Interest-motivated Discovery Learning in Interdisciplinary Engineering: A Student's Perspective

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***Abstract*—The article, rather than from an educator's perspective, discusses the responsibility of the students on interdisciplinary engineering learning. Interest-guided discovery learning method is suggested according to the special requirement of interdisciplinary engineering. Despite the guides from course tutors or project advisors, students are encouraged to actively search opportunities to plan to learn knowledge and skills required by different disciplines involved. The function of laboratory research participation is discussed as an early training and familiarization with research methods and skills, as well as a way to build up confidence. Interdisciplinary knowledge acquisition and synthesis is demonstrated through an engineering student's own learning experience in bio-inspired robotics.**

***Index Terms*—Interdisciplinary engineering, discovery learning, bio-inspired robotics, student research.**

I. INTRODUCTION

Interdisciplinary engineering is much older than a recent concept. It emerged as soon as engineering science started to become specified into subdisciplines. In the study published by the U.S. National Academy of Engineering [1], it is stated that:

> *"Since the late 19th century, when the major subdisciplines of engineering began to emerge, engineers have been aware that solutions to many societal problems lie at the interstices of subdisciplines."*

While engineering science as a general category has more and more specific disciplines, the need for engineers to work across traditional disciplinary boarders and with basic sciences becomes stronger.

As the first part of the chain, international engineering education community has focused attention on this need in recent years. It seems that an engineering degree program emphasizing inter- or multi- disciplinary focus would be appropriate. It sets forth also in [1] the desired attributes of engineering graduates in 2020 and described the U.S. National Science Foundation's role in providing an environment to solve interdisciplinary problems. In China, a national education reformation of university unification and disciplinary adjustment in the last decade has targeted at improving interdisciplinary education and research, including engineering disciplines. In a presentation by the Chinese Academy of Engineering on the Facing 21st Century Innovative Engineering Gifts Cultivation Forum stated: [2]

> *"University disciplinary construction and adjustment should be based on the objective laws of technology development and progress... Contemporary technology development trend is…highly integration based on highly differentiation…resulting the emerge of new inter- and multi-disciplines."*

Similar statements can be found in other national engineering organization guidelines, such as [3] from the UK and [4] from Korea and Japan, etc.

Interdisciplinary engineering teaching and learning has been recognized by education and research evaluators. In a study [5] by the Carnegie Foundation for the advancement of teaching, Sheppard selected schools that "ensure attention to issues that are critically important to engineering education…", looking at "programs that are highly interdisciplinary". In the first released evaluation report [6] on China Higher Institution Scientific and Technological Innovation Competitiveness, 15 out of the top 20 most competitive institutions were benefiters from the disciplinary adjustment movement mentioned above. The evaluation included factors such as undergraduate teaching, etc, which had been added elements of crossing disciplinary borders. At the same time, there are more and more engineering schools around the world which have started courses or even degrees in interdisciplinary engineering. [7, 8, 9]

However, there is a shortage of student's perspectives from a learner's point of view published on how we can actively learn for interdisciplinary engineering research. Four pieces of paper were retrieved at the time when this article was being written. Preston described how department designed courses had helped him understand in depth biotechnological related problems and offered him undergraduate research opportunities that detailed class learned concepts and trained his practical skills. [10] Snow gave several examples of students who learned to integrate environment engineering with other disciplines, such as epidemiology, etc., with professional or field work experience in a graduate program of water systems and science. [11] A progressing work was mentioned by Matusovich et al. to in-depth investigate how female engineering students were attracted to an engineering-projects-in-community-service program and how the service-learning matches their objectives. [12]

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Atakpu-Abraham et al. found from a student's survey that "courses that provided an overview of one or more engineering disciplines and connected the field of engineering to other engineering or non-engineering disciplines are likely to have increased student's ability to communicate more effectively about engineering overall." [13] All these students' viewpoints were opinions surrounding certain university program or courses. Besides what is being taught by tutors and designed by courses, are there other methods we can use to make learning more efficient? How do we decide what to learn in order to do better further research in an interdisciplinary engineering field? In this paper, an interest-motivated discovery learning method is suggested with first hand material from an interdisciplinary engineering student's perspective, in which learner's responsibility is emphasized related to further study plan or career development.

