An "Apprenticeship" Research Program for Improving Undergraduates Innovation in Food Science Study

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ABSTRACT

Engaging undergraduate students in research has become important for cultivating potential innovative talents. This study investigated the influence of a two-year-apprentice research program on undergraduates' knowledge, technical skills, innovation and achievement in food science research. A total of 45 students were distributed to 3 individual projects based on their interests with a faculty adviser in each project. In this program, the undergraduates had experienced three stages of research activities, including marginal participation, full participation and practicing professional identity. The evaluation of the apprentice research program efficiency was carried out in terms of questionnaires, interview and the achievements from the participated undergraduates. The results demonstrated that early participation in research enabled undergraduates with certain scientific knowledge, research skills, advanced cognitive abilities and professional socialization. Therefore, the apprentice research program for undergraduates was successful in food science education.

Keywords: *apprentice, innovation, scene learning, professional socialization, food science*

I. INTRODUCTION

Undergraduate research has been given much attention as undergraduate students are the main force of scientific and technological innovation [1]. Several US universities have short-term research project for undergraduates which usually last for one semester [2]. Government or academic organization will provide special funding for the short-term research project, aiming at providing scientific training for undergraduates. The participated undergraduate students will be involved in a real research project with the guidance of professors. This scene learning has been proved to improve cognition, personality, scientific thoughts of the participated undergraduates [3]. One of the most significant advantages of undergraduates' research experience is increasing their intention to pursue postgraduate study [4]. Furthermore, a positive association between early involvement in research and the success in graduate studies was observed [5]. In addition, the undergraduate research experience has increased their knowledge, creativity, enthusiasm and effective communications [6].

In China, the research education for undergraduate student mainly focuses on the introduction of research significance from the ideological level or the experiences of Europe or North American college research education [7]. However, the lack of participation, poor mentorship and short of funding specially for undergraduates become major challenges for undergraduates' research education in China [8]. As a result, most fresh graduates feel well-prepared for the theoretical aspects such as readiness for life-long learning; nevertheless, they lamented weaknesses in problem solving or innovative thinking. Inadequate undergraduate research opportunities lead them have difficulties transferring their roles to graduate students or scientists in industry, as well as limit their scientific innovation [9]. In order to solve those problems, increasing efforts by higher education institutions have been made to engage undergraduate students in research activities [10]. Considering Chinese education system, an "apprenticeship" research program has been established in this study based on the US "scene learning" module with modifications [11]. The apprenticeship research module is a two-year program which is distinguished from other undergraduate laboratory or research projects by involving students in three stages of the research process: marginal participation, full participation and practicing professional identity. It provided an early opportunity for undergraduate students to develop their interests in formal research through senior students and faculty mentorship. This program was aiming at stimulating minds, broadening perspectives, expanding intellectual and social networking, and strengthening connections in the University and global community. By the end of program, the feedback from participated students, including questionnaires, interviews and their achievements were summarized and evaluated. It will be helpful for assessing the efficiency of apprenticeship research program on the innovation cultivation of undergraduate students. Therefore, an apprenticeship research program is able to immerse undergraduates in basic research concepts, technique skills training and professional socialization.

II. METHODS

A. Participants

The apprenticeship research team was a community of practice consisting of apprentice (sophomore), scientists (juniors), mentors or leaders (seniors) and teachers ("Fig. 1"). A total of 45 undergraduate students (15 sophomores, 15 juniors and 15 seniors) were enrolled in the apprenticeship research program. Three projects which held by three different faculties were open for participants to select based on their backgrounds and interests (See "Table I"). Each project lasted for two years including three stages of research work.

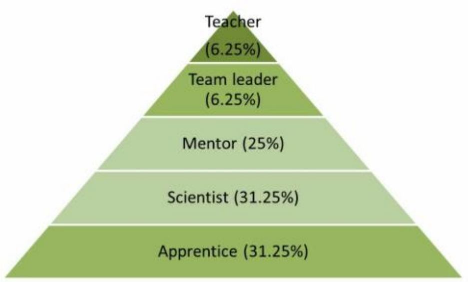

Fig. 1. The personnel organization of the apprenticeship research program.

TABLE I. THE PROJECTS FOR UNDERGRADUATES' RESEARCH PROGRAM

Project Name	Faculty
Umami taste and its association with energy status in harvested Pleurotus geesteranus stored at different temperatures	Guang Xin
Antagonistic Effect of Blueberry Anthocyanins and its interaction with of ELF-EMF	Xiyun Sun
The Protective Mechanism of Blueberry Anthocyanin and its Non-covalent Binding to Whey Protein and Bovine Serum Protein	Bin Li

B. The selection of research project

Before the research work officially started, the undergraduates (sophomore) who agreed to participate the program took a pre-test evaluating their interests and academic qualifications for admission. Then, the enrolled sophomores were distributed to the three research projects. Next, an orientation was provided to the participants about the safety matters, lab locations, instruments and research manual. According to the changes in their roles as the research proceeded, the learning process is divided into three stages ("Fig. 2").

