# *MOOE: A New Online Education Mode*

## *Virtual Simulation Experiment MOOE Platform for FPGA*

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***Abstract*—This paper proposed a new kind of online education mode, MOOE (Massive Open Online Experiment). MOOE was produced based on the thoughts of the Internet thinking and the opening-and-sharing resources and was the organic combination of MOOC and experimental teaching. The main contributions were made: (1) Instructed MOOE's concept and characteristics. MOOE build a network laboratory with the advanced information technology to make experimenters complete all the experimental activities through the Internet without the limitation of time, space and resources. (2) Analyzed the similarities and differences between MOOE and MOOC. MOOE was the extension and expansion of MOOC, which realized the online learning of all the teaching activities including the theoretical courses and their related experiments. MOOE inherited the advantaged of MOOC, but paid more attention to the virtualization of experimental equipment, operations and contents. (3) Described the implement and application of MOOE by taking an experimental course titled "FPGA Based Multi-core Computing" as an example. The feasibility and advantage of MOOE were proved by the actual statistical data of the course.**

***Keywords—MOOE, MOOC, Online, Experimental teaching, Visualization***

## I. INTRODUCTION

The Internet had altered the way people learned, worked and lived. In 2002, with the help of the Internet, MIT put forward the campaign of OCW (Open Course Ware), marking the beginning of Open Education.[1] In 2012, the rise of MOOC (Massive Open Online Course) extended and deepened the Open Education, offering various degrees of expansion in terms of the open contents, open forms and open scales. Characterized by massive, open, online and sharing, MOOC was a new-style online educational mode and it had brought a reform to education. [2-4].

Although MOOC had made great contributions to the changing of educational idea, teaching modes: learning patterns, teaching environment and evaluation mechanism, it also had some problems, especially its scanty supporting power to experimental teaching. [5] Experimental teaching was the efficient way to train learners' ability to deepen the understanding of knowledge, master the technical skills, foster engineering accomplishment, practice scientific thinking, cultivate innovative ability and strengthen exploring spirit, which was also the indispensable part in educational system. [6,7] However, MOOC realized the networked and digitalized teaching by segment video. MOOC actually cannot satisfy the online experimental demands of virtualization and visualization in terms of experimental equipment, instrument and operation due to MOOC's interaction was mainly used to transmit information among users. [8-10] In view of above problems, the concept of MOOE (massive open online experiments) was put forward, which was produced based on the thoughts of the Internet thinking and the opening-and-sharing resources and was the organic combination of MOOC and experimental teaching. [2] MOOE, a new experimental teaching mode and regarded as "laboratory in the Internet", adopted some advanced technologies like virtualization, cloud computing and network communication to achieve the online learning of experimental contents, the online use of experimental resources and the online guidance of experimental process. It also solved the problems owing to the limitations of time, space and resources and could rapidly construct complex and good-isolated experimental environment. MOOE was the extension and expansion of MOOC. MOOC was mainly responsible for the spreading of theoretical knowledge, [11] while MOOE focused more on the training of practical skills. MOOE not only made up the MOOC's deficiencies on experimental teaching, achieving the situation that the Internet can realize the whole teaching process including teaching, learning and practicing, but also showed the thought of the unity of knowledge and action. By the application of MOOE, learners can internalize, compose and build their own knowledge system when they had "watched" the teaching video and "manually worked on the hardware". Therefore, the learning pattern based on the control of time was transformed into the pattern based on the learner's individual capacity.

The rest of the paper is structured as follows: Section 2 instructed some related researches about MOOC and virtual experiments. Section 3 proposed the concept of MOOE and its characteristics and analyzed the similarities and differences between MOOE and MOOC. Section 4 presented the building methods of MOOE including the design of platform architecture and the visualization of the experiments. Section 5 analyzed some statistical data from a course which used the MOOE to indicate the advantages in terms of open time, settings and the efficiency of equipment. Finally, section 6 showed some conclusions and outlines future work.

