World Transactions on Engineering and Technology Education
Vol.14, No.1, 2016

Maker-based STEAM education with Scratch tools

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ABSTRACT: Maker education has been carried out, effectively, in China using Scratch programming tools. Through Maker education, students enhance their STEAM (science, technology, engineering, art and mathematics) knowledge and skills to meet the requirements of the 21st Century. Four types of Scratch tools suitable for students are introduced in this article. Maker-based STEAM education with Scratch tools is summarised from five aspects, viz. the basic idea, teaching objectives, teaching content, teaching strategies and teaching evaluation. This mode of teaching will open up a road to allow more students to participate in innovation and cultivate their STEAM abilities from an early age.

INTRODUCTION

Science, technology, engineering, mathematics (STEM) education is an education strategy that was proposed in the United States to promote its national competitiveness and the innovative abilities of its labour force in the 1980s. It emphasises breaking the boundaries separating disciplinary fields and cultivating students' science and engineering. Currently, Chinese and overseas educators are paying close attention to STEM education as a way to cultivate complex and innovative talent in a growing workforce. Science, technology, engineering, art and mathematics (STEAM) education is STEM education plus *A* for *arts*.

The STEAM education has become increasingly common, and can include the arts, sports, humanities, computer science, research, innovation, global communication and co-operation, all of which are needed in the 21st Century. Hence, STEAM has developed into an inclusive, interdisciplinary, comprehensive education system [1].

The Maker education movement started much later than STEAM education and involves learning by making or doing things. Significantly, Maker education can make use of the Internet and rapid developments in information technology. There has been an upsurge of innovative education on campuses accompanying the rise of the Maker movement and the spread of the Maker culture in recent years [2]. Maker education is based on the use of digital technology to describe a new education mode that will redefine information technology courses and integrated practical courses.

Scratch is a visual code, dragging, educational programming tool launched by the MIT (Massachusetts Institute of Technology) media laboratory [3]. It has a friendly interface and is entertaining to use. It is greatly liked by teachers and students, both in China and abroad. One reason for the prominence of Scratch is that it stimulates students to create digital information interactive systems. The students increase their creative computing ability in the process of playing with and sharing, interactive media that they have created.

Another reason for the popularity of Scratch is its ability to connect to many hardware platforms, e.g. the Picoboard sensor board, MakeyMakey/Crazyer circuit board, Arduino single chip, and the Kinect somatosensory equipment, which are described later. Most of these platforms are cheap, open-sourced and cross-platform, as well as offering an easy-to-use hardware programming environment. The students can use a variety of input and output interfaces to make interactive media without the limits of keyboard and mouse, and which combines virtuality with reality.

Adhering to the Maker culture of designing, producing, sharing, exchanging and open-source, the student makers (also known as *little makers*) in medium and small schools in China no longer depend on expensive laboratory equipment, but under the guidance of teachers, they come into contact with cutting-edge information technology, such as robots, the Internet of Things and smart homes. The students use easy-to-use Scratch tools, such as Arduino, to design, produce and share; and to learn how to transform ideas into reality, e.g. the *Arduino Creative Robot* courses in Wenzhou Maker Space, in which students use the Arduino microcontroller (a Scratch tool) to build a robot [4]. These courses are important platforms by which to stimulate students' innovation and a portal into *the land of imagination*.

During the process of innovation and self-exploration, students' innovative interest has been stimulated, their creative abilities cultivated, their STEAM education promoted, and their teamwork and problem-solving skills exercised. These are just the weak links in current school education. To cater for the need of contemporary students to *be good at playing* with cutting-edge digital technology, Maker education has provided the means and platform by which to cultivate the complex and innovative talent needed in the future.

SCRATCH TOOLS

Picoboard Sensor

Picoboard sensor is a circuit board, connected to the computer via a USB interface, which can support Scratch and is used to sense the external environment. It has five hardware interfaces to sense and detect the external environment, including sound, light, buttons, sliders, and a custom, resistive-type, sensor. It can support digital and analogue inputs. Since the Picoboard sensor board is a data-input circuit board, it can only perceive outside information by getting external data through hardware interfaces and cannot output control information [5].

After connecting the Picoboard sensor board, the interactive methods to manipulate the Scratch program are diverse. A controller can be combined with other material (such as foil paper) to make a Scratch program connect seamlessly with the outside world.

