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The influence of the maker movement on engineering and technology education

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ABSTRACT: With the emergence and wide application of digital fabrication equipment and open source hardware, the *maker movement*, featuring cooperative innovation and user self-production, is a new trend around the globe. Because of its close and natural relationship with engineering and technology, it has drawn the attention of educators in this field. From two perspectives - digital tools and maker space, the authors of this article summarise and analyse cases of maker space education in engineering and technology. Based on the analysis of educational rationales and learning methods of maker space education, a conceptual model of maker space education is devised. Then, the influence of maker movement on engineering and technology education is discussed, and possible related future topics are raised.

INTRODUCTION

Open source hardware, 3D printing, laser cutting and other technologies have led to a decrease in the cost of industrial manufacturing. The wide application of social media is making technology and exchange more convenient. A cooperative-innovation and self-production-based *maker movement* is emerging. This movement is now transforming manufacturing industry from standardised and mass production to customised production, which is expected to lead to a new industrial revolution [1]. Such a change has obvious influences on engineering and technology, as well as its education, thus, attracting wide attention.

No generally accepted definition has yet been given to *makers*, who are usually thought to be focused on using tools and materials to turn their ideas into real products through self-design and production, as well as cooperating and sharing their experiences with others in the process. The *maker movement* is a description of the trend of fast increase of makers, firstly proposed at the Maker Faire hosted by MKE Magazine in San Mateo, California in 2006 [2]. With the ever-increasing influence of the movement, the number of Maker Faire participants reached 215,000 in the Bay Area and New York in 2014; in 2015, 150 Maker Faires were held around the globe; 59 Faires are already planned to be held in 2016 (as of 8 January 2016), according to the official Web site of Maker Faire [3].

Cooperation and innovation are core ideas of the maker movement, and are also driving forces of technological progress, and social and economic development. This is why the movement has drawn the attention of governments. At the first-ever White House Maker Faire hosted in Washington in June 2014, President Obama called on …*every company, every college, every community, every citizen*… to join …*us as we lift up makers and builders and doers across the country*. He also announced that more than 150 universities and colleges, 125 libraries and 90 mayors had participated [4]. China's State Council Office issued guidance opinions in March 2015, and required governments at all levels to encourage the mass public to innovate and speed up the construction of maker spaces [5].

The emergence of the maker movement and the spread of the maker culture have attracted the attention of educators, especially, those in the related fields of engineering and technology. An increasing number of higher education institutions have set up maker spaces for students and have attempted the application of maker ideas into teaching. In an investigation of 127 colleges and universities listed in the US News and World Report's Best Undergraduate Engineering Programmes Rankings in 2014, Thomas et al found that 35 of them had set up maker spaces [6].

NMC (New Media Consortium) Horizon Report: 2015 Higher Education Edition pointed out that in the next two to three years, maker education and maker spaces will be accepted by more and more higher education institutions, and that STEM (science, technology, engineering and mathematics) have a broad prospect in the application in education [7].

In 2015, China's Tsinghua University has opened its *i-Centre* maker space (covering 16,500 m^2) to teachers and students, making so far the largest maker space on campus in the world. On the one hand, engineering and technology education emphasises the fostering of students' cooperative innovation ability, in line with the idea of the maker movement; on the other hand, engineering and technology education focuses on practical training, and a sound training environment can be provided by having maker spaces for students. Therefore, the maker movement will have a profound impact on engineering and technology education.

The remainder of the article contains:

- An introduction of related cases in engineering and technology education from two perspectives - digital tools and maker spaces;
- A summary of the idea of maker education and a proposal of a conceptual model of maker education;
- A discussion about the influence of maker movement on engineering and technology education;
- A conclusion of this article, and further research implications.

ENGINEERING AND TECHNOLOGY EDUCATION PRACTICES BASED ON MAKER MOVEMENT

The maker movement has a bright prospect in the application in engineering and technology education, mainly demonstrated in the following aspects: first, along with the movement come a range of digital tools suitable in engineering design and manufacturing; second, maker spaces set up by makers or organised by universities or governments. Currently, engineering and technology education practices based on makers mainly takes the form of informal learning initiated by students. It is mainly because maker culture emphasises the realisation of ideas based on self-interest and passion, and because of the lack of courses and programmes designed that are based on maker ideas. The following is a summary and analysis of some cases of maker education in engineering and technology fields.

