

A New Framework of Science and Technology Innovation Education for K-12 in Qingdao, China

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Recently, the development of new technologies such as Internet of Things, Big Data, and Cloud Computing have promoted the intelligentization of many industries and deeply changed the way of human production and living styles. Last year, AlphaGo defeated the top level human experts of Go chess many times, marking the start of a new IT era, and here IT is not Information Technology but Intelligence Technology. The new challenge of the K-12 science and technology innovation education (STIE) is to cultivate young students with advanced scientific literacy and help them to keep up the fast development in the Intelligent Technology era.

For the new IT era, we present a new STIE framework with iSTREAM multidisciplinary integration and CDIOS comprehensive processes ideas for K-12 students. iSTREAM and iCDIOS are natural extension of well-known STEM and CDIO (Conceive, Design, Implement, and Operate) programs, where i represents the new IT intelligent technology element for individual, inspiration, intelligence, invention, innovation, integration, interdisciplinary, international. Robotics, Research, Arts, Entrepreneurship, Management and Service are added and emphasized to provide comprehensive and systematic learning storylines from all dimensions.

This work is supported by many selected elementary and middle schools in Qingdao, a large coastal city with good educational background in China, and is also cooperated with educational equipment companies, normal universities, academic institutes, and local government. In this report, a brief review of our efforts on iSTREAM and iCDIOS will be first presented, and then the corresponding STIE framework, including vision, dimensions, ways, etc. will be introduced.

1. Background

With rapid development of science and technology, we have entered a knowledge-, innovation- and talent-driven era, in which interdisciplinary and innovative high-tech talents became the key winning resources. To keep up with the changing science and technology, it is very important to provide science education for schools from kindergarten to 12th grade and even just pre-kindergarten. Especially STEM (Science, Technology, Engineering, and Mathematics) or STEAM (add Arts into STEM) education originally from the US gives us a very valuable reference and inspiration. Over twenty years before, many countries such as the US, the UK, Germany, France, Japan, etc, issued successively corresponding policies and standards for STEM education, emphasizing the interdisciplinary nature of science education and the combination of science, technology and engineering practice. Furthermore, Seymour Papert, the inventor of LOGO computer language, who is also thought as the father of the maker movement, has advocated a concept of “learning by doing” [1]. Till 2012, the concepts

of maker, maker space and maker education have gained more and more attention [2]. STEAM and maker education have their own strengths and weaknesses and have a good complementarity [3]. Therefore, Science and Technology Innovation Education (STIE) is proposed to combine the STEAM and maker education, and is accepted by more and more K-12 schools in China.

1.1 Global Science Education

In 1996, American NRC(National Research Council) of NAS(National Academy of Science) issued the first national document “National Science Education Standard”[4] . In 2010, NAS, Achieve Inc., and AAAS (American Association for the Advancement of Science) started a new round of science education reform program, and issued “A Framework for K-12 Science Education” in 2011[5] and NGSS (Next Generation Science Standard) in 2013[6]. In NGSS, for the first time, engineering and technology education was listed separately and added to the standards of science education, and interdisciplinary learning and combination of science and engineering was emphasized. Knowledge from K-12 was reorganized into three dimensions: Science and engineering practice, crosscutting concepts and disciplinary core ideas. But how to implement this standard and balance interest among all stake holders such as government, business, industries, finance, etc. needs to be further studied. In 2014, NAS Publishing House published “STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research”[7], pointing out that there should be balance between integrated learning and disciplines learning.

In 2006, British Department of Education and Skill issued “The Science, Technology, Engineering and Mathematics Programme Report”[8], aiming at integrating the resources of all stake holders to provide a coherent, diversified and lifelong education network for all learners at a national level. At the same time, German Federal Education Department started two-step reform process and issued “Development of national education standard”[9], redefining education objectives, competency models and evaluation systems based on three-dimensional capacity model (capacity, subject knowledge content and ability level).

In France, science education standards are developed for primary school, junior high school and high school, respectively. In 2008, France implemented new science education standard “the new curriculum for primary school”[10], including discovery-oriented curriculum for primary students, experiment-oriented for junior high students, and integration-oriented curriculum for senior-high students. Japan's recent education reform was in 2008, with a focus on emphasizing scientific inquiry methods and life-related problem solving activities.