## II. Related Work

MOOE evolved from MOOC. MOOC originated in 2007 and it proposed a new curriculum model aimed at developing open courses based on the Internet. In 2007, Professor David Wiley in Utah State University opened a course "Intro to Open Education (INST 7150)" to make learners around the world participate the course and share the course resources freely. [12] Later, Professor Alec Course in University of Regina offered an online course Media and Open Education (EC&I 831) and invited many experts from other countries to take part in teaching. The above two courses had laid theory foundation and implementation experience for MOOC. [13]

MOOC was first proposed by two Canadian academic Dave Cormier and Bryan Alexander in 2008. In September of the same year, two Canadian academic Stephen Downes and George Siemens set up a course "Connectivism and Connective Knowledge Online Course (CCK08)" based on MOOC. This course applied open teaching methods and provided open content to make learners participate in the study in various form, e.g. YouTube, Facebook, Blog, Twitter and other social software systems. [14] In 2011, some experts and scholars from Britain, the United States, Belgium and other countries in the field of E-learning launched a project "Mobile Learning" to provide several ways of communication and collaboration to learners to make them know about mobile learning and create their own mobile learning project. The above two examples developed their MOOC courses based on the learning theory of correlation, which is called cMOOC. [15] And in 2012, New York Times reported an article entitled "The Year of the MOOC" and MOOC was on the rise in the world. Now, the open online courses were offered mainly based on the learning theory of activism, which was called xMOOC. cMOOC and Xmooc were the two chief types of MOOC. On July 30, 2013, Malcolm Brown, head of "Action Learning Plan" published a blog "Moving into the Post-MOOC" on the website EDUCAUSE. He thought the development of MOOC had entered into the age of Post-MOOC with some new changes in teaching methods, teaching platforms and credit certification. [16]

The arrival of Post-MOOC promoted the reform of experimental teaching and appeared some new remote experimental teaching modes, e.g. online experimental teaching, virtual simulate experimental teaching and blending experimental teaching combined virtual simulation with real environment, etc. India's Dew University built an online virtual laboratory to make their students take online classes and do experiments supported by 20 top universities in the United States. [17] Yale University applied mobile experimental teaching method in the biological curriculum and teachers can share their research achievements obtained in the laboratory with students through iPad immediately. [18] In order to overcome the lack of online experiments in online courses, some famous universities, e.g. Stanford University, Massachusetts Institute of Technology, Columbia University and the UK's Open University, increased some new experiments to the opened courses based on virtual the virtual laboratory. It had three types: mobile interaction experiment, self-determination experiment and collaborative experiment. [19]

Furthermore, some advanced universities had obtained some achievements in the future classrooms and laboratories. E.g. Nanyang Technological University's COTF, Tokyo University's KALS, the university of Pittsburgh's Scalable Collaborative Learning Space. Some professors in Harvard University introduced Hackerspace into teaching and changed the traditional classroom to an open and heuristic environment. [20] MIT implemented a plan "Technology Enabled Active Learning" embodied the idea of "classroom is laboratory". [21]

## III. Characteristics Of MOOE

MOOE (massive open online experiments) derived from MOOC, also a type of online courses that obtained online teaching resources by Web and had massive interactions. MOOE complete all the teaching activities including theory courses and related experimental courses by the online learning. In other words, MOOE included MOOC. MOOE was deep combination of information technology and experimental teaching, on the basis of computer technology, software technology, hardware technology and the Internet technology and using computer and various experimental facilities as its tools. It created a virtual experimental environment with the capability of remote operation and experimenters can achieve diversified experiments through the Internet without the limitations of time, space and resources.

MOOE had mainly five characteristics: interactivity, openness, sharing, large scale and online, which were described in detail as follows:

### *A. Interactivity*

MOOE's strong interactivity derived from the strong interactivity of experiment course. MOOE was mainly to complete the on-line theoretical learning by viewing online videos and its interaction types and communication forms were relatively simple. Rather, MOOE copied the whole process of experiment teaching by the Internet and it would not only realize the on-line teaching, but also provide a series of functions with strong interactivity, e.g. on-line use of experimental equipment, on-line operation of experimental contents; on-line guidance of experimental process, on-line display of experimental results. MOOE made learners get a real sense of interaction with teacher, equipment and group members in the way of on-line learning and they also can complete an experiment cooperatively.