Digital Tools

Digital fabrication equipment (e.g. 3D printers and laser cutting machines) is often used in maker education, and can quickly turn 3D models designed with computer-aided design software into real objects. 3D printing is a rapid prototyping technology based on additive manufacturing. Its rationale is to turn adhesive materials (e.g. special wax materials, metal powders and plastics) into 3D objects by level-by-level printing. Laser cutting is a technology based on reductive manufacturing. A high-power laser beam is directed at the workpiece material, which then either melts, burns, vaporises away or is blown away by a jet of gas, leaving an edge with a high-quality surface finish. Digital fabrication equipment is commonly applied in the professions and courses of machinery, architecture and design. Table 1 shows some of its applications in engineering and technology education.

Table 1: Cases of digital fabrication equipment application.

Education institutions	Course or profession	Case description
University of Virginia	Engineering profession and science courses	A rapid prototyping laboratory with six uPrint 3D printers of Stratasys Company and one Fortus 3D production system for students of engineering or taking science courses
Owensboro Community Technical College	CAD and machine tool programme and curriculum	Student creation of 3D models with CAD and printing - enhancement of real world experience and design abilities
University of Delaware	Mechanical engineering programme	3D printers for mechanical engineering majors - enhancement of practical and creative abilities
North-eastern University	Architecture programme	Laser cutters for architecture majors (three times a day at most, 30 min a time) under the guidance of monitors

Sun et al believe that the educational features of 3D printers are demonstrated by the personalised creation with *design thinking* embodied inside, which can satisfy students' needs for personal creation and contribute to their transformation from consumers of education to creators [8]. As a type of digital fabrication equipment, laser cutters have similar educational features to 3D printers.

Engineering and technology education focuses on the fostering of students' problem-solving abilities, as well as their innovation and critical thinking. Project-based learning is an effective approach to strengthening these abilities. Conceptual model building with CAD can train students' innovativeness; digital fabrication tools changing these models into physical models can help students to evaluate themselves through comparison with design purposes and engineering results; therefore, accomplishing the goal of improving critical thinking.

Open source hardware refers to computer, electronic and electromechanical hardware designed in the same way as open source software. Designers usually make public their circuit paper, mechanical print, components used, HDL (hardware description language), IC layout and SDK (software development kit). Using open source hardware as a basic platform, students can re-program it and add new components to realise diversified innovative ideas. Right now over 50 types of open source hardware platforms are available in the market. Among these, Luo and Zhu believe the most suitable for maker education include Arduino, BeagleBoard, Raspberry Pi, pcDuino and Edison. In particular, Arduino is the most suitable for new learners [9]. Open source hardware can be used for engineering and technology education, such as in computer, electronics and electromechanical majors. Also, as OSH is easy to comprehend and learn, it is also applied in STEM education facing K-12. Table 2 shows some applications of OSH.

Table 2: Cases of OSH application.

Education institutions	Learners	OSH platform	Case description
University of Cambridge	Adults and children, particularly computer science	Raspberry Pi	Raspberry Pi is developed by Raspberry Pi Foundation, which is devoted to improving computer science and related education on campus and making computer science learning more interesting
State University of New York	Students on campus	Raspberry Pi	In its *Information in the 21st Century* course, Raspberry Pi replaces traditional textbooks and provides students with clearer understanding of IT
Zhejiang Wenzhou High School (China)	K-12	Arduino	*Arduino Creative Robot* course aimed at primary and secondary school students - divided into three sessions: LED, fans and dollies, which teaches K-12 students to make robots with Arduino and shares course resources on-line
iD Tech	K-12	Arduino	iD Tech is an education institution devoted to STEM. It provides engineering and programming with the Arduino platform courses for students aged 13 to 17 to develop their software and hardware skills

Maker Space

A maker space is a place for makers to conduct creative activities, similar to a workshop or laboratory. It provides makers with not only the necessary digital tools, hand tools and raw materials, but also a realm for idea exchanges and communication. Along with the maker movement, maker spaces have begun to show up on campuses, where teachers and students of different majors can communicate and cooperate in creative activities. For engineering and technology education, a maker space is an incubator for engineers. With maker spaces, students can apply learned theories and technologies in specific engineering projects, consolidate knowledge with practice, and enhance their engineering and technological abilities.

