Engineering Outreach: A Successful Initiative With Gifted Students in Science and Technology in Hong Kong

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***Abstract*—The primary goal of engineering outreach is to attract prospective students to engineering education and the engineering profession. Gifted students, especially those identified as possessing unusually high abilities in science and technology, are especially promising students to attract to careers in engineering. It is critical to cultivate these students' interests and develop their potential for engineering while encouraging them to pursue engineering studies beyond K-12 education. This article presents examples of the successful learning outcomes of an ongoing University-based Electronics Technology Project Study (UETPS) program, a joint endeavor between the IEEE Hong Kong Section, the Education Bureau of the Hong Kong SAR Government, and the Hong Kong Academy of Gifted Education (HKAGE). The UETPS program promotes electrical, electronic, and computer engineering education in Hong Kong and is aimed particularly at gifted students as well as their parents, teachers, and schools. Project applicants underwent formal identification procedures by the Gifted Education Section of the HKSAR Education Bureau and were identified as being gifted in the area of science and technology. Selected participants then participated in one-year research projects in electronics and computer engineering under the guidance of university professors in their respective engineering departments. This program addresses an urgent need of the engineering education sector by reaching out to highly talented K-12 students and their surrounding communities. According to the evaluation results, the UETPS program has significantly enhanced the participating students' interest in engineering as a career choice and encouraged them to pursue undergraduate studies in engineering. This article also discusses lessons learned and proposes strategies for future potential implementers.**

***Index Terms*—Engineering education, gifted education, IEEE student activities, outreach.**

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I. Introduction

GIFTED students possess unusually high talent and aptitude, which may be expressed in a specific academic field. They are among the top 5% of the K-12 population. As the primary goal of engineering education outreach programs is to attract promising students to enroll in engineering education and eventually pursue an engineering career, outreaching efforts that target this gifted minority, especially those gifted in the area of science and technology, are essential.

In Hong Kong, gifted education has received attention from both the government and schools since the early 1990s [1]. To respond to the K-12 education needs, and as an engineering outreach activity since 2006, the Hong Kong Section of the Institute of Electrical and Electronics Engineers, Inc. (the IEEE Hong Kong Section), the Gifted Education Section of the Education Bureau of the Hong Kong SAR Government (EDB), and the Hong Kong Academy of Gifted Education (HKAGE) jointly organized the University-based Electronics Technology Project Study (UETPS) program. Its main objectives were to promote engineering education in Hong Kong, especially so for science and technology gifted students studying at secondary levels (equivalent to grades 7–12 within the U.S. education system), as well as the wider community of their parents, teachers, and schools. In UETPS, university-based engineering training is offered to secondary school students identified as gifted in science and technology. Pedagogies including inquiry-based learning, scaffolding, and cognitive apprenticeship, are implemented to inspire their interest and develop their potential in engineering. Overall, the program helps attract the science- and technology-talented youngsters to opt for electrical, electronic, and computer engineering programs in their undergraduate studies, where they will be prepared to contribute to society as future engineers. This article documents specific ways in which such efforts have been implemented as a model for other educators.

II. Background

A. Giftedness and Gifted Education

In educational psychology, giftedness is considered as a category of special needs, characterized by unusually high ability in one or more areas, to the extent that students require special educational services in order to help them meet their full potential [2]. There exists considerable disagreement as to a clear operational definition of "giftedness" among experts [3], [4]. Traditionally, students who possess intelligence quotient (IQ) scores of over 130 in composite tests are regarded as gifted students, and those who have reached 160 or above are described as exceptionally gifted [5]. Instead of this uniform, single definition of giftedness, it can alternatively be defined as reflecting possession of unusually high ability or aptitude in one or more areas, including general intellectual ability, aptitude in a specific academic field, creativity, visual or performing arts, and leadership [6].

Apparently, gifted students who possess high abilities can achieve normal school objectives with ease. However, students with special gifts and talents may become frustrated when normal school experiences do not offer sufficiently challenging tasks and assignments and thus fail to help them develop their unique abilities [7], [8]. Some educational psychologists have suggested ways to foster the special abilities and talents of gifted students, such as providing individualized tasks and assignments, establishing study groups of students with similar interests and abilities, and teaching complex cognitive skills within the context of specific areas [2]. Studies have found that for the highly technological subjects of science and engineering, cultivating a creative and supportive surrounding environment is essential [9]. Research has shown that special considerations are essential to gifted education in science and technology. These include frequent interaction with mentors, access to authentic equipment and materials, and sufficiently challenging curricula that entice students to embark on self-initiated learning [10], [11].

B. Gifted Education Programs in Engineering Contexts

There are few international studies of gifted education programs involving engineering and computer science training. For example, a series of gifted enrichment programs are offered by the Gifted Education Resources Institute (GERI) at Purdue University, West Lafayette, IN, which include a summer residential camp offering a variety of training, such as in civil and electronic engineering, for students between grades 5 and 12. Participants must present documents that provide evidence of high achievement or potential in a corresponding talent area [12]. The Education Program for Gifted Youth (EPGY) at Stanford University, Stanford, CA[13], offers multimedia distance-learning courses to gifted and talented students in subjects including computer science. Students (normally aged between 6 and 14) admitted to the program must demonstrate a high degree of mathematical or verbal ability on the basis of standardized testing. Examples outside the United States include the Residential Space Science Summer School offered by the United Kingdom National Academy for Gifted and Talented Youth, where gifted students ages 11–16 met at the Imperial College London, London, U.K., for three weeks and carried out space science research [14]. The Science Mentorship Program jointly offered by the Singapore Ministry of Education and various engineering departments in universities in Singapore [15] targets secondary-3 and -4 (grades 9 and 10) students to obtain the Gifted Education Program (GEP) qualification. Compared to these overseas references, one unique feature of UETPS is that it comprises a multiparty and multidisciplinary joint endeavor between the Hong Kong SAR Government Education Bureau and professional organizations from engineering (IEEE Hong Kong Section) and education (HKAGE) as well as faculties from engineering departments in different local universities.

Encouraging results have followed the completion of gifted education programs. For example, research evidence suggests that programs for gifted students inspire students in higher education more effectively [16] and are more likely to engage students to pursue related professional degrees and subsequent careers [17]. Furthermore, participants have typically shown increased interest in the subject studies [18]. These findings, together with the successful reference cases from overseas, establish a solid foundation for implementing the UETPS program as a strategy for engineering outreach.