### *B. Openness*

The openness of MOOE was an inheritance of MOOC and was the characteristic of the experiment teaching itself. Experiment teaching aimed to train the learners to be applied talents with the abilities of engineering practice, linking theory with practice and technology innovation. Compared with theory teaching, the cultivation of leaners' experiment teaching was more complex, its training mode was more flexible and its training objective was more diverse. It needed more abundant teaching resources, more effective teaching methods and more independent learning process. Therefore, openness was especially important to experiment teaching. MOOE allowed the learners from all over the world to take the on-line

experimental courses through the Internet. The learners could learn the courses and complete the experiments independently, freely and unlimitedly. The open of MOOE not only referred to time and space, but also included the teaching subjects, the learning objects, the teaching modes, the learning patterns, the teaching contents and the experimental resources, which indicated it was an all-round opening pattern.

### C. Sharing

Sharing was the important characteristic of experiment teaching. Experimenters usually completed the experiments through collaboration and communication. In the process of sharing, experimenters can not only get the better resources, but also obtain some inspirations or thoughts. "The personal learning decided the depth of learning, but the group learning decided the breadth of learning". And the traditional experiment teaching mainly focused on how to share the physical recourses and it increased the utilization ratio of recourses by prolonging the open time, establishing a resource sharing platform, etc. But based on the traditional sharing mode, the experiments were restricted on the scale, type, object and effect. With the advanced computer technology and information technology, MOOE combined the open teaching with the Internet to deal with the conflicts between the growing number of experimenters and the shortage of experimental resources (e.g. teachers, equipment and courses) and proposed a new sharing concept, "sharing equipment, sharing teacher, sharing course, sharing member, sharing process, sharing thought and sharing method". MOOE made full use of sharing and highlighted the member sharing, thought sharing, method sharing based on the resource sharing, which completely changed the experimenters' current subordinate position of resources and made them complete the experiments anytime and anywhere and share the resources as many as they want.

### D. Large Scale

The traditional experiments were greatly affected by capital, site, equipment, etc., which resulted in that the experimental settings cannot be scaled up arbitrarily, the experimental resources cannot be shared easily and the experimental contents cannot be updated rapidly and the teaching effect cannot be known timely. With the advent of MOOE, these problems had been solved rather completely. MOOE made it possible to have a "world lab". The large scale of MOOE was shown in two aspects: large-scale participants and large-scale data analysis. First, large-scale participants indicated the experimenters from all over the world can assemble their own courses, at will. They can choose the world's teachers, share the world's equipment and connect the world's members. MOOE had broken the binding relationship between learner, lecturer and course and also broken the binding relationship between lab, equipment and experimenter. MOOE truly made the experimenter become the main body of the course. Second, large-scale data analysis indicated MOOE had the ability to store massive data, which was applied to accurately record the behaviors of experimenters, habits, results, etc. And these data was extremely valuable to the researchers to do big data analytics and data mining to form a behavior analysis or prediction for some course or some learner, which had great reference value in the improvement of course.

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### E. Online

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## IV. Differences between MOOE and MOOC

MOOE, which was more suitable for online teaching on experimental courses, derived from MOOC and these two concepts shared dissimilarities as well as commonalities.

### A. Different from teaching contents

MOOC was a massive online teaching mode and was also a new kind of opening-and-sharing educational resource for spreading the knowledge better by the Internet. The concept of "course" in MOOC had narrow sense: specifically means the theoretical courses based on teachers' lecture. Teaching video was its main component, which indicated the teaching process was widely spread and shared by the Internet in the form of video. [22,23] By contrast, the concept of "course" in MOOE has wide sense, realizing the online learning of whole teaching activities including theoretical courses and experimental courses. Compared with MOOC, MOOE had more complete teaching procedures, more abundant content and more diversified teaching forms. On the basis of MOOC, MOOE made the organic combination of the learning of theoretical knowledge and the cultivation of practical ability, which made the only distance between the teaching and learning a machine. Therefore, MOOE was the favorable supplement of MOOC.