At the 2013 Global STEMx Education Conference, Finland, Australia, New Zealand and other countries have participated to discuss science education for new era. Along with science education reform, original meaning of STEM (Science, Technology, Engineering, and Mathematics) has been extended into many versions such as STEAM, STEMx, and etc. In STEAM, A (art) was added to emphasized the cultivation of humanistic literacy, While in STEMx, x means computer science, computation thinking, innovation and reform, global

communication and others, showing a great inclusiveness. And in this article, iSTREAM is also proposed as a new extended version of STEM.

1.2 Science Education in China

In the mid-1990s, with rapid development of economy, Chinese universities began large-scale enrollment, and then higher education transferred from elite education to mass education, which also caused a relative decreasing in the quality of students with lower learning abilities. In 2010, China has become the second largest economy obtained by the expense of resources and the environment. Therefore, there is an urgent need for innovative talents to transform economy of China from resources-extensive to innovation-extensive. Upon the arrival of intelligent technology era, innovative talents with science and high-tech literacy are imperative needed more than ever. Since 2015, China has initiated “Double Chuang” or “Tri-Chuang” national movement for Makers, Entrepreneurship and Innovators (MES) across all levels of government, researches, and education agencies. It is crucial to enhance and cultivate the science literacy of Chinese people K-12 and beyond by systematic science education reform to keep up with international advanced education development.

Along with global science education reform, China has been on the move and successively issued corresponding policies such as “National Science Literacy Action Plan” (also known as 2049 plan), “Guideline for National Science Literacy Action Plan (2006-2010-2020)”, “Implementation of National Science Literacy Action Plan (2016-2020)”, etc., aiming at cultivating and enhancing Science literacy for all Chinese Citizens for the construction of an innovative and comprehensive well-off society.

However, challenges remain and problems need to be solved in China. First, “One mile wide but one inch deep” exists in China too [11]. All knowledge for K-12 needs to be reviewed from a systematic view, from a “theory with practice” view, from a “from life, by life, for life” view. That’s to reorganize knowledge based on big ideas in different subjects and cross-cutting ideas to guide students to know better and live together with this natural and social world in harmony. Then, teachers are the key, therefore, they need to more open and get trained on new educational ideas, new teaching skills, new teaching scenarios and advanced educational technologies[12]; Third, evaluation system needs to be transferred from test-oriented system to multi-dimension-oriented systems step by step. Social education resources such as museums and open scientific platforms need to be fully utilized for citizens [13]. Last, there are no integrated and unified standards from educational equipments, science innovation curriculum, innovation labs, evaluation mechanism, etc. [14], so a top-down systematic design of science innovation education system for K-12 and beyond needs to be designed to motivate all stake holders and optimize social education resources from all levels.

1.3 STIE in Qingdao

Qiaodao, also known as "Eastern Switzerland", host city for International Congress on ICT (Information & Communication Technology) in Education twice, is a modern, advanced, international and coastal city. As one of the pilot cities of China's Ministry of Education, Qingdao pulls full strength to STIE. Recently, the Qingdao government issued "Measures for Primary and Secondary school management in Qingdao"[15], which is the first local government regulation on school with a focus on building a new ecosystem among government, schools and society based on government management, school self-running, social participation and supervision .

Qingdao Academy of Intelligent Industries (QAII) is an academy focusing on the industrialization of intelligent technology based on the Institute of Automation, Chinese Academy of Sciences (CASIA). QAII has utilized rich resources of frontier intelligent products and specialists to STIE, and is certified as a Qingdao Science popularization education bases, an Innovation Education Base for Qingdao primary and middle schools and a science popularization education bases by Qingdao Association for Science and Technology, Qingdao Education Bureau, and Chinese Association of Automation, respectively. QAII is committed to promote and implement k-12 STIE and build an effective standard system by Qingdao Education Bureau.

2. Proposed STIE Framework

2.1 Problems of STIE in China

Since 2014, STIE has been quickly spreading in China with more education funding from Chinese government, but problems come up successively. First, there is plenty of education equipments with different quality levels from various supplier companies, which makes a headache to pick the right product, so there may be a big waste on equipment with bad selection. Second, support services on equipment are generally not enough, especially lack of curriculum development and teachers training, and it is a very hard work for school teachers to study these equipment and develop curriculums in their spare time; Third, most curriculum mainly involves knowledge instillation with less engineering and technology practice, which is not very helpful to promote students science literacy; Forth, tons of off-campus STIE training institutes with a variety of education ideas cannot give systematic top-down curriculum design and related standards covering all grades, and teachers and students are tired to follow kinds of STIE services. Especially, it is very important to build a comprehensive evaluation index system to guide the selection or construction of equipment, curriculum, campus and off-campus STIE spaces, activities, etc. Finally, there is a high requirement for STIE teachers with cross disciplinary background and rich engineering experience, so a well-designed STIE framework is necessary for these teachers to help them effectively promote the students science literacy.