C. Overview of Gifted Education in Hong Kong

According to the Hong Kong (SAR) Education Bureau, the mission of gifted education in Hong Kong is to explore and fully develop the potential of gifted students, both systematically and strategically, by providing them with opportunities to receive education at appropriate levels in a flexible teaching and learning environment [19]. Basically, a school-based approach for gifted education has been adopted in Hong Kong, within which gifted students receive their education in normal schools. Gifted education is thus implemented as a part of normal education, and schools are expected to provide sequential and multiple educational activities for their gifted students at different levels. Nevertheless, special measures and off-site support outside schools are provided for exceptionally gifted students, in order to help them develop their potential more fully [20], [21].

1) Operation Levels of Gifted Education: A three-tier operation mode is adopted in implementing gifted education by the Hong Kong Education Bureau [22]: whole-class (level 1), pull-out (level 2), and off-site support (level 3). The first two levels are school-based, while the third level involves organizations external to the schools.

For level 1 (whole-class), the core elements advocated in gifted education (high-order thinking skills, creativity, and personal-social competence) are integrated in the curriculum for all students. Appropriate groupings of students and differential teaching methods are applied in order to meet the different needs of each grouping, with enrichment and extension of curricula offered across all subjects in regular classrooms. Level 2 (pull-out) operations are also conducted in normal school education settings, but are designed to be implemented outside the regular classroom. In particular, pull-out programs of a generic nature are conduced to allow systematic training for a homogeneous group of students—that is, those who show exceptional achievement in specific subject domains such as mathematics and sciences. Level 3 operations correspond to off-site support as provided jointly by the Education Bureau and external organizations such as local universities, museums, and educational bodies. In such collaboration, expert groups are formed to both initiate and develop resources, such as those available at [23], [24] to support gifted education. These organizations also helped in providing workshops in gifted education for local schoolteachers, such as [25].

2) Identification of Gifted Students: Rather than relying solely upon the more traditional use of professional composite IQ test evaluations, the Hong Kong (SAR) Education Bureau has adopted broad, multiple criteria for classifying student giftedness, such as those defined by Marland [26]. In general, those students regarded as being gifted [19], [22] show exceptional achievement or potential in one or more of the following areas:

1) a high level of measured intelligence;
2) specific academic aptitude in a subject area;
3) creative thinking (demonstration of high ability to invent novel, elaborate and numerous ideas);
4) superior talent in visual and performing arts such as painting, drama, dance, music;
5) natural leadership of peers (demonstration of high ability to move others to achieve common goals);
6) psychomotor ability (for example, outstanding performance or ingenuity in athletics, mechanical skills, or other areas requiring gross or fine motor coordination).

In Hong Kong, students with excellent potential in certain domains are admitted through specific routes such as citywide competitions or school nominations. The school nomination exercise begins in September and October of each year, when teachers are invited to nominate their students according to the guidelines provided [27]. Screening and identification are conducted in November and December. The screening exercise includes an initial examination and activities such as written tests or group interviews. The schools are informed of the results in January, and in turn, then inform the students and parents concerned.

3) Support Measures for Gifted Students: The "support measures for the exceptionally gifted student scheme" [21] was launched by the Hong Kong (SAR) Education Bureau in 2001 to help nurture and develop the potential and talents of gifted students as identified by the procedures described above. The scheme falls into the level-3 gifted education operation framework. In addition to the programs designed for these gifted students, professional development programs are also made available for both their teachers and their parents. Currently, enrichment programs in four domains are offered—namely, leadership, science, mathematics and the humanities. Multidisciplinary programs *across* domains are also provided. UETPS is a program for students gifted in the science domain.

D. Related Pedagogies

UETPS draws upon a number of educational theories including inquiry-based learning, scaffolding, and cognitive apprenticeship. A brief overview follows of these pedagogies and research findings indicating how these pedagogies enhance gifted students' learning.

1) Inquiry-Based Learning: Inquiry-based learning is a pedagogy developed from Dewey's work in the United States [28], which proposes that learners may acquire new knowledge through formulating questions. Instead of simply answering questions posed by instructors, learners are encouraged to formulate (and test) new hypotheses in order to solve problems. Through the process of inquiry, individuals construct their own new perspectives and knowledge. In this way, self-generated (and autoregulated) inquiry motivates learners to need, or want, to know. Inquiry-based learning also places emphasis upon the development of an individual student's inquiry skills and thus enhances an inquiring attitude [29]. Inquiry-based learning is thus very different from general project-based learning: The former emphasizes the inquiry processes throughout the entire project, while the latter focuses more upon the development of the ultimate deliverables. Traditional education does not favor inquiry. In conventional direct instruction, students are not encouraged to raise questions. They are instead taught to listen and memorize standardized answers to solved problems. In contrast, UETPS seeks to establish close mentor–mentee relationships between participating students and professors in order to facilitate inquiry-base learning, with the aim of working toward the solution of *un*solved problems.

Research concerned with inquiry-based approaches to learning have revealed positive effects upon important aspects of learning with gifted students and has been expressed in terms of significant increases in content knowledge, including scientific concept difficulty levels [30], marked increases in (and deeper levels of) higher order thinking [31], and an increasing interest in careers in science and engineering [32].

2) Scaffolding: Scaffolding is a major constructivist concept developed by Bruner [33]. Metaphorically resembling the way(s) in which the scaffolds of a physical building operate, a similar process may be said to facilitate knowledge construction. In order to enable such scaffoldings, a significant learning task should not be so simple that learners can quickly respond with ease. When learners are being asked to solve nontrivial problems, they will often require greater support in order to detect and utilize the most salient, available information, when working toward reaching the most accurate conclusions and desired outcomes. In this way, an instructor (providing scaffolding as a more capable, knowledgeable peer) can provide instructional aids to facilitate the learning process. Instructional scaffolds can be provided in both tangible and intangible formats, including regular meetings and discussions between the learners and their mentor-instructors, with relevant reference materials being exchanged with, prepared by, or collected by the instructor.