Maker spaces in higher education institutions take various forms, such as in libraries, schools and departments or student associations. They can be operated by teaching faculty or students. Most maker spaces on campus are open and free (or after a simple registration procedures) for students to use. Some maker spaces are aimed at a narrow range of disciplines (e.g. only computer, mechanics, etc), but most do not have a limit on majors (i.e. all engineering and science disciplines) [6]. Table 3 shows some cases of maker spaces, which demonstrates that maker spaces have some core elements-tools, environment, communication and training.

Table 3: Applications of maker spaces.

Education institutions	Name of maker space	Case description
Georgia Institute of Technology	Invention Studio	Open to all students and faculty members; provision of resources and location to turn ideas into reality; student-run; equipped with prototyping instructors to guide on equipment operation
Stanford University	Create Space	Open to all students and faculty members of all majors without registration; provision of various equipment and resources; a place for exchanges of ideas for students of different disciplines
Tsinghua University	i-Centre	A fundamental industrial training centre initiated by the university open to all students to promote the communication of students of different majors; all undergraduates receive engineering education at i-Centre
North Carolina State University	Open Hardware Makerspace	Provision of tools and space for students to build *anything*; conducting activities related with K-12 education and training of maker skills to promote multi-discipline communication

EDUCATIONAL RATIONALE AND LEARNING METHODS OF MAKER EDUCATION

Right now, engineering and technological education fosters students' engineering and technological abilities mainly through theory and mathematical modelling rather than practical training. This approach became mainstream after the re-engineering of engineering education (1935 to 1965) [10]. Although it teaches students theoretical knowledge, it does not teach students the practical skills to apply these theories in engineering projects. The emergence of the maker movement provides engineering and technology majors with a new approach, but the educational rationale involved in maker education is solidly based.

Maker education emphasises problem-driven learning, i.e. when students transform ideas into reality in the process of *making*, they actively learn knowledge and skills in order to solve real problems, which is very consistent with constructivism. Constructivist learning theory believes that knowledge is not taught by teachers, but obtained by meaningful construction through communication with others (learning peers or teachers) and utilisation of necessary learning materials in certain social contexts [11]. Constructivism is, indeed, the core educational rationale of maker education.

The consistency of approach is demonstrated in the following three aspects:

- Most maker education practices are informal learning rather than formal learning based on classroom teaching;
- Maker spaces provide maker education with social contexts for learner communication;
- Makers (learners) obtain knowledge by meaning construction through making.

In terms of learning methods, those related to maker education include: project-based learning, action learning, problem-based learning and collaborative learning. In engineering and technology education, these learning methods are widely applied in some non-maker education practices.

For example, De León conduct teaching activities using project-based learning in a geology course; results show that students have good expectations in relation to the course and their performance in future as professional engineers [12]. Wang used problem-based learning in a mechatronics course, which shows that students in the experimental group are better than control group in learning interest, academic results and innovation ability [13]. Liu et al set up an on-line learning platform based on collaborative learning and used it in the flipped classroom of Multimedia Educational Software course, enhancing students' learning interest [14].

Although based on the same learning method, maker education is different in that:

- Students instead of teachers formulate the themes of making activities based on personal interest;
- Students construct diverse knowledge structures in the making process rather than a single knowledge structure through fixed teaching content;
- Students communicate with teachers and peers of different disciplines rather than within one single discipline;
- Students experience real and complete engineering project procedures rather than simulating or experience part of the project.

Figure 1 is a conceptual model of maker education that demonstrates: the core educational theory of maker education originates from constructivism, students conduct learning activities through project based learning, action learning, problem-based learning and collaborative learning, digital tools and maker spaces provide physical tools and environment for maker education; the above theory, learning method and physical conditions all support the practices of maker education.

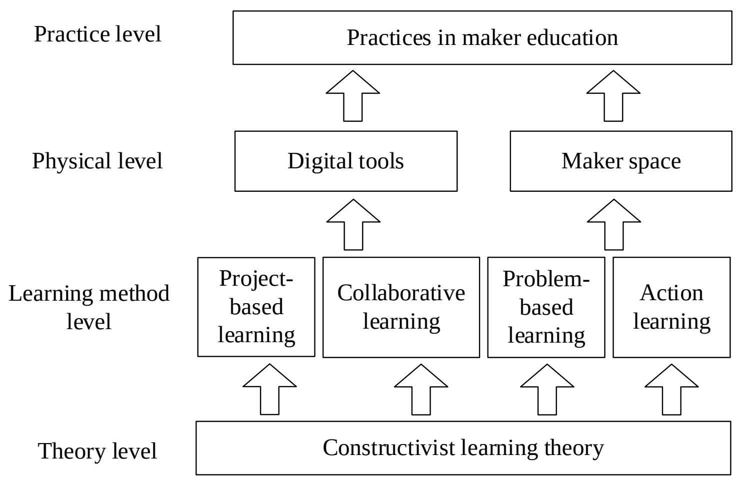

Figure 1: Conceptual model of maker education.