Fig. 2. Three stages of the apprenticeship research program.

Stage I: Marginal participation (learn as an apprentice). Students performed a literature review that reflected their current knowledge and background information about their chosen project. During the first semester, they were briefed about the research and voluntary basis of their participation. Generally, they started from basic lab works such as washing bottles, arranging equipment, collecting research materials, organizing research documents and other research related activities. In addition, service work such as communication with different affairs, financial reimbursement, and procurement etc. were also completed by the apprentice. The basic lab works were considered to be an important step for a novice undergraduate to enter into a community of practice and to acquire practical culture based on situational learning theory. The primary tasks and the time spend on the tasks for the apprentice at stage I was shown in "Fig 3".

Stage II: Full participation (work as a scientist). At this stage, the sophomore stepped into their junior year with full participation in the apprenticeship research program. As the apprentice gradually understood the activities of the team and gained the trust of the junior students, they were integrated into the team and officially began their research. They had the assigned research tasks and learned knowledge, methods, and techniques to complete the project. During this stage, junior students worked as scientist searching literatures, operating experiments and collecting data. The primary task and the spent time on the tasks for the junior students at stage II was shown in "Fig 3".

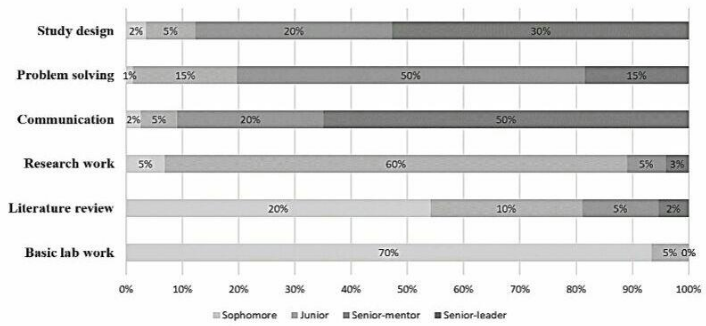

Fig. 3. The primary tasks and the percentage of time spend on the tasks.

Stage III: Practicing professional identity (act as a mentor or leader). After one year and a half of research work, junior students were upgraded to a higher level. However, the research training did not end, on the contrary, they entered the more advanced research training stage as mentors or leaders. Instead of learning how to complete specific research task, the mentors were responsible for independent study design, problem solving and organizing other team members to work on the project. On this basis, they assisted the other team members following their steps to implement research programs and obtain data and results. In each research team, the most outstanding student eventually grew into the project leader, arranging the entire research project. The main tasks of the team leader included: 1. Propose a plan to develop novel food product which was related to the current project. Then, the developed food product was used as an entry item in the food product development competition; 2. Discover innovation point of the research project and prepare an outline for writing a scientific paper; 3. Communicate with guide teachers and arrange seminars. The primary tasks and the spent time on the tasks for the mentor or leader at stage III was shown in "Fig 3".

Teachers guidance. The teachers' guidance was carried out in the form of seminars. Regular seminars on a bi-weekly basis were scheduled and the teachers were invited for goal setting, disciplines delineating, problem solving and scientific behavioral norms guiding.

C. *Evaluation of apprenticeship research program*

The achievements of apprenticeship research program for undergraduates were evaluated by the improvement of the innovative thoughts (the rewards they got from national, state or school levels), the scientific paper published and the feedback from the participated students (interviews).