### B. Different from teaching patterns

MOOC achieved the online learning of the theoretical course by short video and interactive practices. The teaching activities, course resources and targets involved in MOOC were relatively simple and MOOC's core function was the video-watching and interactive communication, which can be done by the Internet. So, MOOC can be acted by sheer online teaching. Offline teaching can be regarded as the favorable supplement of MOOC, but not the prerequisite. MOOE developed from MOOC, realizing the online learning of experimental teaching. Learners can accomplish the whole experimental process under the guidance of teachers. [11,22,23] Experimental teaching had strong characteristic of practice, requiring learners to touch the equipment, observe the phenomenon and probe into the principle in the real experimental situations. Although MOOE achieved interactive functions like screen sharing, multiplayer session and electronic whiteboard by adopting the advanced WebRTC technology, (described in Section 3), it cannot substitute the

vital offline experimental teaching. Hence, MOOE was the hybrid teaching pattern combined the online teaching and offline teaching and offline teaching was the prerequisite of MOOE.

### C. Different from evaluation systems

MOOC had employed the diversified and procedural evaluation system, not only measuring learners' mastering degree of theoretical knowledge, but also tracking, analyzing and evaluating learners' whole learning process, psychological changes and studying habits by utilizing intelligent technology. [14,15] But the standard of MOOC's evaluation system targeted the check of the theoretical knowledge, not absolutely suitable for MOOE. MOOE learned from the experience of the MOOC's system, considered the experimental operation as the main component of the experimental check, based on the principles of formative evaluation and summative evaluation and used the methods of teacher's assessment, peer's assessment and self-assessment and it build up the dimensional online experimental evaluation system including experimental theoretical evaluation, experimental operational evaluation, experimental report evaluation and experimental interaction evaluation. MOOE evaluation system paid more attention on the check of experimenters' exploring ability, focusing on other factors which did not exist in MOOC's evaluation system, like the ability to design a reasonable plan, to operate normatively, to observe the problems acutely, to analyze the problems accurately and to discuss the problems cooperatively.

### D. Different from the difficulties to build platform

MOOC platform needs to realize the functions like uploading and watching videos, interacting practices, society discussion, sharing information and integrating resources. It mainly involved the load balance of servers, concurrent access of data and occupied bandwidth of streaming media, which nowadays can be solved perfectly. [4-7] As a result, the construction of the MOOC platform was relatively easy to achieve. However, MOOE should rely on the browser to fulfill the whole experimental teaching activities. It had strong interaction and should complete the remote operation of resources, virtual assembly of the equipment, synchronized sharing of the screen, audio and video conversation among many people. Compared with MOOC, MOOE had more complicated functions and was much more harsh to fulfill. Many techniques it used had few previous cases, for instance, the built-in remote desktop in the browser, remote equipment operation by means of the browsers and data transmitting of multiplayer video, requiring our research and exploration on our own. Consequently, it was quite hard to design, construct and develop the MOOE platform.

## V. IMPLEMENT OF MOOE

MOOE fully inherited the advantages of MOOC and combined the theory teaching and experiment teaching very well under the thoughts of massive, open and online. The MOOE in this paper highlighted the features of full time-space, follow-resources, universality and personalization. With the advanced techniques of virtualization and Internet, our MOOE broke the limitation of time and space to make learners complete the experiments anywhere and anytime; it broke the limitation of experimental resources to make learners use the resources as they need; it broke the tight coupling relationship between the experimental platform and experimental equipment to make learners complete the experiments through the general browser; it broke the limitation of off-line experimental contents to make learners build their own on-line lab. The design methods of our MOOE were as follows:

### A. Virtualization of Experimental Resources

An experimental platform that meets MOOE's online experimental standards should be established. Adhering to the principle of "to materialize the virtual experiment, to contextualize the scene of user operations and to generalize the experimental equipment", MOOE aimed at achieving zero difference between virtual and physical experiment, reducing the disturbances and influences of virtualization and making experimenters use pragmatic physical resources and perceive real experimental phenomena in the far end. Currently, most of virtual laboratories usually adopted the way of logging on the local host by VPN to share and use the remote experimental resources, e.g., the FPGA remote experiment system set up by Fayoum University in Egypt and Universidade de Brasilia and the remote experiment system made by Hosei University. [24-26] This method was relatively simple, but it may be easy to lead to the security vulnerabilities caused by users' excessive operable authorities over resources. In this paper, we designed a MOOE experiment platform based on B/S structure which had four-layers, they are access layer, transformation layer, storage layer and terminal layer, as shown in Figure 1. This platform took the Linux Web server as its core and adopted ThinkPHP frame. The Linux Web server communicated with the Windows cluster server equipped with a set of bottom experimental equipment through LAN and communicated with users through Ethernet, which constituted the complex network architecture to separate the control flow from the data flow effectively. Experimenters interacted with Linux Web server by browsers. Their operations and results are input and output in a hierarchical operational way of "experimenters <-> Linux Web sever <-> Windows cluster severs <-> experimental equipment" and the design principle was similar to IOS's (International Organization for Standardization) hierarchical network model and each layer can work independently and work collectively. The Linux Web server played the role of transfer station, which was used to receive, transit and store information and ensure that the experimental process is safe, reliable and recognizable. The Windows cluster severs is specially designed for compatibility with different experimental equipment (with or without network card).

