Research-Based Learning Remodels the Characters of Undergraduates for Creative and Innovative Personnel

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Abstract. Purpose: To explore effective measures to train undergraduates into creative and innovative personnel; **Procedures and Methods**: Problem-oriented class teaching model infiltrated with critical thinking training (POCTM) in classroom and research-based learning (RBL) in lab have been performed for over ten years to remodel the characteristics of creative and innovative talents; **Results**: An empirical study of clinical medical students in the past 10 years inspire us to compose a novel and effective training flow to empower undergraduates with the abilities of double talents-Innovation and Creation; **Conclusions**: ATTBP is an effective RBL model to train innovative and creative talents, which may be of referential value to higher education of other developing countries.

Nowadays, the increasing demand for universities to graduate students with higher order problem-solving and critical and creative thinking skills enhances research-based learning (RBL) gradually to stand out among many teaching approaches. RBL is a multifaceted approach for connecting research and instruction, integrating learning, teaching and research. Its central idea is to actively involve students in ongoing research activities and let them develop their own research interests and questions. Accordingly, the research activity is regarded as an important tool for teaching and learning. At least, it contains students' active involvement, adequate research tools' application, inclusive research approaches and research outcomes. Here, we would like to share our exploring experiences in this respect with peers as follows:

In the past decade, nearly 20 undergraduates have been successfully mentored by our lab, the Key Laboratory of Arrhythmias, Ministry of Education, Tongji University School of Medicine, Shanghai, China. During their time in the lab, most of these undergraduates published their first publications as first author[1-5], and most went on to pursue graduate degrees in medical science or medicine. At present, a group of three undergraduates majoring in clinic medicine are being trained in our lab.

Since 2008, nearly every tier 1 comprehensive university, including Tongji University, has created a variety of innovative scientific research training programs for undergraduates. Students in these programs are not only valuable human resources but also primary idea providers for research labs. Equally, lab life can help undergraduates become budding researchers and some of them even

publish first-author research papers. However, mentoring undergraduates requires the investment of time to give the students a solid basic knowledge as well as training them in critical and creative thinking and experimental skills. It is a big changeover from classroom to the lab, a process of mutual adaption between undergraduates and mentors. During the process, mentors must spend time and energy since undergraduates are less well-developed than graduates[6].

Recently, an author shared his experiences from lectures to the lab and suggested that perform without understanding, perform with understanding and student researcher were the three steps required for undergraduate researchers[7]. However, we believe there are five steps from the classroom to the lab which we believe are essential to the successful development of an undergraduate into a budding researcher with creative and innovative personnel. The discrepancy may be attributed to the students' different foundations. Although not every student will move through all of these steps, laying a solid foundation of knowledge, arousing interest in scientific research, inspiring critical and innovative thinking, setting aspirational goals and training experimental skills can help draw undergraduates into the excitement of research, keep them focused on the task and further guarantee their tasks are completed to a high quality. The steps are performed in both classroom and lab, respectively, and are listed as follows:

In the Classroom

Step I Teach a Solid Basic Theoretical Knowledge and Arouse Interest in Scientific Research

In our Cell Biology class, we encourage undergraduates to observe their surroundings, rekindle their childhood curiosity and recall what they studied during their Biology and Health classes in middle and high middle school. When delivering lectures on the structure and function of cells, we encourage students to rethink the structure of their own bodies from the perspective of cell sociology; and when delivering lectures on cell signaling and the specific performance of cell life activities (birth, senility, illness and death) we encourage students to think about human cell society from a sociological perspective in theoretical classes; and in experimental classes we guide them to trace the thinking trajectory of great scientific discoveries of predecessors. Through these measures to inspire their interest in Cell Biology, we not only refresh their basic theoretical knowledge but also arouse their interest in scientific research.

Step II Inspire Critical and Innovative Thinking

According to Bloom's taxonomy of educational objectives[8], higher education should aim to cultivate and enhance students' higher-order thinking ability, including at least systematic thinking, integrative thinking, critical thinking and innovative thinking. We therefore adopted a problem-oriented class teaching model infiltrated with critical thinking training (POCTM) to develop students' logical thinking, stimulate their critical thinking and foster their innovative thinking[9]. As an example of their originality and ingenuity, we present Figure 1, which is the Logo of one three- undergraduate training group.

Figure 1. Logo of one three-undergraduate group

The logo is composed of two parts: picture and text. The text is composed of three letters of different but linked colors; and the design is a butterfly with gradually changing colors and open wings. The three English letters DJH are the initials of Ding, Jin and Han, the three members' family names. Although they use different colors to express their individual characteristics, the

three letters still have a sense of mutual dependence on each other, showing that the group members help each other and make progress together to achieve success. The whole design is a butterfly, alluding to the students breaking from their “cocoon”, with the help of their mentor and under their own efforts, to one day become talented pillars of society to the country. Looking more closely at the color change of the butterfly body, we can see that each color overlay pattern is actually a different letter: from the bottom to the top we can see a red D, a light green J and a dark green H.

In summary, bold hypothesis and careful verification are the rationales that scientific research must adhere to. Strong interest in scientific research, solid knowledge reserves and flexible thinking should run through the whole process of class teaching.