III. RESULT AND DISCUSSION

A. *The benefits of apprenticeship research program*

There were total 45 students and 3 teachers enrolled in this undergraduate research program with the objective of encouraging undergraduate students to get involved in research. The undergraduates research team is a community of practice consisting of teachers, leaders, mentors, scientists and apprentice. The structure and percentage of their roles were shown in "Fig. 1". The application of knowledge, methods, techniques were distributed in the community from teachers to apprentice grade by grade [12]. Each participant in the community preserved, delivered and increased the culture of the community from different perspectives [13]. The learning experience of undergraduates in the scientific research program reflected the principle of social constructivism that this is an apprenticeship module [14]. Involved in the real scientific research, the apprentice learned cognitive and practical skills through hands-on practice. The teachers and mentors (senior students) provided professional guidance and demonstrations, figuring out the most appropriate way to motivate the undergraduate's innovation on research. Upon the focus on professional activities of a special project, students acquired cognitive and practical skills and were able to continually integrate their knowledge into their daily work [15]. This learning experience validated social constructivist theory that is to provide a "scene learning" for undergraduates which enhanced learning efficiency by applying and stretching cognitive and practical skills [16]. By the end of the apprenticeship program, all the participants took a survey about their experience in this research project ("Table II"). The average score was all above 4.0 for all statements, while, "Gain hands-on skills related to the research", "Improvement of Innovation thoughts" and "Improvement of scientific thoughts and plan making" were the top three with an average score ≥ 4.5 ("Table II"). Therefore, the apprenticeship research program significantly developed undergraduates' scientific skills and enhanced their innovation thoughts.

TABLE II. FEEDBACK FROM THE PARTICIPATE UNDERGRADUATE STUDENTS AFTER THE COMPLETION OF THE RESEARCH PROJECT

Item	Score M (±SD)
This apprenticeship research project helped me to…	
Increase my interest in research work	4.48 (±0.33)
Learn a food science topic in depth	4.25 (±0.20)
Gain hands-on skills related to the research	4.92 (±0.17)
Improvement of scientific thoughts and plan making	4.51 (±0.69)
Item	Score M (±SD)
Improvement of Innovation thoughts	4.89 (±0.42)
Establish good communication with team members or other staffs	4.36 (±0.34)
Develop an orientation toward future work and education	4.34 (±0.81)

[a.] Note: 5 - point Likert scale 1 = strongly disagree; 5 = strongly agree.

The discussion of each stage was demonstrated below:

1) Marginal participation: The marginal participation described the first stage of participated undergraduates grew from novice to skilled scientist. This identity construction required constant and full participation in community practice and more time and effort. The attitude and ability of the novice in engaging in marginal affairs would gain the trust from senior students and be accepted for contributing to the community. In the interview by the end of the program, several students talked about their feelings at stage I which were indicated below:

- Xiao Li said:

Don't refuse to do anything minor since small things helped me accumulate scattered knowledge. And maybe just because of this, I had more understanding and recognition about team and the project in a short time.

- Zhu Chen said:

When I joined this program, I was a sophomore. A senior student divided the project into several modules for each new member and patiently explained potential problems and how to solve them. I think the seniors are more approachable, relatable, and able to personalize teaching than faculties."

- Sihui Tian said:

Senior students maybe did not deliberately emphasize the professional socialization of scientific research, but they always conveyed the attitude, spirit and values that are needed for research with action. I got a good start with the help of those senior students. At that time, they assisted me to be familiar with the technology, and be part of this team, making my communication circle more extensive. Their work style affected us remarkably.

2) Full participation: As the improvement of their abilities, personality and professional abilities, the participated undergraduates upgraded from the edge to the center and became core power of the research community. Trough marginal participation, the apprentice has gained certain scientific knowledge and skills as well as knew about the potential value of scientific research culture [17]. However, during the first stage, they have not experienced the feelings of working as a scientist. Thus, full participation in the project was to switch the students' role from a novice to a scientist [18]. At the second stage, junior students worked as scientists and involved in the actual research work, helping them establish a scientist's sense of identity and independent thoughts [19]. Compared with first stage, the students at this stage were the core of research project. In other words, they had to handle more challenging tasks, including defining scientific questions, conducting experiments, and analyzing results independently. Therefore, the apprenticeship research could also be considered as an advanced scene study which made the program more complete, comprehensive and advanced. The feedback from students about this stage (stage II) were as follows:

- Wenjun Wu said:

When I stepped into the second stage of the project, I had to do almost everything independently which is really a turning point for me.

- Libin Sun said:

There is a lot of differences between stage I and stage II. For example, except skills or techniques, I need to think how to design the study and how to deal with troubles occurred during my experiments. Only in this way, I finally understand which is the key point and which step needs special concern in my project. You will be in a completely independent status.

3) Practicing professional identity: At stage III, the senior students became either team leaders or the mentors. Generally, the primary work for mentors were to guide sophomore students. From the aspect of organization perspective, the mentors' guidance is the basic driving force for effectively operating scientific research team. From the aspect of students themselves, acting as a mentor to guide others is a process of in-depth learning [20] (Arnesson & Albinsson, 2017). Based on learning pyramid, students can master 90% of the learning content via mentoring others. Thus, rather than a waste of time, guiding new team members is the best way to learn effectively. In addition, it is a great way to cultivate the sense of responsibility and dedication spirit. Through practicing professional identity, students gained higher-level cognitive capability and a wide range of professional socialization, including communication, coordination, team management, responsibility and entrepreneur spirit. Besides, they fully experienced the socialization of scientific research. The feedback from students about this stage (stage III) were as follows:

- Huijun Cui said:

After recruiting new members in the team, the important work of our senior students is to work with them. To be honest, we are really very happy to guide them because I want them master solid lab skills and contribute more to the team.