*1)* **Access Layer:** Windows cluster servers, which was mainly used to physical connection, data communication and program download between them. The key point is the definition of connection mode. According to the categories of experimental courses, MOOE can realize three types of experiments, they were: hardware experiments with network card, hardware experiments without network card and software experiments, as shown in Figure 2.

- Hardware experiments with network card: The characteristics of this kind of experiments are the experimental equipment can be connected to MOOE directly to be accessed by the Internet due to its network card. Based on the features of this kind of experiments, MOOE realized the one-to-many connection mode by putting a router between experimental equipment and Windows cluster servers which can scale up the experiments and expand its capacity. But this kind of connection mode had some problems about equipment identification, scheduling resources, etc. Some useful methods, e.g. recording the experimenters' behavior, identifying the equipment by MAC, are used to solve these problems.
- Hardware experiments without network card: This kind of experiments cannot be accessed by Internet directly due to without network card. But most of the hardware experiments have serial port which is used to translate data. Therefore, firstly, the hardware experiments can be connected to Windows server via serial port and then, it can be accessed and controlled by Internet indirectly through the Internet connectivity of Windows server. The difficulties of this kind of experiments are the synchronous processing and real-time response to the network data communication between the Windows server and the Linux Web server in the upper layer and the serial data communication between the Windows server and the experimental equipment at the bottom layer. An advanced programming technique of multi-thread method was used to solve the concurrent execution between different tasks. When high performance and high efficiency were required, it can use a multi-core processor as the Windows server and process data in parallel.
- Software experiments: This kind of experiments referred to the software tools experiments (e.g. programming experiments, mechanical drawing experiments) and the demonstration experiments. In MOOE, experimenters can not only learn the contents, observe the results, submit the reports and discuss the questions via online, but also can share the software resources (experimental tools, experimental environments) through the browser, which can make the experimental operations more convenient by reducing the trouble of local installation and diagnostic, which was boring and even always failed for some people. Compared with the two previous experimental types, the platform infrastructure of software experiments was simple and need not the Access Layer and all the operations can be implemented by the Linux Web server. But the difficulties in this kind of experiments were how to load the experiment resources (tools, environments) through the browser. We embedded a Remote Desktop into the browser by writing a browser plug-in in C++ language which made the users easy to use the remote experiment resources. It was the important function in our MOOE.

*2)* **Transformation layer:** Transformation layer regarded the Linux Web server as a core which formed an abstract layer between the browser in its upper and the experimental equipment at its bottom. Linux Web server was mainly responsible for handling the users' data from browser and managing the hardware resources from the equipment side. In MOOE, the Linux Web server acted as a role of Operation System and on one hand, it provided a united and clear Web interface which can reduce the learning difficulties due to complex operation, and on the other side, it provided a standard hardware interface which can hide the differences of different equipment and make the experimenters can complete all kinds of experiments through MOOE. In our design, the Linux Web server can obtain the experimenters' operation behaviors by invoking the Action property of page. It used expect script to save and execute the experimenters' serial communication command, used shell script to copy their submitted application programs to the Windows server automatically and used database to record the experimenter's information, the experiment's status and the document's location, etc. And expect is an automated interactive language which can be used to realize the automate interactions between the Linux Web server and the Windows server. With the help of expect script, the experiments can operate the hardware resources through the browser and so as to make it possible that the resources can be abstracted and shared in the MOOE.