In the Lab

Step III Establish a Research Group and Set an Aspirational Goal

We suggest using undergraduates' class and assignment performance data to seek serious, responsible and highly-motivated members to establish research groups of three students each. Groups then come to the lab, where they are guided to set an aspirational goal that can be achieved through their own hard work. This aim is mainly manifested in supporting them to successfully apply for the National Undergraduate Innovation Training Program (NUITP) or Local Undergraduate Innovation Training Program (LUITP), or the University Student Innovation Training Project (SITP). Being successfully awarded a project will undoubtedly strengthen their research interest. At this point, research-based learning (RBL) begins formally.

Step IV Train Basic Skills for Experiment Design and Implementation

Before undergraduates begin carrying out experiments, they should be taught basic skills including how to perform a literature search, how to read literature and take relevant notes, how to write medical reviews, how to design and perform experiments, how to keep records, how to prevent bacterial and viral contamination of materials and how to protect themselves against potential chemical or pathogenic injury. The main skills required are critical reading, experimental design and data recording; and these are usually shown via power-point and brainstorming discussion. Experimental skills are trained using three steps: first, undergraduates watch us perform the experiment while we tell them the key points; secondly, we watch the students carry it out while emphasizing the key points; and thirdly the students do it themselves. Gradually, undergraduates understand the concepts of experiments and learn to perform their designed experiments independently. At this point, they can be regarded as emerging researchers.

During implementation of the plan, the undergraduates should be taught correct methods to collect and analyze data; our personal experience shows that this should take place at least three times. At this stage, appropriate drawing software, e.g. GraphPad Prism series, Origin series, ChemDraw etc. should be recommended for reference and practice.

In addition, journal clubs should be held no less than once every two weeks to ensure that each undergraduate gives at least one talk during their time in our lab. This is essential to teach them the measures to get the frontiers of research, read literature critically and learn from peers’ research methods. Above all, they should try to find possible deficiencies among the literatures and consider ways to improve or corroborate them; this allows them to gradually broaden and deepen their scientific research thinking.

Step V Compose and Publish a Research Paper

After two to three years of training in our lab, most undergraduate groups have completed their own training program of research. At this point, two books[10,11] are recommended to them on how to compose and write their own research paper. We always emphasize that an outline is necessary for any type of writing, whether for an article or a review or something others, and that the introduction and discussion sections are vital. Of note, the discussion section can best reflect the level of the authors.

When the first draft is ready, we help them to revise the manuscript at least three times, mainly focusing on using short sentences whenever possible, straightening out the logical order, avoiding grammatical errors, wrong words and excessive conclusion, and discussing the results thoroughly and fully combined with previous work in the fields. We also help them to adjust the artwork according to the requirements of their target journal.

We strongly suggest that undergraduates write articles with their experiment data at this stage to train their analytical, reasoning and critical writing skills and further lay the foundation for their confident participation in international academic conferences. Without this step, undergraduates cannot become mature researchers.

Only after the above five steps of trainings have been completed, can the undergraduates grow into mature and experienced researchers, most of all, they must maintain a curiosity and interest in scientific research; this is sometimes achieved through further study abroad or at home.

Management

Time

Due to the full schedule of class every weekday, undergraduates entering our lab could only perform self-directed study at evenings, weekends and vacations when completing their innovative training programs. Driven by motivation, curiosity and responsibility, they learn to successfully manage their own time for basic research training via RBL.

Students

Undergraduates who enter our laboratory are usually in groups of three students. Each group selects a leader who is responsible for the overall work plan, the deployment of personnel to ensure seamless workflow between pre- and post- experiment and smooth completion of the overall research plan. Any member can contact us by mobile phone or WeChat at any time to seek guidance or to report unexpected problems. This way, we train their leadership capability and team-working spirit.

Project

Usually, the training projects for undergraduates are managed via Scholarmate, a social networking platform (https://www.scholarmate.com/oauth/index). Once three undergraduates have formed a group, we set up an area for them there. They upload their assignments and experimental records, on time, according to our lab rule. This can foster their electronic management skills, use of networks, improve their team-working spirits and increase their appreciation for the importance of rules, discipline and responsibility.

Summarily, arousing curiosity and interest (A), thinking sharpening (T), technology training (T), basic research performing (B) and publishing originality (P), abbreviated as ATTBP, are five key steps for undergraduates to become budding researchers. We are sure the ATTBP model can inspire more undergraduates all over the world to experience more exciting university lives and become qualified undergraduate researchers, further innovative and creative talents.

In addition, mentoring is a key part of undergraduate teaching, representing fantastic opportunities for both parties to have an impact on research. The ATTBP model can help both mentors and students to become aware of their own stage of development. The model can help mentors to identify what stage their students are at, further help them develop their skills (including designing and performing experiments, critical reading, thinking and writing), eventually enabling them to become better researchers. The model also enables students to set goals and seek guidance from mentors and peers to make the most of their time in the lab. Students might be from different countries and at different stages for different tasks, but most of them will accelerate through the stages as they develop the tactics to master new skills[7]. Inspiring and investing in students pays dividends for the lab and the scientific community as a whole.

Summary

ATTBP is an effective RBL model to remodel innovative and creative talents, also of referential value to undergraduate cultivation in other developing countries.

Disclosure of Potential Conflicts of Interest

Authors declare no potential conflict of interest.

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