The paper is consisted of three major parts. Chapter II will analyze different types of study motivations with a focus on interest's importance for being a good learner. Chapter III will introduce learning methodologies that support the learning process discussed here. A planned learning process to actively solve the problem is then suggested in Chapter IV, including how to profound understanding of an interesting topic or hypothesis by participating student's projects and cross-disciplinary courses, the good about early research practices, etc, using a case study in the area of bio-inspired robotics.

II. MOTIVATIONS

We choose to study a discipline for many reasons. A survey with 874 university students in the area of Beijing [14] showed that 47.7% students selected their major based on interest, with 23.3% on future job market and 10.9% on major popularity. Another survey with 185 people showed a similar result, including those who had graduated or who were studying for a degree at the time. [15] Even though 49.7% students believed that they had chosen an interesting major to study, only less than one third admitted them fully or partially understood what their majors were about when they made the choice. The results can be interpreted from different aspects. Some high school graduates take the subjects they used to be good at as their primary interest without a real understanding, and some students choose to go for career oriented study by knowing the major but putting down individual interest. Course design in the high school can also be an important factor in introducing university majors to students, and developing/killing a student's motivation in learning.

Student's motivation can be described by the expectancy-value theory developed by Fishbein. [16] The theory reveals that learning has to have perceived values out of the following four categories: [17]

--Intrinsic motivation: out of their own interest.

--Social motivation: in order to please people whose opinions are important to them.

--Extrinsic motivation: because of the value they attach to what the outcome brings, such as scholarships or better job hunting, etc.

--Achievement motivation: in order to compete and win.

There is no definite evidence found showing which motivation is the best for short term learning. However, the author believes that interest will be the most effective motivation to learn interdisciplinary engineering, especially if the learning continues and turns into a research oriented process. There are three reasons for that.

First of all, the motivation function of interest in learning was advocated by Dewey in 1913 that the positive contributions of the idea of interest are twofold. [18] It protects us from a merely internal conception of mind and from a merely external conception of subject matter. Thinking of the mind as an inner world of itself is not compatible with the conception of interest as an activity that moves toward an end and search for means. To avoid externality of subject matter, the presented mater must mean something complete to the students in its readiness and fixed separateness. This means that interest it not obtained by thinking about it and aiming at it, but by considering and aiming at the conditions that lie back of it, and compel it. [19] Interest is of great importance for:

--deciding what to do for future life, so called life or career plan.

--continuous learning, as it is spontaneous, giving someone a positive psychology to willing to do so.

--leading to life success and satisfaction after continuous working on it.

Secondly, the characteristics of interdisciplinary engineering learning and research require that a student should have a variety of background knowledge. Such big amount of information absorption needs the learner to have the strong willing to embrace different disciplines and have the energy to carry on with them for a period of time until they are absorbed and further integrated.

Thirdly, interest motivated learning is specially recommended for students who are research oriented as it normally takes a relatively long time. As for a Doctor of Philosophy candidate, it takes 3-7 years, if not longer, to complete study on a certain project. Plus 3-5 years on earning an undergraduate degree, one's effectiveness and productivity of learning in such a long time span in life would be doubtful if he/she does it without interest. The unappealing learning topic does not contribute to post-study career development either. Some students would choose a totally different area to work, like finance, and the knowledge and skills learned in the university would partly be a waste.

Therefore, it is important for students to understand what area they want to study. Such a decision is necessary for both bachelor degree targeted and research oriented students. Universities can help students to maximize their chances of finding out what they are interested in by implementing various course arrangement systems, such as dual degree courses and major re-selection in senior years, etc. Through exposure to different modules and levels of knowledge, engineering students should be able to find their interest in more and more detailed area, which helps them with future career development no matter in industry or research laboratories.