*3)* **Storage Layer:** Storage layer recorded all the experimental information in the form of database, e.g. the experimenters' behaviors, the time for experiments, the experiment places, etc. Storage layer can save and restore the context, which can not only realize the discontinuous operation and the distributed cooperative work, but also can provide some valuable data for big data analytics in the future. For small experiments, the storage layer and the access layer can be merged together and the Linux Web server can act as a storage medium. When the scale became larger, MOOE need to provide some advanced functions, e.g. massive data storage and high-reliability, by applying some new techniques, e.g. cloud storage and distributed storage system.

*4)* **Terminal Layer:** Terminal layer was the Web-browser interface which was operated and faced to by experimenters directly. The greatest feature of MOOE was it used the B/S architecture to let the experimenters complete the whole process of the experiment, including preparation, exercise, review, answering, only through the browser. MOOE simulated the actual teaching process by reproducing the teaching entity, e.g. teacher, equipment, blackboard, and the teaching activities, e.g. classroom teaching, practical operation, experiment instruction, visually through the Internet. MOOE tried to create a similar learning atmosphere like in-school courses. In order to let the experimenters learn the on-line courses better, our MOOE provided four terminal modes. They were: courseware and operation mode, operation and video mode, whiteboard and courseware mode and whiteboard and video mode and it allowed the experimenters to switch freely.

### B. Visualization of Experimental Instruction

The main problem in MOOC was the lack of effective communication and guidance. The teachers and learners can only communicate with each other by interactive exercises, on-line answer and community discussion. Most of these communications were achieved via word, even with video capability, and it was only applied for chatting. These defects of MOOC made the teachers and learners have the problems of communication impediment and teachers cannot rapidly know the learners' problems and situations. Especially for the experimental guidance and the results observation, MOOC was helpless. Our MOOE had made a breakthrough on this problem and implemented an advanced technology named WebRTC (Web Real-Time Communication) to realize the real-time communication and online interaction based on web. WebRTC is a kind of communication protocol to realize the real-time audio and video communication based on the browser, which can make the developers develop rich real-time multimedia applications quickly and easily. At present, WebRTC was plugged in Chrome by Google and was fully open source. WebRTC can embed the audio and video communication functions into browser without plug-in and without installation, which met the demands of MOOE perfectly. In MOOE, teachers can communicate with the remote learners by real-time communication, screen sharing, electronic whiteboard and document transmission without barriers, distance and delay. Teachers can control the remote learner's computer to debug directly through screen sharing; teachers can observe the actual experimental results to find the problems accurately through video communication; teachers can realize the massive on-line learning through multi-people session. MOOE made the remote learners no longer interact with the screen alone, but reach out to more people, "the world classmates and the world teachers".

### C. Visualization of Experimental Contents

The visualization of experimental contents mainly referred to the visualization of teacher's teaching process and the visualization of experimental materials, e.g. courseware, experimental instructions. Based on the MOOC's short-video teaching method and fragmentation-learning thought, the visualization in MOOE focused on how to divide the experimental contents, how to record the video tutorials and how to reorganize the experimental materials. First, MOOE segmented and refined the off-line experiments by the relatively independent experimental steps, then the supporting materials and operation videos would be produced, finally, some related subjects would be designed for each video. Video production need to take account of organization and pictures and pay attention to the connection between the explanation of knowledge and the process of operation, which can add the usability and visual interest to the on-line courses. The video in MOOE was better under 10 minutes in length. The fragmented experimental teaching units are not only easily to be understood, simulated and operated by the leaners, but more importantly, it changed the traditional teaching pace and the inherent content arrangement designed to meet the requirements for the logicality and systematization in the off-line class, to allow teachers to have more flexibility and options to design contents. MOOE need to reorganize the visualized contents. On one side, reorganization made teachers concentrate on what they do best and upload the best experimental materials without restricted by the teaching plan. In MOOE, these teaching materials with rich contents and various forms were reorganized into different units with different learning goals according to a certain logic and purpose. On the other side, reorganization made the original course content with fixed-length and fixed-material become a dynamic, controllable and organic whole. The learners can choose the appropriate contents according to their own learning pace and learning ability which can enhance their enthusiasm, initiative and empowerment.