Research has revealed encouragingly positive evidence for the impact of skilful scaffolding focused upon reasoning, self-regulative thinking, and process-based approaches to learning science with the use of learning tools and gifted children's rapid learning [34]. Furthermore, activities requiring gifted students' negotiation with experienced teachers have resulted in demonstrable changes in students' evolving conceptual understanding

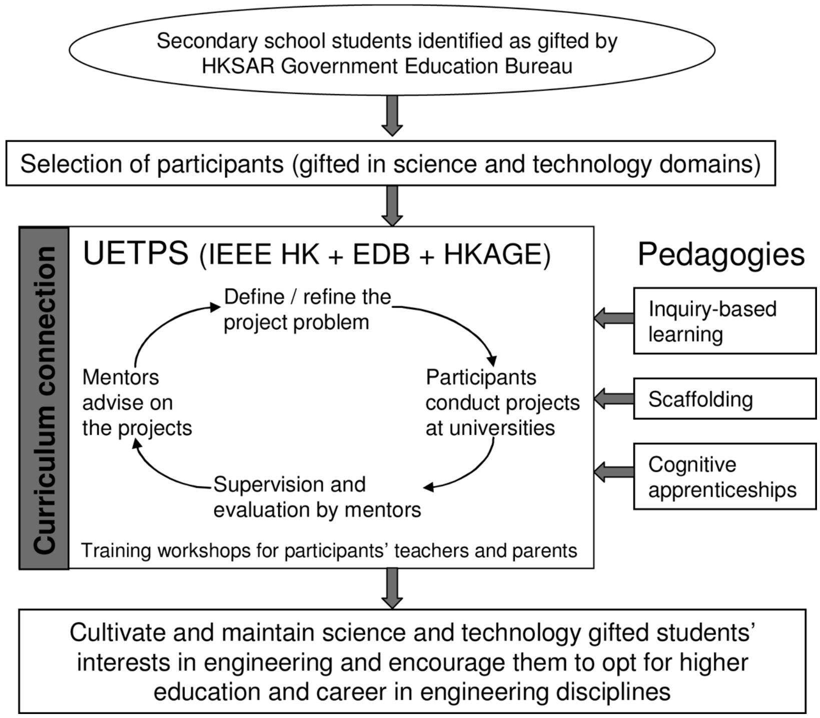


Fig. 1. Implementation framework of the UETPS program for science and technology gifted students.

and their beliefs about the nature of scientific problem-solving [35].

3) Cognitive Apprenticeship: Cognitive apprenticeship describes an educational practice in which a teacher and a student (or a group of a small number of students) work together in a mentor–mentee relationship in order to accomplish a challenging task or to solve a difficult nontrivial problem [2]. Through cognitive apprenticeship, students often learn not only how to complete a task, but also how to *think about a task*[36]–[38]. Cognitive apprenticeship typically has the features of modeling, coaching, scaffolding, articulation, reflection, increasing complexity and diversity of tasks, and exploration [39]. Cognitive apprenticeships also require the setting up of deliberate, intensive communication and interaction between teacher and students, a practice which is rarely affordable in normal classroom settings.

Research has shown cognitive apprenticeship serves as a viable tool for effective science teaching and learning [40]. Qualitative research concerned with the investigation of the characteristics of gifted students has shown that optimal cognitive apprenticeships will include methods involving focusing, coaching, scaffolding, articulation, reflection, and exploration as playing an important role in the development of giftedness [41], [42].

III. Implementation

UETPS was first launched in 2006 jointly by the Gifted Education Section, Curriculum Development Institute, Hong Kong SAR Government Education Bureau, and the IEEE Hong Kong Section. The HKAGE has also provided coordination and administration support since 2009. The program reaches out to prospective engineering students in local secondary schools while also providing supportive educational developments for gifted students working in the science and technology domains. Its implementation framework is depicted in Fig. 1.

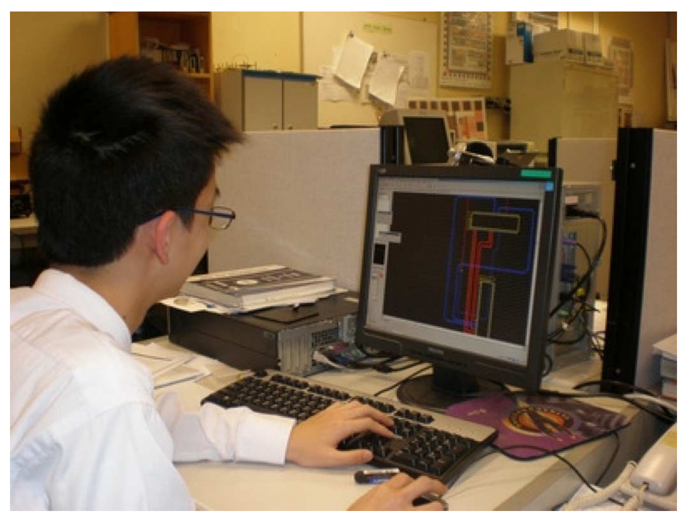


Fig. 2. A participating student performing a circuit design experiment in an electronic engineering laboratory at university.

A. Schedule

Each implementation of UETPS spans a single year. Throughout each one-year study project, participating students (the mentees) undergo their study in groups under the guidance of professors and/or chartered engineers (the mentors). Mentees negotiate with their mentors for the project title, appropriate meeting times and venues, and their scheduled number of meetings. The experiments and projects were conducted in university laboratories (Fig. 2). Upon completing the project,

TABLE I
SCHEDULE OF THE UETPS PROGRAM

Date	Event	Details
May – June	Application and consultation period	Student participants (the mentees) contact the potential mentors of their chosen projects to obtain a deeper understanding of the projects' probable time requirements, as well as to allow solicitation of advice from their potential mentors.
July	First meetings	Matched mentees and mentors get to know each other; all participants sign the Student's Pledge of Commitment; each group also generates and agrees a completed project plan.
July – March (next year)	Project study	Mentees conduct the project under the supervision of respective mentor; mentors complete individual student Progress Reports; a minimum of 20 hours of face-to-face contact are required per group.
Early March (next year)	Submission of the final project report	Reports to include sections including Introduction, Background, Method and Results, Discussion, Conclusion, and References.
March (next year)	Closing and project presentation	All groups present their final report and the learning outcomes developed. Awards are presented to best-performing groups in terms of overall project design and implementation as well as technical knowledge.

each group is required to write a report and also deliver a presentation. Upon the project's completion, participants who have met all the requirements of the project scheme, and who are recommended by their mentors, will be awarded certificates. Awards are also presented to the best-performing groups in terms of overall project design, implementation, and technical knowledge. The program schedule follows the course as provided in Table I.

B. Selection of Participants

The participants are local secondary school students. Most are attending Secondary 4 to 6 (equivalent to grades 10–12 in the USA), with a few exceptions. They come from diverse school backgrounds within the Hong Kong secondary education system, ranging from ordinary grammar schools to top-tier, academically advanced schools. All applicants must first undergo the rigorous selection procedures for gifted students as described in Section II-C2 and be identified as gifted and talented in the domain of science. Before the start of the program, mentees contact their potential mentors, often through face-to-face meetings, according to their area of interest. During early contacts, mentors also evaluate their potential mentees' suitability for participation in the program. In particular, the following criteria were imposed for the selection of participants for engineering training:

1) whether students understand the concepts associated with potential projects and are capable of learning and conducting such research projects;
2) whether their interest in engineering research is such that they can commit to the significant time commitment for the projects.