III. LEARNING METHODS

Learning interdisciplinary engineering is a long and effort required process. Besides guidance from universities and tutors, student's understanding of reasons for course arrangements and useful learning methods is also helpful. In this chapter, I will discuss the function of guidance in learning, and learner's initiative in finding a research topic, followed by an introduction of how discovery learning is a good method for interdisciplinary engineering students.

A. Guided learning

Engineering students in early undergraduate years usually receive fundamental education such as mathematics, physics, and major related general courses, etc. Besides being a preparation for advanced courses, such arrangement is practical guidance for freshmen and sophomores who are lack of understanding towards what they will learn and how the courses will help develop their interest and skills in engineering science. In so far as there is any evidence from controlled studies, it almost uniformly supports direct, strong instructional guidance rather minimal guidance during the instruction of novice to intermediate learners. [20] In later years of study, a student is trained to become more familiar with the current application and future research trend within his/her specific engineering major. During this stage we may have more chances to learn interdisciplinarily, and be encouraged to learn more independently, as a preparation for professional career immediate after graduation or further research work. Considerably guided interdisciplinary engineering training may be sufficient for industrial job need as the main training purpose is experience, familiarity and confidence. [3] However, no course arrangement can answer the interest from every individual. This is more obvious for those who want to pursue a research degree such as a doctorate. Students' own effort will be a definite advantage for both choosing a matching research area and future work progress.

B. Learner's initiative

As mentioned previously, the two major choices after graduation of an engineering student are finding a job and doing a further degree. Course designs for undergraduate interdisciplinary engineering studies target at preparing students with realistic projects and strong industry links. [3] Undergraduate study will enable graduates to work in multidisciplinary engineering environments or to be system integrators. From this point of view, getting involved in realistic projects under the course guidance will be the best thing that one is encouraged to do if he/she plans to go into industry after bachelor graduation.

In an institute, academic resources are organized by tutors. Research projects and facilities are under the supervision of professors and research staff. What students are suggested to do is to actively search resources that will deepen understanding of his/her topic alongside with receiving arranged classes. That is where I see student's responsibility in learning is. The decision to make such extra effort is up to students themselves, they will learn no matter in a cross disciplinary course, or in a laboratory.

For a research oriented student, effort is needed in finding research area or topic that attracts him/her the most, as well as seizing gliding opportunities that would contribute to the understanding and familiarity with the topic. An interesting topic can be gradually selected from what are taught in the fundamental and major courses. The motivation of doing further research under the topic can be enhanced by increasing involvement in projects and student research.

Initiative is a good way to form one's own knowledge structures. Through different trying, a student can understand better what is most related to what he/she wants to do, and what are the current international activities and resources in the same area. More practically, students with initiative are better appreciated by tutors and advisors, which adds positive points for further development and research job application.

C. Discovery learning

Having discussed the importance of educator's guidance and learner's initiative, we move on to methodologies which make the learning process more effective and scientific. In pedagogy, there are methods called active learning and discovery learning which emphasize learner's role in minimally guided learning processes. Those learning methods started a big education movement in the U.S. back in 1960s. Since the last decade in the twentieth century, new learning methodologies including problem-based learning and inquiry-based learning have become more and more popular in teaching science and engineering courses. Fanduizhe think that they are just alternative names for the same thing as unguided or minimally guided learning, which not only is less effective, but also may have negative results when students acquire misconceptions or incomplete or disorganized knowledge. [20] Advocates argue that they are not minimally guided instructional approaches but rather provide extensive or at least considerable guidance to facilitate student learning. [21]

In my opinion, all the methods emphasize learner's own effort in trying to understand new things through a discovery learning process, no matter what their names are. The originator of discovery learning theory Bruner stated that discovery learning takes place in problem solving situations where the learner draws on his or her own past experience and existing knowledge to discover facts and relationships and new truths to be learned. [22] This is detailed by Ormrod, according to whom discovery learning is *"an approach to instruction through which students interact with their environment by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments"*. [23]

As indicated in [1], the purpose of interdisciplinary engineering is to provide solutions to new problems. This intrinsic characteristics requires discovery learning, and it is encouraged for students who have found an interesting research area. It was discussed in the previous session that initiative is important for a student to gain multidisciplinary knowledge and extensive practical skills, and this is where the discovery activities are based on. We need to notice that discovery here doesn't necessarily mean a new breakthrough in science and technology. It applies more to new knowledge acquisition for individuals.