2.2 Demand Levels of K-12 Schools in China

According to our research, there are three demand levels for STIE in China’s K-12 schools. First, learning motivation for core subjects, such as mathematics, physics, geography, Chinese, etc. may be increased through STIE. It's true that some students show low interests on core subjects learning because of boring classes and heavy pressure. STIE classes generally involve many core subjects and demonstrate related knowledge in more interesting way. Second, STIE performance is considered in the evaluation system of school enrollment policy. With the process of education reform, more and more universities, middle and elementary schools pay more attention to enroll students with excellent comprehensive capacity and would like admit students with science and technology talent, so many students are intending to enhance their scientific innovation performance to enter into better schools. Last, also the most important demand is to cultivate students' scientific literacy, innovation spirit and practical abilities. In general, STIE gives more possibility to inspire the potential and motivation of students with flexible teaching and learning model, and it is a good test area to the new round of education reform in China.

2.3 Design Philosophy of STIE Framework

In September of 2016, “core competencies and values for Chinese students' development” (CCVCSD) was released in Beijing Normal University [16]. As shown in Fig. 1, its key point is to cultivate "all-round developed persons" from three aspects with six literacies: cultural foundation including humanistic connotations and scientific foundation, independent development including learning to learn and healthy living, and social participation including responsibility and practical innovation.

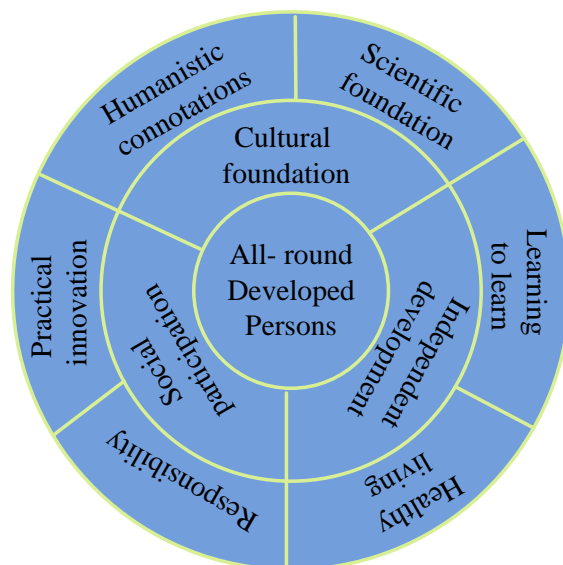


Fig. 1 Core competencies and values for Chinese students’ development

From the viewpoints of multi-disciplinary and cross-disciplinary integration, the idea of iSTREAM is proposed as an extension of STEAM with considering the characteristics of Chinese K-12 students, such as the deficiency of training about leadership, critical thinking, project management, etc. In addition, Considering to strength the education of innovation, entrepreneurship, and especially problem solving capability for K-12 students, iCDIOS is presented based on CDIO (Conceive, Design, Implement, and Operate) engineering education approach. The letter i in iSTREAM and iCDIOS means intelligent science and technology, innovation spirit, inspiration, etc. In iSTREAM, Robotics, as an independent element is added since we believe that Robotics will be an independent subject

with coming era of human-machine collaboration; Mathematics is changed into management to cultivate Chinese students' abilities related to management; In iCDIOS, S as service is added to complete the whole engineering process.

2.4 STIE Framework

Based on the aforementioned problems, situation, and ideas, a comprehensive STIE framework is proposed, as shown in Fig. 2, including STIE equipment, STIE curriculum, on-campus STIE laboratory, off-campus STIE education base, STIE activity, information support platform and evaluation index system. STIE framework is designed from the system thinking viewpoint, involving all factors of STIE. Obviously, the proposed framework is effective to help K-12 schools and government to make plans for the STIE, and we believe the implement of the framework will promote the core competencies of CCVCSD for all K-12 students and finally impel education reform in China.