C. Curriculum Connection

Most projects offer an early preparation for gifted students to enter first-year engineering undergraduate courses while simultaneously requiring mastery of the fundamental knowledge (and beyond) of current territory-wide secondary-school-level science and technology curricula, namely the Hong Kong New Senior Secondary (HKNSS) Physics and Information and Communication Technology curricula [43]. In this sense, UETPS helps bridge the gap between university engineering education and secondary school science education. Basic skills in problem-solving, scientific investigation, thinking, and communication were also involved in the UETPS engineering training. Fig. 3 depicts these relationships.

D. Outreach to Participants' Teachers and Parents

Throughout the project period, subject teachers (usually those of physics and information communication technology) at the participants' own schools were regularly contacted to provide their feedback on participants' learning progress at school.

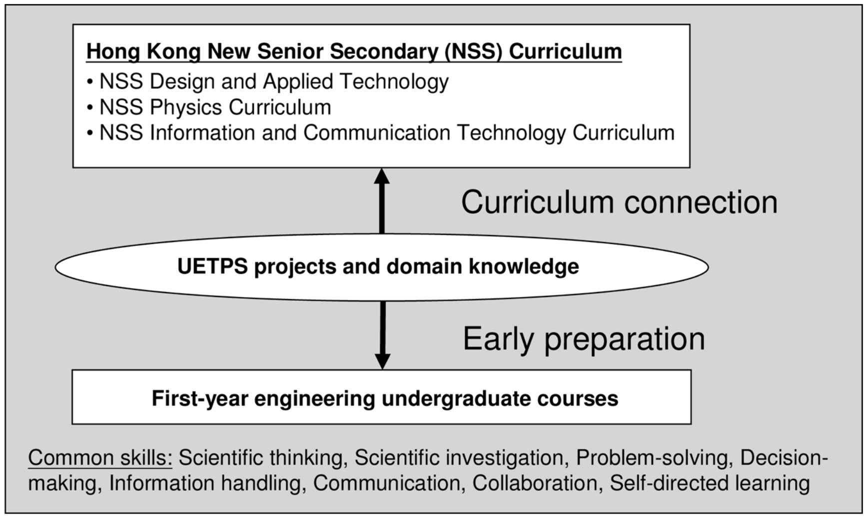


Fig. 3. Curriculum connection between UETPS, Hong Kong New Senior Security curriculum, and engineering undergraduate education.

These teachers also learned about their students' progress in conducting project learning at their university engineering departments and provided recommendations to the program organizers. Participants' parents were also invited to join the Parent Association for the Exceptionally Gifted, where they attend workshops for parenting gifted children, and exchanged their experience in developing their children's talents and interests with other parents. At the beginning of each program period, all participants' parents are invited to visit engineering laboratories at universities and to attend workshops conducted by engineering professors that introduce the engineering disciplines and ways to study engineering. Thereby, UETPS not only reached out to the participating students, but also to their teachers and parents.

IV. Case Studies

In this subsection, two case study student projects for gifted students in science and technology are described in detail. In each case, details such as connections with the curriculum, the particular problem to be solved, interactions between mentor and mentees, and the student's feedback are discussed. The first case study project was conducted by a single mentee, while that of the second case study was conducted by a group of students.

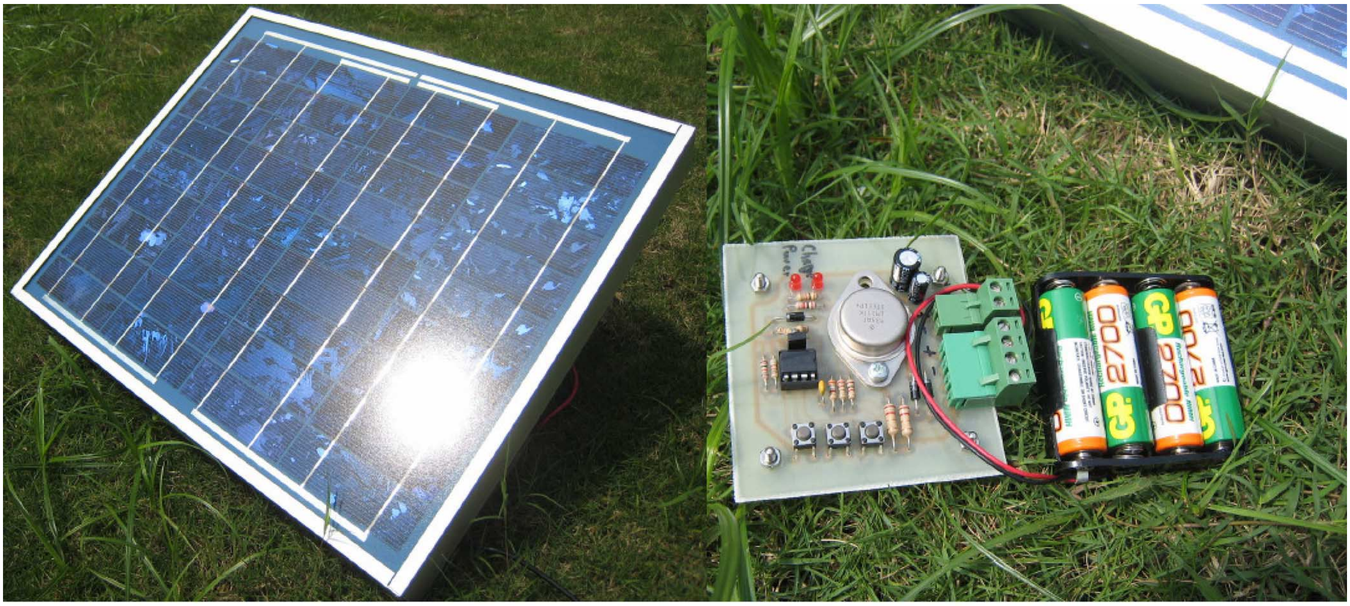
A. *Case 1: Photovoltaic Charge Controller*

In this project, a Secondary-4 (equivalent to grade 10 in the USA) student designed and built a photovoltaic (PV) charge controller under the supervision of the mentor, who was a chartered electrical and electronic engineer with long industrial experience. The system was to charge AA batteries for domestic use. The PV charge controller consisted of two integrated circuits (ICs) (MC33340 and LM317) and a diode (1N4002). The PADS Logic software was used to draw the circuit. The final product is shown in Fig. 4.