MakeyMakey/Crazyer Circuit Boards

MakeyMakey/Crazyer are two types of small circuit board that have similar functions, but the realisation of the functions are different. They are connected to the computer via a USB interface, and alligator clips are used to attach to other objects to achieve an external mapping keyboard. MakeyMakey was researched and developed by two doctoral students, Jay Silver and Eric Rosenbaum, from the MIT media laboratory [6]. Crazyer was researched and developed by a group of young people from the Wenzhou area of China [6].

These two magical circuit boards can make everyday objects into a computer input device, e.g. make stairs into a piano, or make bananas into a keyboard or make plasticine into a game controller. As long as an object's surface (such as plasticine, water, the human body or various plants and metal) is wet or conductive, the microcontroller, then, can sense the weak currents, and send a key, mouse or executive routine signal to the computer and, thus, make the connected object *own* the same touch-sensitive function as, for example, a mouse.

Arduino Microcontroller

The Arduino microcontroller is an open-sourced, programmable microcontroller, and it can be used to set up robots and intelligent machines. Digital or analogue input/output ports are important channels for the Arduino microcontroller, to connect with the outside world. By these input/output ports, the Arduino microcontroller can be connected to a variety of input and output devices. The common input devices include photosensitive components, thermosensitive components, ultrasonic components and potentiometers. The common output devices include LEDs, motors and buzzer. When Arduino carries out an action by displaying output for input data, it achieves the goal of perceiving and, then, controlling the external environment [7].

Compared with the Scratch sensor board, the Arduino microcontroller has an interface that can input/output data bidirectionally. Hence, the interactivity of an Arduino microcontroller is far better than the Scratch sensor board, and a feedback system can be set up between the inputs and outputs. Usually the Arduino IDE, S4A, Ardublock, Mind + are used to develop the environment for hardware programming.

Somatosensory Equipment

Equipment that supports somatosensory interactions has gradually become available. Kinect (the whole body somatosensory equipment), ordinary cameras, and leap motion (gesture-sensing device) are the three somatosensory interactive devices. Kinect is a 3D somatosensory camera (also known as somatosensory equipment) developed by Microsoft Inc., which integrates many advanced visual technologies, and has the functions of skeleton-tracking, gesture-recognition, face-recognition, voice-recognition and others; its slogan is, *You Are the Controller*. Kinect has become the natural interactive device by which to break the boundaries of man-machine control and will change future life and entertainment [8].

Kinect for Windows supports somatosensory application programs and can be connected to the Scratch programming environment by the Kinect2Scratch drive program. It allows students to develop their own, customised somatosensory game or other somatosensory application, such as playing music using hands, operating an aircraft war game using the feet, recognising odevity (odd or even) with body movements [9]. The students can experience the basic concepts of screen substitution and skeleton-tracking by playing and making. Scratch 2.0 also supports somatosensory application development based on a camera. It can detect the range on the video screen and when the range exceeds the set change value, the subsequent behaviour will be activated.

STEAM-MAKER EDUCATION BASED ON SCRATCH TOOLS

The STEAM and Maker education are deeply entwined and greatly increase students' innovative consciousness and practical ability. The use of digital technology and the cultural atmosphere of Maker education will enrich the content and means of STEAM education and renew the vitality of STEAM education. Conversely, the interdisciplinary integrated nature of STEAM education, with teaching based on a project or problem, means Maker activities are suitable for such education.

Hence, the targets and direction of Maker education become clearer when applied to STEAM education. Scratch tools will play an important, supporting role in this process. The following section will explain STEAM-Maker education based on Scratch tools, and consider basic ideas, teaching objectives, teaching content, teaching strategies, teaching evaluation and the learning environment.

Basic Ideas

Maker education sets at the core, students' independent research and manufacturing or doing, and is rooted in Dewey's progressivism and constructivism [10] raised by Professor Seymour Papert, creator of the Logo language. It emphasises that during learning, students make use of knowledge to build external, specific and shared artifacts, as well as to build interpersonal relationships.

For subject integration, there is integrated STEAM education (integrated STEAM or iSTEAM for short) [11]. Studying the characteristics of various disciplines explores the teaching methods that integrate the STEM subjects. The design-based learning methods commonly used in technical/engineering education involve the design and production of products in problem-based learning. This achieves the goal of cultivating students' STEAM skills, innovation and practical ability.

Teaching Objectives

The overall objective of Maker education is to use computing platforms and cutting-edge digital techniques, such as 3D printing, and to apply interdisciplinary knowledge in creating artifacts. The aim is to learn and master problem-solving methods applicable to real problems in the real world. This cultivates and improves creative design ability, teamwork, problem analysis, problem-solving and practical innovation, as well as enhancing STEAM education. For three-dimensional objects, Maker education can include the basic principles of physical computing, hardware assembly, electronic component identification, circuit construction, programming, function debugging and 3D print modelling. Process and method, under the guidance of teachers, is by imitation, independent research or manufacturing by hand.