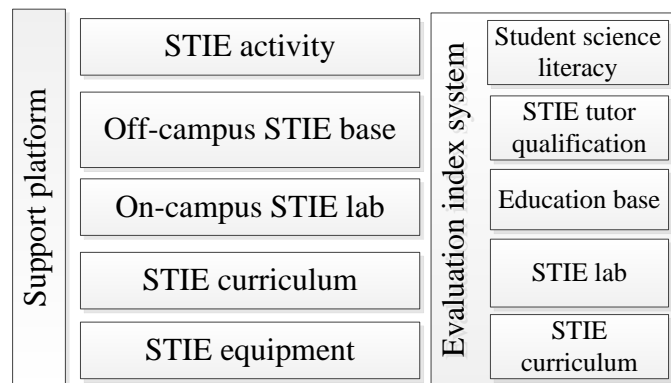


Fig. 2 Structure of STIE framework

There are couples of challenges for the implementation of the framework. First, educational contents are required to track the rapid development of intelligent technology and show the latest cutting-edge technology development to K-12 students; The second challenge is multi-disciplinary and cross-disciplinary integration based curriculum and learning environment design and professional lecturer team training; Last, the teaching and learning mode should be flexibly adjusted with the different educational requirements for knowledge popularization and engineering practices for different ages.

3. Description of All Components in the STIE Framework

All components in the STIE framework are described in detail in this section.

3.1 STIE Equipment

STIE equipment is the physical concept-carrier of iSTREAM and iCDIOS. Some popular educational equipment, such as drones series, 3D printing series, IoT (Internet of Things) system, robot series, VR series, etc., are utilized for STIE in QAIL, and most of them are originally developed as industrial application. There are four rules to convert the industrial products to STIE application: 1. Encapsulation (similar to word): the STIE equipment should be designed easily to be understood for objective K-12 students, and some technical details are concealed and transparent for the students; 2. Modularization (similar to grammar): To

employed the industrial products for STIE, it is very necessary to design many modules, such as input from sensors, output to actuators, computing and processing, connecting package, etc. and objective students can analyze, organize, and utilize these modules freely; 3. Systematization (similar to sentence): To design curriculum with the equipment, it is important to conceive the teaching and learning scenario when the industrial products are transformed to STIE; 4. Standardization (similar to paragraph or article): the whole STIE framework should be inspected, some equipment may not be suitable to be used for STIE for a certain grade of K-12.

3.2 STIE Curriculum

STIE curriculum is the soft carrier of iSTREAM and iCDIOS. Curriculum system for K-12 should be designed from a systematic and integrative view to smoothly and seamlessly deliver core ideas of each subject i(intelligence)、S(Science)、T(Technology)、R(Robotics)、E (Engineer) 、 A (Art) 、 M (Management) and cross-cutting ideas behind them to learners, which is a balance between division and integration. Guiders or teachers are main concept-delivers and bridges between physical concept-carriers and learners. So through teachers training services, teachers or guiders will learn how to realize and deliver core ideas by content organization, scenarios design, utilization of teaching skills, etc.

3.3 On-Campus STIE Lab

On-campus STIE lab is the off-line learning and communication platform for all learners and guiders. Working as an innovation unit or a maker space, the on-campus STIE lab contains STIE equipment, STIE curriculum, teachers, learners, scenarios, etc. to create an inspiring atmosphere for innovation.

3.4 Off-Campus STIE Base

Off-Campus STIE Base is the off-campus, off-line platform for learning and communication. Working as an experience center with cutting-edge science and technology exhibition, advanced intelligent equipment are assembled and deployed in the innovation education base. By demonstration, lecture, and on-site experience, students can know the state-of-art engineering practice and tendency of the intelligent technology development.

3.5 STIE Activity

STIE Activities including competitions, tours, expeditions, camps, etc. are supplement and extension of four components mentioned above, which make this framework an open system. First, learners and guiders could get out of schools, experience fresh and up-to-date science and technology, brainstorm with new minds, get more chances to find, ask and solve life-related questions and generate new inspirations. Second, through all kinds of activities,

this framework can make full use of community education resources, and generate more certain economic and social benefits.