1) Curriculum Connections: This project involved knowledge of PV systems (using solar cells to convert sunlight into electricity), circuit design, and construction. These contents required the use of basic concepts taught in the compulsory modules "Heat and Gases—temperature, heat, and internal energy" and "Electricity and Magnetism—circuits and domestic electricity" in the HKNSS Physics curriculum. The design and construction of the circuit also involved subject contents and techniques taught in existing first-year engineering undergraduate courses in Hong Kong, such as "ELEC151 Digital Circuits and System" (offered by the Department of Electronic and Computer Engineering, The Hong Kong University of Science and Technology) and "IEG1810 Electronic Circuit Design Laboratory" (offered by the Department of Information Engineering, The Chinese University of Hong Kong).

2) The Inquiry and Challenges: The problem to be solved in this project was to design and construct a PV charge controller for charging AA batteries for domestic use. The main challenges of this problem were the instability of the current produced by PV cells and the potential damage to the PV cell if the battery voltage were higher than that of the PV cell.

3) Mentor–Mentee Interactions: Originally, the project was to produce a pedometer (an electronic device that counts the number of steps a person has walked). However, the mentee found this less interesting than working with PV systems. Therefore, he proposed his own *inquiry* to the mentor in early meetings. The mentor accepted the change, as students often learn best when intrinsically motivated. A *cognitive apprenticeship* was thus built and maintained between the mentor and the mentee. For example, the mentor guided the mentee to think about the circuit using vivid analogies of daily life, such as by making the analogy between a more effective charging method and the shaking down of rice inside a container to accommodate extra rice being poured in. According to the mentor, the mentee might have underestimated the project difficulty level at times. Therefore, the mentor intentionally arranged a "wrong" component to be included in the circuit, which gave unusual readings for the circuit's measurement. He then *scaffolded* the mentee to solve the problem by guiding him to think about the possible causes of the measurement errors.



(a) (b)

Fig. 4. Photovoltaic charge controller built by participating student: (a) the PV cells and (b) the controller circuit.

The mentee modified the circuit himself and took different sets of readings. After rebuilding and retesting the circuit several times, the mentee finally figured out the cause of the error and identified the wrong component in the circuit. The mentee seldom experienced "failure" in an area within his gifted domain (which can be very frustrating to many gifted students). Howeveer, with the mentor's guidance, the mentee successfully explored the debugging process (which can be frustrating but critical for engineers) while learning techniques and strategies for engineering problem-solving, testing, and validation.

4) Project Outcomes: A PV charge controller for charging AA batteries was built. Two enhancements were implemented in the controller over conventional designs: 1) instead of controlling the charging process simply with a diode, an IC was designed so that the charging process could be stopped automatically when the temperature became too high; and (2) a better charging result was enabled by converting the dc current from the PV cells into pulses. The participant also gained knowledge in electric and electronic engineering as well as the experiment techniques for solving engineering problems.

5) Student Feedback: The following is an excerpt of the feedback given by a mentee (male, 16 years old): *I learnt a lot of useful things in the program and it was a very meaningful experience to me. It is also a very rare chance to learn such knowledge for a Secondary 4 student in Hong Kong. Furthermore, it makes me feel that the government really provides more programs to fulfill the needs of gifted children and give the opportunity for them to learn something that they are capable of, but out of their school syllabus.*

6) Comments: The above case corroborated the effect of scaffolding in gifted students as suggested by [31] in that the mentee changed his beliefs about the nature of scientific and engineering problem-solving. Through such cognitive apprenticeship, the Secondary-4 mentee had the opportunity to learn directly from an engineer who is an expert in electronic and electrical engineering and acquired knowledge and experimental techniques that are normally taught only at more senior secondary or even undergraduate levels.

B. Case 2: A Sensor-Based LCD Thermometer

In this project, a project group of two secondary-4 (equivalent to grade 10 in the USA) students went through a formal research process, including literature review, problem formulation, problem-solving, prototype-building, testing, and modification, resulting in their final deliverable. They built an LCD thermometer under the guidance of an associate professor in the Department of Electronic and Computer Engineering in a university in Hong Kong. A Ph.D. student also worked with the students occasionally. This case is of particular interest in that the gifted mentees demonstrated both an attitude toward and an aptitude in scientific research normally shown only by final-year undergraduates or even postgraduate research students.

1) Curriculum Connections: This project involved knowledge of circuit design and construction as well as of semiconductor and temperature sensors. Parts of these contents were related to the compulsory modules "Heat and Gases—temperature, heat, and internal energy" in the HKNSS Physics curriculum and "Electronics—electronic signals, devices and circuits" in the HKNSS Design and Applied Technology Curriculum. In addition, the project also involved contents taught in a number of existing engineering undergraduate courses in Hong Kong such as "ELEC151 Digital Circuits and System" (offered by the Department of Electronic and Computer Engineering, The Hong Kong University of Science and Technology) and a more advanced course "ELE4510 Physics and Technology of Semiconductor Devices" (offered by the Department of Electronic Engineering, The Chinese University of Hong Kong).

2) The Inquiry and Challenges: The primary goal of the inquiry was to build a digital thermometer using a temperature