INFLUENCE OF MAKER MOVEMENT ON ENGINEERING AND TECHNOLOGY EDUCATION

Decreasing costs of digital tools, increasing the number of campus maker spaces and the emergence of innovative culture promoted by the maker movement have all brought infinite possibilities of the application of *maker* in engineering and technology education. Meanwhile, the ecosystem of engineering and technology education will also be affected, and even altered, by the maker movement. Such changes are shown in teaching models, course design and teacher-student relationship. In the following section, the authors discuss the influence of maker movement on engineering and technology education.

Practical Teaching will have More Room for Development

Engineering and technology education emphasises learning by doing, because hands-on approaches can promote the internalisation of knowledge and the enhancement of abilities. Such a practical teaching method is mainly demonstrated as practical training and final year project in traditional engineering and technology education. Practical training usually happens along with the course teaching process and is planned by teachers. Most similar to the actual design and build processes in an engineering project, the final project, however, does not engage students until late in their degree programme [15]. Students cannot obtain full exercises through real engineering projects, which is definitely not conducive to the fostering of engineering skills.

Open source hardware and digital tools facilitate students' earlier participation in real engineering projects, mainly because they reduce the cost of time and money in design and production. Educators can leave more room for students and encourage them to realise their ideas based on their interest and through rapid prototyping, giving guidance in this teaching process. Obviously, this raises higher requirements for teachers' abilities, because only a sophisticated maker can foster another innovative maker with engineering skills.

Courses and Learning Programmes will be Adjusted

The current engineering and technology education, in order for students to fully master the theories and technology of a certain subject, tends to arrange many theoretical courses in the study programme; and some technical courses also contain much theory teaching. Theory and mathematical modelling, though conducive to students' establishment of the knowledge structure of their major, cannot foster their engineering and innovative abilities well.

On the other hand, some educators suggest introducing maker related content or courses into the curriculum or study programme, so as to promote the fostering of makers. For example, the introduction of Raspberry Pi into computer constitution principle courses can help students better understand the working rationale of computers; the introduction of digital fabrication course into the study programme of mechanical majors can contribute to faster comprehension of rapid prototyping technology. Most higher education students learn maker technologies through informal learning, while formal learning can be beneficial to their mastery of these digital tools.

Teacher-student Relationship will be Altered

In traditional engineering and technology education, teachers are course designers, teaching activity organisers and knowledge communicators; students' initiative is limited. In such a classroom-based teaching model, students mostly obtain knowledge through one-way communication and, thus, construct a single knowledge structure. The lack of learning initiative suppresses students' innovation.

In maker education, however, students realise their ideas based on collaboration and technical means, by which they then obtain knowledge. They have higher initiative, because they actively raise ideas and eventually solve problems. Teachers play the role of supporters who help students solve difficulties that they meet. Therefore, teachers need rich experience and sound knowledge; they also need to observe student activities more closely, so as to give effective support.

CONCLUSIONS

The maker movement originates from technological progress and an innovation culture. Its close relationship with engineering and technology is demonstrated in its provision of a personal and low-cost approach to design and production. This is why educators in engineering and technology pay close attention to maker-related elements, such as digital tools and maker space, and have done related research and teaching practices. These maker elements have a broad prospect in the application in engineering and technology education, mainly, because they create conditions for students to participate in real engineering projects, through, which students can enhance their technological skills and innovative abilities.

It is worth noting that in most maker education cases, students experience informal rather than formal learning. On the one hand, this shows that research and practice need to be done on the application of maker education in formal learning.

On the other hand, it means maker education has natural informal-learning features. The maker movement is deeply influential for engineering and technology education, and educators should undertake more research and practical effort into it. The core rationale of maker education is fairly consistent with constructivism, and its learning methods are not brand new; thus, related existing education theories can be used to interpret it.

Further research should be done on the following topics:

- The integration of maker elements (e.g. digital tools, maker space) with formal learning;
- Ways of evaluation of students' learning results in maker education;
- The formulation of curricula and study programmes based on maker rationale.

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