3.6 Support Platform based on Parallel Teaching and Learning System

Support Platform based on a Parallel Teaching and Learning System(PTLS) is an online learning and communication platform based on ACP (A: Artificial Societies, C: Computational Experiments, P: Parallel Execution) approach. By building one or more artificial societies including learner models, guider models, environment model, etc., each real entity has one or more corresponding virtual entities. That is to say, we are not alone, and there are one or more “copies” of us in artificial societies; By carrying out different kinds of computational experiments in artificial systems to find the most suitable strategies such as teaching methods, learning scenarios, etc. Then, these strategies will be applied in real education process to test their efficiency. After that, real education process will generate feedback into virtual system to do more strategies optimization. Then such interactions will keep back and forth until balance between real education process and virtual system is obtained. That is parallel execution [17-19] as shown in Fig. 3, in which real learners and virtual learners, real guiders and virtual guiders are evolved together by learning from each other through computational experiments to find the most suitable teaching strategies.

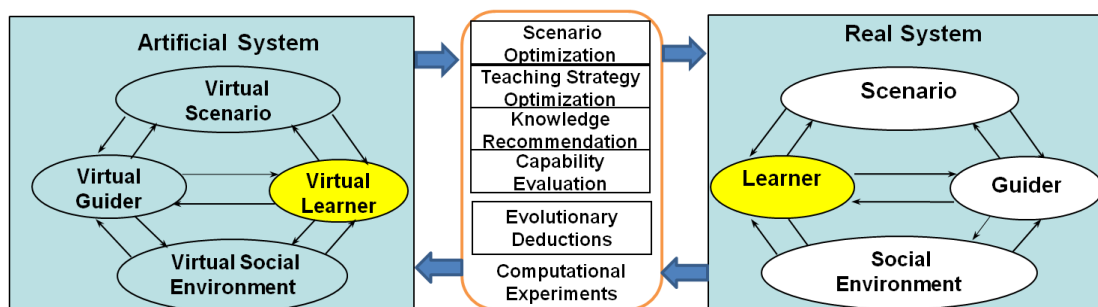


Fig. 3 Supportive Parallel Teaching and Learning System

3.7 Evaluation Index System

Based on iSTREAM and CDIOS, an Evaluation Index System(EIS) was dedicatedly designed to ensure that equipment, curriculums, labs, tutors and students science literacy are STIE-qualified. That is to say, with right input (equipment, curriculum, lab, tutor), we could ensure the right output (students science literacy). By doing so, we believe we can achieve a much better result in a more efficient way.

4. Implementation model of STIE

In order to provide an effective, sustainable, all-win STIE ecosystem, we originally present implementation model of STIE by balancing and motivating interests of all stake holders including government, commerce, industry, university, research institute and finance entities.

Under guidance and support from local government (generally education bureau), iSTREAM research institute design the STIE framework and standards in a top-down way, and lead the STIE equipment suppliers, training institutions to develop curriculum with the support of normal universities and finance companies. This implementation mode features top-down system design, balance of benefits, and concentration by professional participator.

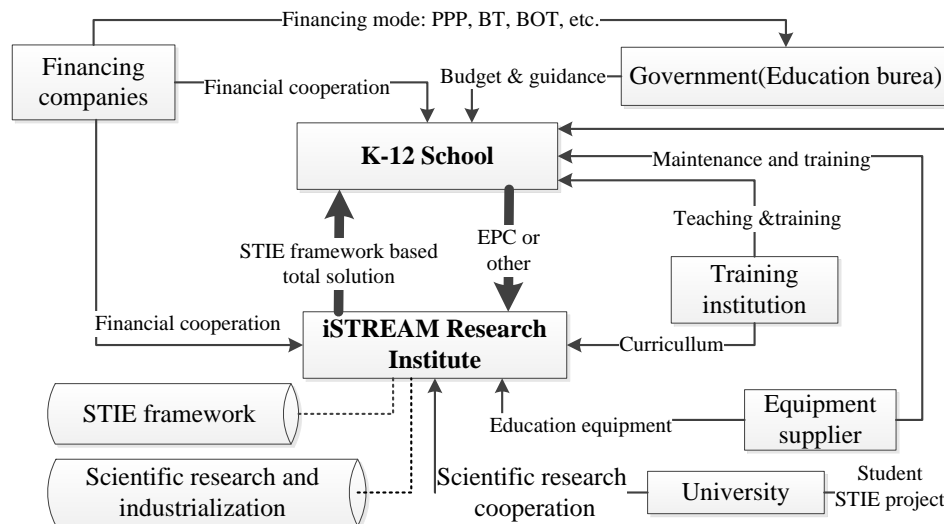


Fig. 4 Multiple cooperation of government-commerce-industry-university-research-finance

5. Application Case

So we take Qingdao as an example to show how this framework works and challenges we have met.