IV. INTERDISCIPLINARY ENGINEERING LEARNING: A CASE WITH BIO-INSPIRED ROBOTICS

In the previous chapters I have discussed the importance of interest as motivation and effectiveness of discovery learning method in interdisciplinary engineering. It takes a young student a process to develop his/her interest and to plan learning for an interest based topic. Hereby I would combine my own learning experience with bio-inspired robotics and show a possible way of how such learning can be conducted, and how one can learn to solve an interesting problem while training research skills. The chapter as a whole serves also as a general procedure for interdisciplinary engineering learning. The purpose is to suggest a possible way of learning rather than access the effectiveness of the outcomes.

A. Find an interesting topic

I entered Zhejiang University at the age of eighteen with a degree pursuit in information engineering according to my vague interest at that time. In the first year I studied calculus, linear algebra, physics, introductory computer science, and engineering graphics, etc, which was a continuation and development of my knowledge from high school. One year later, I received further courses on integral transformation, ordinary and partial differential equations, probability, circuit theory, digital and analog electronics, and signals and systems, etc. The course arrangement managed to introduce a new undergraduate to fundamentals in electronic engineering, which was a good preparation for more professional senior courses.

Through the introduction from course tutors, I learned that electronics can be used to control mechanical structures, and I became interested in robotics. The specific interest merged in my second year and motivated me to attend Asian Broadcast Union Robocon contest. I joined a team of three, with the other two from different engineering major background. We were guided by the university team advisor to work on mechatronic design of one wired robot and two autonomous ones, to perform tasks of collecting and shooting balls, and locomotion in the contest. During the preparation for the contest, I deepened understanding towards electronics and practiced mechanical design from advisor’s guidance and cooperation with other students. On the other hand, I found something which led my study afterwards. It was a topic out of interest and hands on experience, one that I never realized it would be a big topic for myself and even most robotists nowadays in the world:

> *How can we build up robots that are inspired by human beings and other living existences, such as how they think, move and interact with each other and the environment?*

B. Acquire missing knowledge

Such a problem requires knowledge from more than just electronic engineering and mechanical design. Missing knowledge should be acquired from other disciplines by taking courses and discussing with tutors and students from a different background. It was generally agreed that bio-inspired robotics is an area which covers interdisciplinary fields such as biology, robotics, artificial intelligence, biomechanics, cognitive neuroscience, psychology, electronics, and even sociology, etc. [24, 25] (Fig. 1) Although the idea of borrowing from natural design into robotics has been around for a while, bio-inspired robotics has only come into a fast development in the recent ten years. [26, 27] For such a frontier research subject, it might be too early to have a specific course designed at undergraduate level in most universities.

Having analyzed my missing part for the problem, I decided to take extra courses in biology, human body and computer science, etc. It was the time when Zhejiang University started to encourage cross subject study by making it possible for students to select and organize their own courses in an online course selection system. In the third and fourth year, I studied physiological psychology, cell biology, human senses, human anatomy, pattern recognition, etc. Such interdisciplinary sourcing not only rainforced knowledge to an electronic engineering student, but also gave him enough confidence to enter different subjects. From those courses, I saw in reality how muscles were attached through tendons onto bones so that joints could be controlled, I also learned about concepts such as neural networks, etc.

Discussion with people from a different background helps bringing different ways of thinking and makes one's mind more sophisticated. I once had a discussion with a tutor from the course human senses on the topic of robotic vision. The tutor further explained optical and neural mechanism behind motive vision and three-dimensional vision. I managed to relate it with what I had learned in opto-electronics, which triggered further thoughts in photo detective devices' use with bio-inspired neural network algorithms in robotics. Such joint thinking is a great practice for interdisciplinary engineering learning.