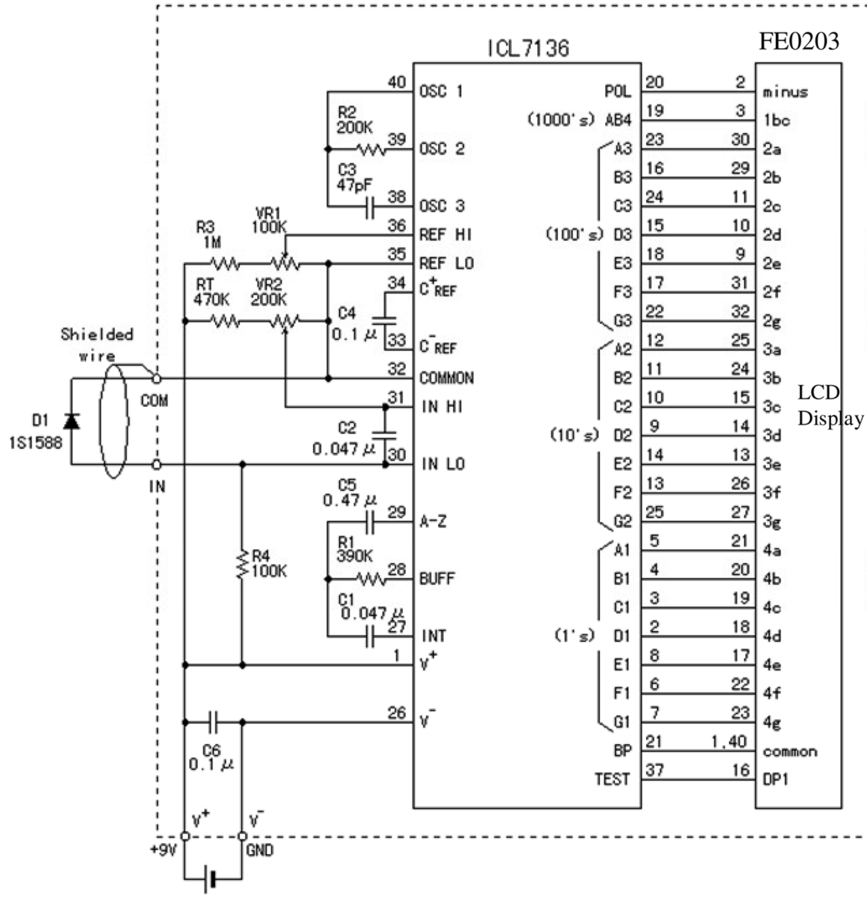


Fig. 5. Circuit diagram of the LCD thermometer designed by participants.

sensor and LCD display. The main challenge here was that, given the mentees had only received conventional science education at the Secondary-4 level, they had to absorb what was for them advanced theory and knowledge, such as the use of silicon diodes and band-gap temperature sensors. It was also challenging but exciting for them to work in an engineering research laboratory environment together with post-graduate students. The main circuit designed by the mentees is displayed in Fig. 5.

3) Mentor–Mentees Interactions: The mentor–mentees group defined the project in four phases. In the first phase, the mentees studied the theory required for building an LCD thermometer under the guidance of the mentor. These theories, which included the working principles of the diode temperature sensors as well as analog and digital systems, were regarded as being advanced for normal students of Secondary-4 level (grade 10). Nevertheless, the mentees were quite able to explain these principles in their own words after the learning process. In the second phase, the mentees searched for and purchased the required components on their own. They went to shops in Ap Liu Street (a specific location in Hong Kong famous for selling electronic parts and components), but could not obtain the components. In the end, the mentor provided the required components, including a band-gap diode temperature sensor (1S1588), an A/D converter chip (ICL 7136), and an LCD display (FE0203). Although the mentees failed to find the components, they underwent experiential learning through the search process otherwise not available within the classroom. The third phase was circuit design and prototype building using the Protel software for printed circuit board (PCB) design and circuit drawing. According to the mentees, this phase was challenging to them. They first learned the software by themselves, and later, with scaffolding from a doctoral student, they mastered the skills and completed the circuit design. In the last phase, the product was built. The mentees documented the learning process and related theories in their project report. The mentor provided guidance throughout the four phases while providing room to allow the mentees to inquire, explore, and learn by themselves.

4) Project Outcomes: In addition to providing tangible outcomes, namely a sensor-based thermometer with LCD display, this project also achieved intangible outcomes, including the advanced knowledge learned by the mentees, the experience of the complete cycle of engineering product design and development, and allowing them to feel the inspiration of engineering research.

5) Student Feedback: The following is an excerpt of a mentee's assessment (female, 16 years old): *This is a very great opportunity for us to learn more about electronics. Rarely can we be involved in the process of making an electronic device. It is really an eye-opening experience for us to have this project done. Besides, the circuit we drew is not an easy one. Having done this project, we really understand how difficult it is to design and make an electronics product work, and starting from*

TABLE II
RESULTS OF THE STUDENT SURVEY

Category A: Effectiveness in Fostering General Learning Skills	**Mean**	**SD**
My confidence has been increased after the project.	3.84	0.75
The project enhances my analytical ability.	4.12	0.67
The project enhances my creativity.	3.88	0.67
The project enhances my problem solving ability.	3.96	0.68
The project enhances my active learning.	4.04	0.61
The project enhances my ability to work as a team.	3.96	0.61
Category B: Effectiveness in Engineering Learning		
The project enhances my learning of science and information and communication technology at school.	3.28	0.94
I seek advice from my teachers about my project when necessary.	2.76	0.93
The project enables me to gain knowledge related to the project topic.	4.15	0.64
The project enables me to learn the engineering research techniques.	4.24	0.66
My level of interest in electrical, electronic, and computer engineering has been increased.	4.08	0.57
I have gained better knowledge in engineering after completing the project.	4.08	0.76
I am interested to further my studies in the electrical, electronic, and computer engineering disciplines.	4.08	0.64
Category C: Evaluation of Mentors and Overall Project Arrangement		
The project goal is clear.	4.17	0.54
The project time is sufficient.	3.48	0.96
The mentor is able to help me to learn the required skills and knowledge in engineering.	4.36	0.57
The mentor is ability to help me to define a clear research problem.	4.36	0.64
The mentor has inspired my thinking.	4.24	0.43
The mentor's explanation is clear and organized.	4.24	0.67
The mentor is able to help me to solve the problems I encountered in the project.	4.28	0.61
The number of meetings with mentor is sufficient.	3.68	0.85
The equipments in the laboratories are sufficient.	4.16	0.85
Mentor and other programme staffs provided sufficient supports throughout the project.	4.20	0.76

this moment, we sincerely admire the engineers and appreciate their efforts made for improving the living standard of all mankind.

6) Comments: Through their participation in the UETPS program, gifted students expressed appreciation toward the engineering profession, its research leaders, and the contributions made by engineers to society. The mentees also came to know "what they do not know} and to ask questions aimed at best answering their own inquiry from their mentor(s) during the process. With appropriate scaffolding through interacting with professors and doctoral students, the gifted mentees thus had the opportunity to develop their interests, potential, and achievement in engineering well beyond that of their normal school class peers.

V. EVALUATION

This section provides an evaluation of UETPS. Multiple data sets (quantitative and qualitative) were used to examine the effectiveness of the program in terms of gifted student learning and the success of this program of engineering outreach.

A. Participant Outreach and Their Characteristics

All student projects were carried out in the form of cognitive apprenticeship, each offering relatively rich, yet typically labor-intensive, mentoring. In order to maintain the quality of the program, the number of participating students was kept to around 20 per year, with a maximum mentor-to-mentee ratio of 1:3. Since the program also involves professional development activities with the participants' parents and teachers, together with the publicity activities organized at the schools, the number of potential target outreach students every year is thus far beyond these figures.

