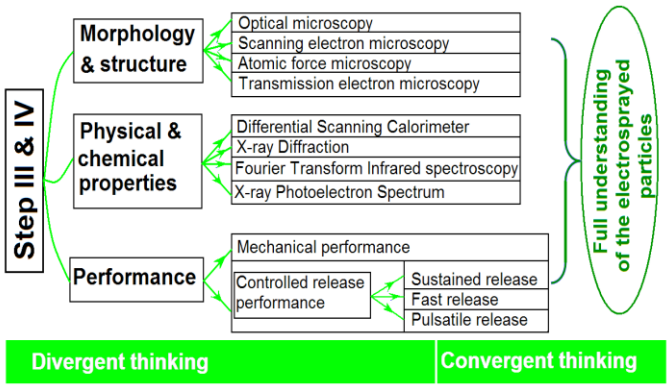

Fig. 4. Divergent and convergent thinking in the characterization and application of microparticles

VI. Summary

With electrospraying as a tool, we explain how to cultivate the undergraduate students' divergent thinking in higher education. From the preparation of the working solution, the implementation of electrospraying process, the characterization of electrosprayed microparticles, and also their final potential applications, each step can be explored as a good example to promote the students to think divergently, learn actively, judge and make a decision using convergent thinking.

Acknowledgment

The financial supports from the following projects are appreciated: the Shanghai Education Science Research Project (C17058), the National Natural Science Foundation of China (No. 51373101), the 2017 Graduate curriculum reform project in USST, and the College Student Innovation Project of USST (Nos. XJ2017286, SH2017189-190-191).

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