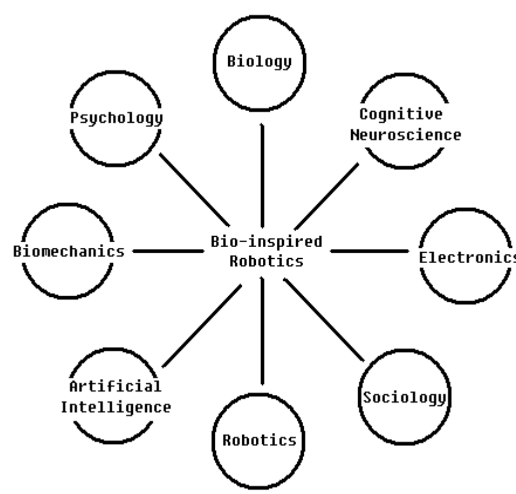

Fig. 1. Bio-inspired robotics covers a wide range of subjects from biology to robotics.

C. Student research

Research activity is usually a higher level of academic practice, which requires developed capability of solving problems and mature technical skills of reasoning and proving. Due to the limitation of knowledge and skills, undergraduate students are normally not exposed to real research works. In a survey in a class of 34 graduated students who were doing a degree in electronic engineering, 18 chose to work after graduation and none of them considered themselves related to any real research apart from course or summer projects. Among the 16 other students who continued to pursue a postgraduate degree, only two recognized themselves were trained in a laboratory research with higher degree students when being undergraduates. Situation may vary between majors, universities and educational systems. However, being lack of knowledges and skills required by scientific research is a general concern for undergraduates entering laboratory work. For the majority, practice activities are most in the form of course works, competitions, vacation placements, and degree projects, etc. Such arrangement is a definite training for student's skills at the same time with short period goals; however active laboratory research involvement has much more contribution in leading a young engineering student to advanced academic works.

First of all, early research activity helps students who have further research plans familiarize with the laboratory environment and commonly used tools such as softwares and electronic devices, etc. Compared to normal practice activities, laboratory research maximizes the chance for students to use such tools. Working in a research environment also contributes to the building of confidence for a student who is a new comer to serious scientific research. At the same time, students have the opportunity to have handa-on experience with usual research methods on reasoning, proving, and mathematics, etc. In my case, I studied bio-inspired neural networks' use in machine classification with a master's degree candidate in a laboratory when I was in my final year in the Zhejiang University. Before that I had already learned such softwares as Matlab from courses related to signal processing and scientific computing. While doing the research with neural networks, I further developed Matlab skills as it was daily research platform for machine data processing and neural network modeling. During a ten months' research training, I became more familiar with common commanding as well as specific computational methods, for example, partial differential equation and weight coefficient, etc. I also learned to demonstrate the efficiency of the bio-inspired neural network model by comparing it with conventional neural networks and even human subjects. My work was published on international conference proceedings [28] and further edited into a book *Advances in Neural Networks* by Springer. Such a trying is positive for young researchers and will greatly broaden their mind of conducting research.

Secondly, working in a team for a common goal is a good training in terms that a student will be able to experience a complete procedure of research, such as progress report to the supervisor, and discussion with other team members, etc. With the professional training that is received nowhere else, a student will learn how to cooperate with professors and colleague students to contribute to the whole project.

Thirdly, laboratory research is more intense than other means of practice activities. We can learn about the situation of the global research in the same area, such as researchers from different institutions. Large amount of academic information absorption will also let us know the active journals, conferences and associations, which are good resources to acquire the latest news and submit our findings for peer review.

It is not practical for universities to arrange research activities for all the undergraduate students, as not all demand such training, and there is a limit of facilities and resources. Therefore, for those who plan to conduct advanced research in the future, it is encouraged to actively pursue opportunities in laboratories based on their interesting problems. It establishes research concept and develops independent skills, which is a positive effort during discovery learning.