Most participants (90%) are male students, 10% of whom were age 14 or below when enrolled to the program; 34% were between 15 and 16, most participants (42%) were 16 to 17, while 14% were age 18 or above. In terms of school levels, 26% were Secondary-3 students, a further 12% Secondary-4. Most participants (40%) were at Secondary 5, the remaining 22% at Secondary 6 or above. The figures indicate that the majority of the participants were senior students about to choose a discipline for their undergraduate studies.

B. Student Survey

A quantitative survey was conducted with students who had completed their UETPS project ($N = 29$), which evaluated the effectiveness of student learning, their level of interest in studying engineering, and whether the program had encouraged them to choose electrical, electronic, and computer engineering as future university electives. The 23 items assessed three aspects of the program: its effectiveness in fostering general learning skills, students' subject knowledge learning in engineering and related domains, and the overall arrangement of the project. All items were responded to via a 5-point Likert scale, where a score of 1 indicated strong disagreement and 5 indicated strong agreement. The results are listed in Table II.

1) Effectiveness in Fostering Higher Order Thinking and Social Skills: The scores of the items in this category ranged between 3.84 and 4.12, indicating that most students thought their learning skills had been enhanced by the project. In particular, they agreed that their higher order thinking skills such as creativity ($\mathrm{Mean} = 3.84$, $[\mathrm{SD} = 0.75]$), analytical ability ($\mathrm{Mean} = 4.12[0.67]$), and problem-solving ability ($\mathrm{Mean} = 3.96[0.68]$), social skills (work as a team with others, $\mathrm{Mean} = 3.96[0.61]$), active learning ($\mathrm{Mean} = 4.04[0.61]$),

TABLE III
RESULTS OF THE TEACHER SURVEY

	Mean	
Students' confidence has been increased after the project.	4.13	1.13
Students' interest in electrical, electronic, and computer engineering has increased.	4.43	0.53
Students have gained better knowledge in engineering after completing the project.	4.43	0.76
The project enhances students' analytical ability.	4.00	1.15
The project enhances students' creativity.	3.86	1.07
The project enhances students' problem solving ability.	4.25	0.71
The project enhances students' active learning.	4.38	0.74
The project enhances students' ability to work as a team.	4.14	1.21

and confidence in learning ($\text{Mean} = 3.84[0.75]$) had been enhanced by their project experience.

2) Effectiveness in Engineering Learning: The scores of most items in this category were generally scored higher than those measuring the effectiveness in general learning skills. Except for two items related to the project experience of participants' learning at school ["The project enhances my learning of science and information and communication technology at school" ($\text{Mean} = 3.28[0.94]$); "I seek advice from my teachers about my project when necessary" ($\text{Mean} = 2.77[0.93]$)], the scores for items in this category ranged from 4.08 to 4.24. These results reflect perceptions of the projects' high effectiveness in enhancing participants' learning of domain knowledge in engineering. For example, knowledge related to the project topic ($\text{Mean} = 4.15[0.64]$), the engineering domain ($\text{Mean} = 4.08[0.76]$), engineering research techniques ($\text{Mean} = 4.24[0.66]$), and increased levels of interest in electrical, electronic, and computer engineering ($\text{Mean} = 4.08[0.57]$) were all scored relatively high. More importantly, participants indicated that they were now more interested to pursue further studies in the electrical, electronic, and computer engineering disciplines ($\text{Mean} = 4.08[0.64]$).

3) Evaluation of the Mentors and Project Arrangements: Participants also commented on their experience of their mentors and the overall project arrangements. In general, mentors received high scores from the participants' evaluation, which ranged between 4.24 and 4.36. In particular, students agreed that their mentors had helped them learn the required skills and knowledge in engineering ($\text{Mean} = 4.36[0.57]$), defined a clear research problem ($\text{Mean} = 4.36[0.64]$), inspired their thinking ($\text{Mean} = 4.24[0.43]$), and aided solution of the problems encountered in the projects ($\text{Mean} = 4.28[0.61]$). Mentors' explanations were also claimed to have been clear and well organized ($\text{Mean} = 4.24[0.67]$). However, relatively lower evaluation scores were recorded for items concerned with the available project time ($\text{Mean} = 3.48[0.96]$) and the frequency of mentor meetings ($\text{Mean} = 3.68[0.85]$).

C. Teacher Survey

A simple quantitative survey consisting of eight questions was conducted with the participants' teachers at school. These questions asked whether changes in learning skills and improvement in engineering knowledge were observable in their students since project participation. Although the sample size is small ($N = 8$), these observations served as useful independent indicators for the accuracy of participant's self-reports as previously presented. The teacher survey results are depicted in Table III.

According to the teachers' observations, significant changes were observed in students' interest in electronic, electronic, and computer engineering ($\text{Mean} = 4.43[0.53]$). Furthermore, they indicated that their students had gained a better knowledge of engineering ($\text{Mean} = 4.43[0.76]$). Consistent with the findings of the students' survey, positive changes were observed in various learning skills and attitude of the students, including students' confidence ($\text{Mean} = 4.13[1.13]$), analytical ability ($\text{Mean} = 4.00[1.15]$), creativity ($\text{Mean} = 3.86[1.07]$), problem-solving ability ($\text{Mean} = 4.25[0.71]$), active learning ($\text{Mean} = 4.38[0.74]$), and their ability to work as part of a team ($\text{Mean} = 4.14[1.21]$).

D. Mentors' and Parents' Feedback

Mentors were involved significantly throughout the entire project, and as such, offer firsthand observations and experiences that may now serve as valuable reference for future implementers. For example, mentors agreed that participants' interests in engineering continued to rise and that the program helped promote engineering as a career choice for the gifted students: *[The project] can increase the [participating] students' interest in engineering. They exceed my expectation. The project is a very effective way to promote engineering to students* (Mentor A, 2008). Mentors also appreciated students' outstanding performances, creativity and their ability to work as a team: *The students were very creative and worked with excellent team spirit. Their performance was satisfactory and encouraging* (Mentor B, 2008). *We highly appreciate the effort put in by the participating students, and observe that they possess high potential in engineering research. They can accomplish and even go beyond, our expectation* (Mentor C, 2007). Consistent with the students' evaluations, however, mentors also expressed difficulties in arranging meetings and project hours with the students: *Basically quite good in attitude, but sometimes difficult to make appointments with them, as all of us are busy* (Mentor D, 2007). *The arrangement is reasonable, only that both students and mentors are very busy, and cannot work the project in a more relaxed manner* (Mentor E, 2007).