## VI. Results Analysis

Our MOOE took the experimental course titled "FPGA based Multi-core Computing" offered by the School of Computer Science and Engineering in our university as an example and the website was launched in the spring semester of 2015. According to the statistics, by August 2015, the largest number of users was 125, which was more than 100 times than that of off-line course, the average learner number of which was only about 20. And the continuous running time of our MOOE was about 3600 hours, which was much longer than that of off-line course, which just had 24 experimental hours. Meanwhile, our MOOE greatly improved the utilization rate of experimental resources.

### A. Extending learning time

Figure 3 shows the learners' respective time distribution of using MOOE and using Multi-core hardware lab to have the FPGA based Multi-core Computing experimental course. According to the data shown in the figure, we can clearly draw a conclusion due to the limitation of opening time of the lab and the number of equipment, a limited number of learners can only do experiments in a limited and fixed time. But MOOE had visitors in all the time and had the highest traffic between 22 and 1 am. Therefore, MOOE significantly outperformed off-line lab in the aspect of optional time and the amount of resource.

### B. Scattering learnig place

Figure 4 shows the place of the off-line experimental course is limited to the fixed lab, but learners in MOOE are not restricted to the physical place and they can do their experiments anywhere, e.g. dormitory, home, study room, library, as long as there is on the Internet and the experiments can be done discontinuously. Based on this, MOOE proposed a new concept: follow-learning, Follow-leaning indicates the resources should follow learners and the course should take learners as center, which greatly improved the flexibility of doing experiments. It made the experimenters pay more attention to the experiment itself and reduce the interference of time and place.

### C. Expanding the number of leaners

Before, the FPGA based Multi-core Computing experimental course can only accommodate about 20 learners due to the restriction of hardware resources and three learners as a group can only share one set of experimental equipment

for three hours in each lab seminar. But MOOE can theoretically support an unlimited number of leaners to have on-line courses. At present, our MOOE can allow more than 200 visitors to access the resources concurrently and these learners can complete the experiments dependently or they can establish a virtual group to work cooperatively. MOOE obtained a more distribution of leaners, a wider range of experiments, and a higher level of participation.

### *D. Increaseing learning outcomes*

MOOE adopted the method of blending teaching, which combined the online independent learning and offline targeted guiding, to satisfy the requirements of different levels of learners, mobilize their learning enthusiasm and improve the learning efficiency and teaching quality. According to our statistics, under the condition of the traditional laboratory, the leaners can only complete 5~6 experiments in the limited class hours. But in our MOOE platform, the leaners can complete 8 experiments in a semester, averagely. And MOOE had deeper influence on the learners with more initiative. They cannot only complete the same number of experiments two times faster, but also can put forward some creative experimental methods.

## VII. CONCLUSION

The appearance of MOOE had brought a revolution to the experimental teaching. We had drawn some conclusions: (1) MOOE changed the conventional teaching ideas: MOOE built a laboratory without walls and broke the limitation of time, location and teaching resources. It provided more equal opportunities and higher quality educational resources to everyone. (2) MOOE changed the teaching mode: MOOE creatively introduced the approaches of blending learning and flipped classroom into experimental teaching. It converted the experimental teaching mode from teacher-oriented to self-education and paid more attention to the process of knowledge internalization. MOOE made experiment teaching return to its true value. (3) MOOE changed the mode of experimental learning: the combination of experimental teaching and Internet provided a variety of new experimental learning modes, e.g. blending learning combined the online virtual experiments with the offline physical experiments, mobile learning with terminal equipment and etc. (4) MOOE changed the experimental teaching environment: MOOE used information technology to make the whole process of teaching, learning, evaluating, testing and practicing, limited by time and space, implemented by Internet. It realized seamless learning and further, the asynchronous interaction could be enhanced much more during the process of teaching and learning. (5) MOOE changed the evaluation mechanism: MOOE provided a more reasonable, more equitable and more varied experimental evaluation by online evaluation in form of peer review and process verification.

Therefore, the practices had proven MOOE had great value and attraction for online teaching and developed a new domain for experimental teaching. MOOE effectively solves the problems of offline experiments with the limitations of time, space and resources and it was worth further research and extension.