- Yi Qin said:

I am very lucky to be elected as the team leader. I am not doing the exact lab work anymore. However, there are things more tough, such as financial issues, personnel arrangement, and balancing every part of the project. I have to admit it is tough days for me, but I harvested innovative scientific thoughts, hands-on skills and better organizing skills.

4) The role of teachers: The appendiceship research program allowed maximum participation for undergraduate students; however, the role of teacher was indispensable [21]. First, teachers focused on goal settings for the research project, while, the students focused on specific experiments operations. Furthermore, the teacher was concerned about delineating basic subject discipline such as basic concepts and theory explanation when guiding students [22]. Using the subject knowledge map, teacher assisted students established the relationship between the project and the subject knowledge system [8]. Additionally, teachers intentionally emphasized the scientific behavior norms, aiming at developing students' scientific spirit and attitude [23]. As mature scientists, teachers are very clear that scientific research has its specific sociality. When students conducted scientific research training, they had to realize both the intellectual development and the professional socialization [24]. Thus, teachers also payed special attention to the education of students' scientific quality. In the interview, Shanshan Chen said: The teachers never talked about detail technical issues in the project, instead, they controlled the direction of the project. Then, I gradually understand that each part of work we have done were under consideration of organizing whole project.

By the end of the program, the participated students ended their program by presenting their research (including research results, awards or publications) at the annual University-wide Undergraduate Symposium. The achievements of this apprenticeship research program were shown in "Table III". There were total 4 students receiving prizes in food product development competitions at national, state and college levels, respectively. Also, three students had publications in some prestigious journals which were related their research project.

TABLE III. THE ACHIEVEMENTS OF THE PARTICIPANTS IN APPRENTICESHIP RESEARCH PROGRAM

	Student Name	Award Name	Entry Name
Product development competition	Yi Qin	"Wens Cup" National College Student Product Innovation and Entrepreneurship Competition	"Calcium" Sweetheart Cheese Ball (Third Prize)
	Zhu Chen	Fresh edible mushroom seasoning	Food Innovation Contest of University Student in Liaoning Province (Second Prize)
	Wenjun Wu	Wheat Germ Tea	Food Innovation Contest of University Student in Liaoning Province (Third Prize)
	Xiao Li	Blueberry Jelly Complex	Shenyang Agricultural University College Student Food Innovation Contest (First Prize)
Publications	Student Name	Journal Name	Publication Name
	Libin Sun	Trends in Food Science & Technology	Advances in umami taste and aroma of edible mushrooms
	Shanshan Chen	Matrix Science Pharma	Aronia melanocarpa, response surface methodology, ultrasound-assisted extraction, anthocyanin, antioxidant activity
	Huijun Cui	Molecules	A "Green" Homogenate Extraction Coupled with UHPLC-MS for the Rapid Determination of Diterpenoids in Croton Crassifolius

B. Extension thinking: improvement of the institutional support for undergraduates research

In this study, the apprenticeship research program was proved to be challenging but very beneficial because the undergraduates not only operated their research work but also designed study plans and solved technical problems. The learning time was sufficient (approximately two years), and there were multi-level interactions among sophomore, juniors, seniors and teachers. This is helpful for undergraduates to develop high-level cognitive ability and had growth in professional socialization [25]. Whether innovative talents can be taught in this way is still controversy. However, it is believed that if education module had the trend of developing the advanced cognitive capability of student, it is can be regarded as an effective way to cultivate innovative talents [26]. From this perspective, the apprenticeship research program is proved to contribute for innovative talents cultivation. In order to support scientific research for undergraduates, institutional support and related management are suggested as follows: First, a diversified reward structure to enhance teachers' guidance on undergraduates' research activities should be set up. Secondly, the undergraduates' scientific research activities should be included in the formal training system, providing a benign interaction with the curriculum system. The best way is to introduce scientific components into the curriculum and integrate them as a whole.

IV. CONCLUSION

The results of this study indicated that the apprenticeship research program is efficient for cultivating undergraduates' innovative thoughts. Through three stages of research work, the participated undergraduates learned study design, technical skills, problem solving abilities etc. Also, they demonstrated positive attitudes and confidence after the research project was completed. The findings of this study revealed favorable outcomes associated with using the apprenticeship research program.

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