Parents' endorsements of their children's participation in the program were notably very important to the success of the students' projects. It is thus also an important step for engineering outreach activities to connect with parents, whose encouragement and positive attitude can significantly influence the academic choices of the students. In his feedback, a participant's parent was encouraged to see his son's participation in a formal engineering training program: *My son is very keen on learning electronics. He began doing electronic experiments on his own since he was young. Before joining the program, he learned electronics in some amateur clubs and bought the components in Ap Liu Street. I am very pleased that the program offered him chances to perform the experiments at university laboratories with engineering professors, so that his interests and potentials could be formally developed* (Parent A, 2009). Another participant's parent expressed amazement regarding his son's high-quality project report writing, one who normally was not competent in writing: *My son is not good at writing. I feel quite surprised that he can produce a high quality project report. He told me that it was because he was really very interested in the engineering project that he was so motivated to produce a good report with careful use of grammar* (Parent B, 2009).

VI. Discussion

A. Fulfillments of Program Goals

The primary goal of UETPS is to cultivate gifted students' interests in engineering and to elicit their potential in this direction. Constructivist pedagogies including inquiry-based learning and scaffolding were applied along with the cognitive apprenticeship of engineering professional mentors and gifted student mentees. Participants in the program to date have demonstrated remarkable knowledge advancements in areas of electrical, electronic, and computer engineering. Indeed, further independent evidence has begun to emerge in that at least two participants of the program have continued to compete successfully in science fair competitions at both the local and international levels. They received the first and second runner-up awards in the Hong Kong Youth Science and Technology Invention Competition (2008), and the Taiwan International Science Fair (2009), respectively.

The program has also implemented its goal of promoting engineering education to gifted students, their parents, and teachers. As indicated by participant evaluations, student interests in engineering rose considerably, with the majority expressing an increased interest in furthering their studies within engineering disciplines. These same students were also observed to have improved in the additional learning skills necessary for technological studies, including problem-solving skills and creativity. Only positive feedback from participants' parents was received in this regard.

B. Lessons Learned

There are a number of lessons that may be learned from the program implementation and that are worth sharing here. First of all, gifted students' needs are quite different from those of their normal class peers, and such needs may fit poorly with the usual daily classroom teaching (evaluation results indicate that they preferred learning with the professors at universities to learning with their own teachers at schools). UETPS offers a nonconventional mode of training for secondary school students who are highly talented in science and technology. The program has thus enabled students who are gifted in the engineering domain (and possibly with closer-to-average performance in other subjects) to develop their potential and talents more fully while also gaining confidence in learning. As noted by a few mentors, their gifted students could be inspired with relatively little scaffolding and were able to learn much by themselves with little guidance. Furthermore, they also possessed a high ability to learn and to master knowledge well beyond their current academic levels. The UETPS program has also enabled gifted students to acquire more contacts and interactions with technologies proven to be beneficial to their learning [42], [44], [45].

However, there are also several concerns with the program implementation that require further improvements. For example, the program is mentor-intensive and can only reach a small number of participants, even though it has also touched their teachers and parents. Therefore, there is a desire to scale up the program in order to make it a more widely available and practical solution for other implementers. Attention could also be paid to the program administration. For example, both mentor and mentees have expressed difficulties in arranging times for meetings. One possible solution is to invite personnel other than the professors and engineers themselves, such as laboratory assistants and postgraduate students as mentioned in the second case study, to assist in the mentorship process. As with many longitudinal programs of various kinds, there will be a few participant dropouts during the program period. Again, due to the labor-intensive nature of the cognitive apprenticeship model, participant dropouts, especially during the middle or near the end of the program, will have wasted resources (mainly mentors' time and students' own learning during their early participation). Therefore, participating students must be really very interested in engineering at the outset and really commit to persevere until the end (program mentors usually make their judgments according to their expertise and experience). By contrast, the mentors participating in the current study felt it well worthwhile spending time with these gifted students, who are highly interested in engineering right from the start. Lastly, participants did not easily relate their content learning experiences in UETPS with their learning at schools. A stronger tie may need to be built here. One possible solution is to place increasing emphasis upon the curriculum connection between the student's university-based projects and their existing school-based curriculum content applications.

C. Future Developments

The UETPS program will continue to run for the foreseeable future. Based upon the concrete and valuable experiences gained over the past years, strategies for further enhancements have been planned, resulting in this program better serving and apprenticing the highest quality engineering education students currently studying within wider schooling communities.

1) Scaling to Reach a Wider Audience: In addition to the existing mentorship-based mode for project execution, the program organizers have proposed a new two-phase execution cycle. In the first phase, workshops, seminars, and demonstrations concerned with selected topics in engineering (such as technology and society, as well as engineering research methodology) will be held. These workshops target a larger number of attendants so that a wider pool of gifted students may come into contact with engineering research studies. The second phase is equivalent to the current mentorship-based project study. Assessments will also be conducted during the workshops and seminars so as to identify potential promising phase one participants to be invited to enter the second phase of the program.

2) Building Stronger Ties With School Education: A stronger tie between the program and secondary level school education needs to be built, both at the curriculum and student levels. For the former, mentors and mentees will be encouraged to carry out project studies that clearly connect to existing school education curricula and to more obviously relate what they are learning in the projects with the corresponding syllabi. Such connections can help bridge the gap between school science education and engineering higher education. Furthermore, student participants can be encouraged with presentations of these previous students' progress (and/or results) in their own schools, to their fellow schoolmates, and possibly to other schools within or outside their own school districts. One additional benefit of this is to facilitate the sharing of their own engineering learning experiences with the wider pool of their nongifted peers and the potential undergraduate student communities considering a career in engineering.

3) Involvement of Educational Researchers and Experts: The participation of educational researchers is very important to the planning, implementation, and evaluation of engineering outreach activities. They can provide invaluable advice regarding learning and facilitation of learning with gifted and talented students. They can also be involved in collecting and analyzing data, while also providing new evidence regarding participants' learning so as to evaluate ongoing program effectiveness and suggest strategies for improvement.

VII. Concluding Remarks

As advocated by some educational psychology researchers [2], students with special gifts and talents may become frustrated when normal school experiences fail to offer tasks and assignments of sufficient levels of challenge and thus hinder the development of their unique abilities. UETPS not only continues to offer a unique learning opportunity outside normal classrooms for gifted students, but also serves as a successful engineering education outreach program for prospective electronics and computer engineering students with exceptional talents wishing to work in the domain of the engineering sciences. Reflections and feedback from the participating students has shown that the program has enhanced their interests and knowledge in engineering. Lessons learned and future proposals for scaling up such a program have also been discussed in this article. The program co-organizers, including the IEEE Hong Kong Section, will continue to support these endeavors while also devoting their collaborative efforts toward sustaining the success of these and future projects.

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