Any programming and function debugging would be from easy to difficult. Students master the methods by which to find and solve problems. They develop their emotional attitudes and values by experiencing the convenience of physical computing platforms in connecting people to the digital virtual world. They raise their learning attitudes, as well as daring to explore actively and co-operating [12].

Teaching Content

The teaching content of Maker education may cover innovation, manufacturing, and intelligence. Innovation is reflected in creative thinking and cross-discipline thinking.

- Innovation thinking:

  Innovation thinking is where the aims are to develop designs that combine disparate situations, such as scientific and industrial scenes, to solve specific project problems. For example, in 2015, Chongqing Vocational Institute of Engineering organised the First Innovation and Entrepreneurship Competition on Engineering Makers. The student competition focused on science and technology inventions, industrial design and services creation. Five patents originated from this competition [13].

  In 2013 at the Shanghai Creative Education Training and Teachers Workshop, the keynote teacher challenged the participating teachers to use a method of detecting if a port on the resistor sensor on a Picoboard sensor board was connected. They had some creative production material available, e.g. copper foil tape. They were to produce a simple device for a game, involving interactions between players. This game demonstrates the relationship between science and a real game [14].

Cross-discipline thinking integrates knowledge and skills in STEAM and other disciplines, e.g. combining arts and humanities with science and engineering. Wu Junjie, a teacher from Beijing Jingshan School combined information technology and scientific research by exploring Picoboard sensor board applications. Tests were developed based on the Picoboard sensor board, using analogue inputs [15]. These tests allowed students to determine if physical quantities in the external environment, e.g. length, and resistance, were well represented by the analogue quantities, e.g. slider value, by Picoboard. This leads to the ability to make automatic measuring instruments. The subtle combination of information technology and scientific research enables the students to experience and understand the importance of cross-discipline knowledge.

- Manufacturing:

  Manufacturing in Maker education allows students to participate directly in the production of systems for the real world. Guided by the lead teacher Maker, the student Maker produces by hand systems to meet real needs based on cutting-edge technology, e.g. 3D printing technology, computing platforms. This may involve hardware assembly, circuit construction and debugging. For example, the students from Wenzhou Maker Space used the Arduino control board to make two interactive devices with different functions, viz. a virtual landscape to reflect the external, real environment, and an electric display stand that is automatically adjusted by motor for optimum positioning [16]. These interactive devices reflect the use of sensory inputs to solve practical problems.

- Intelligence:

  In Maker education students endow artifacts with pseudo-life and intelligence by programming hardware and software systems to achieve communication and interaction between people and people, people and objects, and objects and objects. Because of the open source and other factors, the cost of interface- and hardware-based programming has been going down. *Everyone can learn programming* is no longer an unrealistic slogan.

Teaching Strategies

Maker education is the education appropriate to the rise of STEAM integrated education. Its teaching process and methods are based mainly on projects and problems. At the core of the teaching is students' autonomous exploration and experiencing by hand. The following strategies can be adopted:

- Relevance of the real world:

  Maker education encourages students to return to the real world for inspiration for creative design. In the process of observing the world, they pay attention to themselves and others' needs. From exploring nature, society and other subject fields, it is possible to create interactive media reflecting real society and culture and which links seamlessly together science, art and life. For example, teachers and students in schools create interactive media devices, such as a voting machine.

- Bold innovation:

  The pursuit of innovation is an important orientation of Maker education. Innovation may come from the discovery of small and unique needs, while the way to express innovative ideas is to create personalised, intelligent interactive media, with high added value. These works may be useful, such as a temperature alarm, temperature-controlled fan, networked watering device, remote-controlled desk lamp. Or these works may be pleasurable, such as water lights, an electronic buzzer, musical cake box [17-19]. Wu Junjie sums-up these two points as, *make it real* and *make it cool* [20].

  The interactive media work should be practical and aesthetically pleasing. The creators need to consider the requirements and difficulties. They should be bold in practice and perfect the works on the basis of listening to the views of classmates and users. For example, in order to make interactive media more textured, they can make the works bigger and more interactive with people, so that it is no longer just a cold device, but rather an intelligent device that ingeniously solves a practical problem.

- Iterative learning and learning by *tinkering*:

  Iterative learning is a repeated and progressive process. Professor Mitchel Resnick at MIT once proposed a creative thinking spiral, including five stages which repeat iteratively; namely: imagine → create → play → share → reflect → reimagine [21].