D. Knowledge synthesis

How to find out relationships of knowledge between different disciplines is one of the real challenges learners and even researchers are facing. During my study, I came across many occasions where different terms and ways of explanation from different disciplines actually point towards the same thing. However, people from different fields tend to discuss with names and ways they are familiar with but new to the others. Although that is a barrier for understanding, it is where one can learn what he/she has been familiar with from a different point of view or what is needed but missing in the interdisciplinary study, once the barrier is tackled by going deeper into different fields. Therefore, the progress of integrating knowledge and making the most of all disciplines is not just a simple addition equation, but rather a process where one rediscovers known as well as establishing relationship between known and unknown.

After graduation from Zhejiang University, I went to study further in biomedical engineering in the then newly approved postgraduate programme in the University of Oxford. Having been guided to learn courses in different areas of biomedical engineering, I found out that biomechanics was what was missing in my knowledge and could contribute as another important aspect to bio-inspired robots. I therefore chose to study human gait analysis, muscle modelling, and Ground Reaction Force correlation in jumping using the programme project resource including National Health Service (NHS) gait laboratory.

The three different knowledge clusters and experience from information engineering, neural networks, and biomechanics has formed the most part of my knowledge structure. During both guided and discovery learning, I have found out that neural control can be combined with the musculoskeletal system and form a complete biological cybernetic loop with feedback. Although many issues are still under discussion and waiting to be clarified in the area, it just adds more interest and excitement to my research. At the same time, when this neuromusculoskeletal scheme is transferred to engineering, one of its most promising application is in robot's locomotion and its adaptation to the environment, which I have chosen as my doctorate research topic.

V. CONCLUSION

With support from learning theories and personal experience in bio-inspried robotics, I have tried to demonstrate from a student's perspective, that an interest-guided discovery learning process with emphasis on learner's own effort can be a good way for interdisciplinary engineering learning.

First of all, as interdisciplinary engineering learning requires large amount of knowledge acquisition and a relatively long time, interest would be the best motivation for learners who is targeting to be a top researcher.

Secondly, the intrinsic characteristics of interdisciplinary engineering is to solve problems that a single discipline is not able to. Discovery learning tackles problems from learner's own past experience and existing knowledge to discover facts and relationships and new truths, and is therefore one of the most suitable ways for students.

One might argue that the perspective in this paper is too personal. However there are four issues I would like to remind readers. First of all, it was not comparing to convince which learning methods were the best but rather suggesting a possible way to learn to prepare and get close to the research you are interested in. If such a possibility exists, it is positive to share with the community. Second, as shown in Chapter II, not every one doing multidisciplinary engineering study or research is driven by interest. The paper advocates interest-guided learning and proposes a discovery route of active learning. Thirdly, although example is from the writer himself, it has been recognized by world renowned universities and research projects, especially during doctorate application and interview, experience in neuroscience and biomechanics has been confirmed to be important for a newly established bio-inspired robotics laboratory in ETH, Zurich. Lastly, in any interdisciplinary research lab, members are specialized in different fields and work together to achieve cutting-edge results. For example, the supervisor in our lab is from a background of artificial intelligence and mechanical engineering, while both of my colleagues have a degree in mechanical engineering. However, to know more cross-disciplinary results is always helpful as being proven in my research so far.

Students are suggested to first follow the course guidance to acquire fundamental understanding towards a major and gradually build up their research interests out of the obtained knowledge. In any education system, even the most embracing ones that are designed for interdisciplinary engineering, student's own responsibility to actively get involved in study and practice is never over emphasized. The benefit of cross discipline knowledge digestion, early research experience, and familiarity with engineering research methods and techniques can be obvious in a more advanced research stage and midwifery of new products.

ACKNOWLEDGMENT

L. Wang thanks all the students from Class 1, Grade 2002, Information Engineering, Department of Optical Engineering, Zhejiang University, for their cooperation in survey feedback on the topic of undergraduate research.

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