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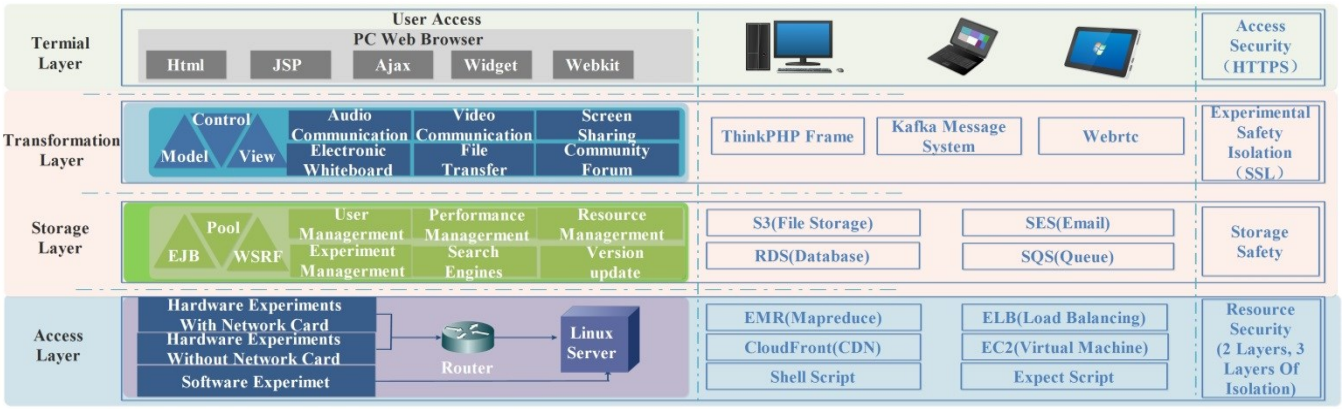


**Figure 1. MOOE's Four-layer Framework**

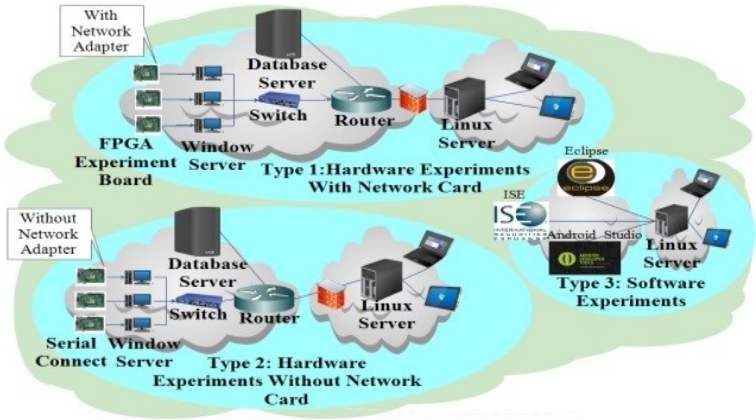


**Figure 2. MOOE's Three Types of Experiments**

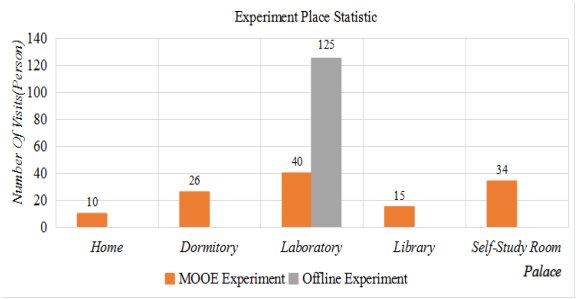


**Figure 3. Learning Places Statistics**

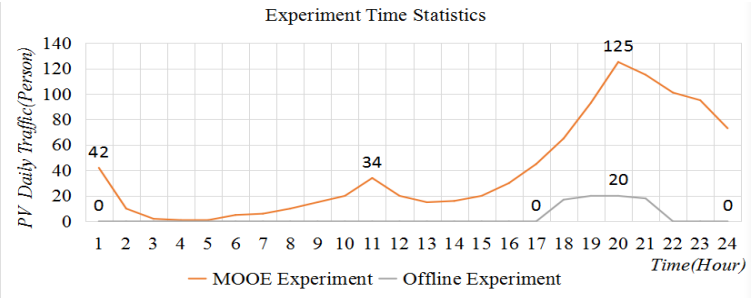


**Figure 4. Learning Time Statistics**