5.1 STIE Equipment

Some equipment we are utilizing in Qindao is briefly introduced here.

3D Printer Series

We consider 3D printing as a powerful and magic technology, which could turn learners' innovative ideas into reality. That is to say, whenever learners need any kind of parts not available at market, they could easily print them out with 3D printers after conceiving and designing on our 3D design outsourcing platform. That is to say, based on 3D-printing manufacturing platform, learners can extend and expand our education equipment based on their innovation, thus creating personalized equipment for all based on one basic series product.

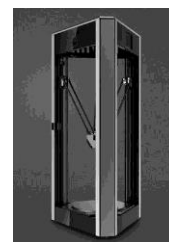


Fig. 5 Industry-level 3D printer

As shown in Fig. 5, we developed industry-level 3D printers to make sure all printed parts are totally reliable with high precision. 3D printer series is one of our basic and powerful scalable

educational products for all grades. For lower grades learners from K-4, we provide easy-touch platform to motivate learner's interest; for middle grades learners from 5-8, we provide easy-design platform to simplify designing process based on tons and tons of models; for higher grade learners from 9-12, we provide an open-platform which could inspire learners' sparkles and empower them with outsourcing ecosystems.

Robotic Fish Series

Bionic robots are popular and playful because they combine everything together smoothly and naturally. As shown in Fig. 6, we developed robotic fish series equipment to meet kids' interest by driving their life experiences. We provide scalable series from easy to complicate



Fig. 6 Robot fish

from K-12. For K-4, we provide basic swimmer robotic fish which could be assembled under guidance. For 5-8, we provide intermediate-swimmer robotic fish which let learners' explore more robotic fish science, engineering and others. With help of 3D printing, learners could change outer skin or skeletons inside For 9-12, based on more comprehension of robot science, engineering and others, learners could conceive, design, implement and operate their own robotic fish or cool stuff swimming freely on the surface or under the water to undertake cool tasks such as detecting pollution, exploring undersea and etc.

Virtual Reality Series

Virtual Reality Series are a fantastic portal to wonderful and magic land for everyone and also bridges to connect real world and parallel virtual worlds where learners could explore all corners of our universe, create their own imaginary worlds, and finish mission impossible in real world. So for K-4, we provide sea-world equipment to let kids explore world under the sea with 3D glasses they made by themselves; for 5-8, we provide parallel-world products to enable learners to explore and "change" our whole universe based on virtual reality design platform; for 9-12, we will let learners create their own games, worlds and curriculums with powerful and easy-to-use VR engine.

Intelligent Drone Series

Drone, as a flying robot, seems a necessary in our life which could bring us a whole new view to our world. Although technically human could not fly, drone could uplift us onto a higher-level and in the coming future UAV might turn human flying dreams into realities. We provide three levels equipment respectively for K-4, 5-8, 9-12. For K-4, we developed mini-I-CAN-FLY which could be easily assembled and extended by 3D printing; For 5-8, we provide birds-I-CAN-FLY equipment which could enable learners to make more complicated and functional drone and even let them operate drone based on a pick-up of theories and picture-intensive software platform; For 9-12, we developed missions-I-CAN-FLY equipment which is truly functional to enable learners to complete cool tasks.

Intelligent Robot Series

Intelligent Robots, as our helpers and partners, will appear in all corners of our life and hopefully could save us from labor and boring routine work. So it's a MUST to let all our young learners to get to know robots and have robot thinking, which is how to work and coordinate with robots to make the best of both sides. For K-4, as beginner level, we introduce building-block based robot series with expansion empowered by 3D printing. For 5-8, as intermediate level, we developed building-block+ dual-software-platform, which could let learners code both with pictures and real coding. For 9-12, there is a jump for intelligent robots transferring from toy-level to function-level, which could enlighten learners to solve real problems.

5.2 Curriculum

Focusing on more than five areas, we developed a curriculum for K-12, from inquiry-oriented, experiment-oriented to integration-oriented. Fig. 7 presents the whole set of curriculum. In our textbooks, learners are considered as project managers who can leverage all resources and knowledge to finish tasks under guiders' encouragement and guidance. No matter how much young learners are, they are considered as self-constructors who can build their knowledge systems by useful exploration. No matter how much young learners are, they are considered to be self-managers who can plan and take care of the whole project process under guidance. So in our textbooks, with a life-related task first proposed, all knowledge points are demonstrated as a beautiful tree to let all learners clearly know their way to learn systematically. Management is emphasized in this book to get an idea of leadership, balance and cooperation.