  This means the creation of interactive media often begins with immature ideas or creative inspiration. Then, it goes through the design, production, debugging, improvement and modifying stages. Finally, the interactive media work is completed. Sharing and reflecting are components in the creation of interactive media, because exchanging and sharing creative achievements causes deep rethinking, and is a source of inspiration and imagination leading to improvement and perfection.

Tinkering is a working style and learning method that emphasis exploration and hands-on experience. It is different from methodical planning to address a problem or project. Rather, it allows students to tackle a problem or project by playing and exploring in an iterative manner [22].

From the idea of a smart device, make the interactive device so that it functions reasonably. Evaluate the device, and explore new ways and research new methods over and over again, constantly tinkering with the hardware and software. This progressively solves the difficulties of circuit construction and mechanical device assembly. It finds the problems in software development and program design, to eventually meet the intended target. The learning process by tinkering is full of confusion, surprise, occasional annoyance or loss, but it is just like real scientific research and engineering manufacture.

- Interdisciplinary integration and co-operation:

  Maker education is centred on the idea of producing enhanced, interactive computer-based devices, which attract students and stimulates learning. Engineering and technology are at the core and it is necessary to apply interdisciplinary knowledge, encouraging students with different interests and traits to participate in collaborative inquiry.

  For example, in May 2014, two students from the Computer Science and Technology normal major of Shanghai Normal University combined with several students from the Music, and Fine Arts majors to co-operate to create the MusicStorm interactive media work centring on music [23]. This work has complete functionality, including playing music, a knowledge quiz, introduction to lyrics, scores for games, simple electronic organ and simple electronic drum. Players can experience the pleasure of making themselves become a member of a band, a music connoisseur, an instrumentalist, a composer or a lyricist.

  The simple electronic organ and electronic drum used the Picoboard sensor board, Makey circuit boards, and other materials. This work has been shown publicly in a creative programming works display called Scratch Day China held in Shanghai in 2014, and its beautiful graphics, fine sound and smooth functioning have been praised by site visitors and other participating members. Thus, interdisciplinary integration and team work can improve the depth and breadth of interactive media work.

- Case teaching, imitation and re-creation of interactive media works:

  Case-based imitation and inquiry is basic to Maker education. The case combines the necessary knowledge and skills and the solution methods and processes to address practical problems. It builds the necessary scaffolding by which to develop students' innovative abilities. The case study should not be limited to imitation, but should encourage students to re-create interactive media works. Expanding the functionality can lead students to produce their own creative ideas and, then, put them into practice. Re-creation is an important method by which to help students accumulate creative design experience and lay a solid foundation for subsequent high level original design and creation [24].

Evaluation

The evaluation of Maker education should focus on the promotion of students' innovation, practical ability and STEAM disciplines. The multi-element evaluation method focuses on the products or Maker *fruits* and Maker learning progress. A network sharing and exchanging platform allows Maker students to show their interactive media works and exchange ideas with the audience for the works and users. Creative ideas will flow from reviewing companions' work.

Many showcase activities for Maker education interactive media works have been organised in China, including Scratch Day in Shanghai in May 2014; First Session Teenagers Maker Cultural Festival in Wenzhou City in November 2014; and Nationwide Students Maker Invitational Tournament held in Changzhou [25]. These live shows have attracted students, teachers, parents, school leaders, off-campus training institutions and others to participate. Many interactive media works present the creators' innovative thinking and unique ideas. The teaching evaluation of Maker education integrates social interaction and is beneficial for the personality development of the student.

CONCLUSION

With open source and the increased availability of digital technology, more IT teachers have turned to Maker education. In this, students face real-life challenges to break the man-machine interaction restrictions of the traditional keyboard and mouse. They design and make interactive media, with unique man-machine interactive methods using diverse inputs and outputs. From the initial programming to the final creation, the interactive media created by Chinese teachers and students has already shown great innovative potential [26][27].

Students are exercised by mathematical modelling, analogue simulation, artistic expression and creative design. The Maker education based on Scratch tools has a theoretical foundation in constructivism. It sets a new education pattern, which adapts to the digital information age and cultivates students' STEAM skills, as well as innovative practical ability.

Faced with the wave of technological change and new concepts in education, it is necessary for the educators to embrace IT and technology education reform. Maker-based STEAM education deepens education reform, to improve education quality. It is a long road from *Made in China* to *Created in China,* but Maker-based STEAM education may open up that road by allowing students to participate in innovative creation from an early age.

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