Fig. 7 iSTREAM textbooks

5.3 Intelligent Drone Lab

we have built two STIE laboratories for Qingdao Experimental High School, and the intelligent drone lab is shown in Fig. 8, which put guiders, learners, education equipment, teaching scenario, etc. together. All guiders are outstanding researchers with rich scientific research experience, overseas life experience, charming personalities from Chinese Academy of Sciences and Qingdao Academy of Intelligent Industries. Besides, all learners are encouraged to build their own innovative corner or mini lab at home, turn their home into first innovative labs, and thus provide basic condition to nurture scientific literacy. And all

learners are encouraged to slow down and observe everything around them with peaceful hearts to feel the beauty of exploration and deep-thinking process.

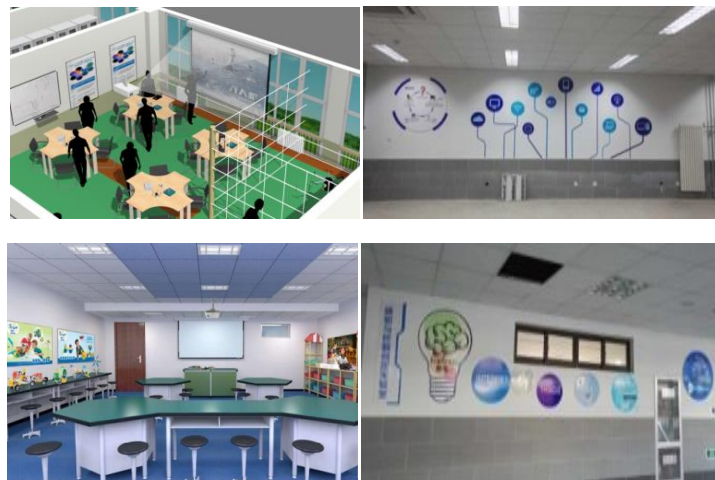


Fig. 8 Intelligent drone lab

5.4 STIE Education Base

An off-campus STIE Base, with four partitions totally about 4000 square meters, was built in the international robot center of Qingdao National High-tech Development Zone. The 1st partition is used to demonstrate different kinds of cutting-edge intelligent industrial robots, who will be activated to operating state; The 2nd partition is used to short lectures to introducing new smart industrial products such as drones, 3D printers, VR, etc.; The 3rd partition is used to show the history, current and future of robot; The 4th partition is a maker space, and visitors can participate some small hands-on projects. In the first year after the STIE base was established, more than 10,000 K-12 students have visited and learned. Fig. 9 shows our dedicated guiders and attentive learners.



Fig. 9 STIE education base with visiting K-12 students

5.5 STIE Activities

As supplement and enrichment of main curriculums, we have held many STIE activities such as summer camps, on-campus lectures and off-campus competitions, workshops, etc. Fig. 10 shows group photos of iSTREAM summer camp. Five groups of campers got their tasks respectively on the first day and carried out their plans in parallel. Without rush and hustle,

without authorities, in a relaxing and inspiring atmosphere, with friendship and collaboration spirit, campers have been sailing in the scientific world and building their own view of scientific world for a week. All campers went through theory inquiring, engineering adventure, and finally real world problems solving journey.



Fig. 10 Group photos of summer camp and ITS-Summer School

5.6 Assessment

Based on the questionnaires about the designed curriculum, lectures, and activities, most teachers and students praised for the novel contents, lively classroom, and interesting practices. Over 80% students gave a general evaluation of excellence, and others thought it is good, and they considered the STIE is a good supplement for the formal classes. Specially, almost all students are very active to give us advices or comments, and their rich curiosity and imagination are shown obviously.

6. Conclusions and Future Work

We proposed a systematic framework for STIE with a workable implementation model, and have carried out in Qingdao with a series of STIE equipment, curriculums, labs, base, and activities. It is proved the framework is very helpful to give an effective and comprehensive education for K-12 students by good comments from students, parents, teachers and educational managers. We are continuing to improve the support platform and build an evaluation index system under cooperation mechanism shown in the proposed implementation model.

7. Acknowledgement

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