Design of Advanced Active and Autonomous Learning System for Computing Education

-A^3 Learning System-

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***Abstract*— In this paper, we propose an advanced active autonomous learning system (A^3 learning system), an educational system based on the use of information and communications technology devices. The A^3 learning system comprises active learning (AL), project/problem-based learning (PBL), and mastery learning (ML). In concrete terms, foundational learning in the software/hardware information fields and PBL from the software design stage to the system implementation stage were conducted using AL and two methods, respectively, by individual students and a group. Furthermore, the Progress Report on Generic Skills test was conducted to evaluate the educational benefits of the proposed system.**

Keywords*— *A^3 learning system; computer education; active learning; problem/project based learning; mastery learning

I. Introduction

With changes in the social structure and the ideal view of human beings desired by the world of economics, there are calls for higher education institutions to nurture human resources that can equip themselves with a scientific way of thinking. This should be done with advanced knowledge and world class technology to face the array of social issues presented both regionally and globally in an autonomous, collaborative, and constructive way, with human resources that have the 21st Century skills to persevere in the future. What is required is a new kind of education that drastically reforms the traditional education system, rears human resources so that each student can reach their full potential and respond to the demands of society, and is conscious of the abilities required of each student by society to understand their own situation in an objective manner. In particular, learning systems that implement active learning (AL) are attracting attention worldwide [1][2][3][4], and the benefits of such systems are highly regarded [5][6]. However, construction of effective learning systems including AL has been lacking, and there is a particular need for systematic education systems, including project/problem-based learning (PBL) and mastery learning (ML), in the field of computing education.

In response to this issue, we have been developing systems to encourage autonomous learning using information and communications technology (ICT) devices, such as computers and tablet PCs, and have constructed a framework for guaranteeing the quality of education while conducting AL trial lessons involving collaborative learning actively using these devices. Using this approach, multiple instances of AL and PBL have been introduced while conducting legacy knowledge-transfer-based lecture-centric courses, enhancing educational benefits, and gaining knowledge of the possibility of encouraging independence in students.

In this paper, based on the above approach, we propose an advanced active autonomous learning system (A^3 learning system), a new educational system based on ICT devices such as computers. Our A^3 learning system contains AL, PBL [7][8][9], and ML [10][11][12][13][14]. This is a departure from legacy-based courses that involve cramming in a fixed quantity of knowledge and achieves a progressive form of learning in which the learning size changes actively and autonomously to fit the objective achievement level corresponding to individual students. Furthermore, the Progress Report on Generic Skills (PROG) test, which has some improvable features [15], is administered to evaluate the educational benefits of the proposed system, and this evaluation method is discussed from the two vantage points of "literacy," which leads to the practical resolution of problems, and "competency," which is the skill of establishing good relationships with the surrounding environment.

The structure of this paper is as follows. In the first section, we present an overview of the background to this study. In section two, we discuss the proposed A^3 learning system and course structure. In section three, we look at the practice of our A^3 learning system's courses, and in section four, we provide an evaluation of the system. Finally, in section five, we provide a summary of the paper and discuss issues for future work.

II. A^3 Learning System

A. Overview of the A^3 Learning System

The A^3 learning system we propose is referred to as the A^3 learning system owing to its three initial letters. The system contains AL, PBL, and ML based on the use of ICT devices, such as computers and tablet terminals, which not only extend the abilities of each student, but also encourage them in active and autonomous learning, reducing the course preparation and management load on the teaching staff.

For students to equip themselves with "firm knowledge," "thinking faculties/inventiveness," "practical skills," and

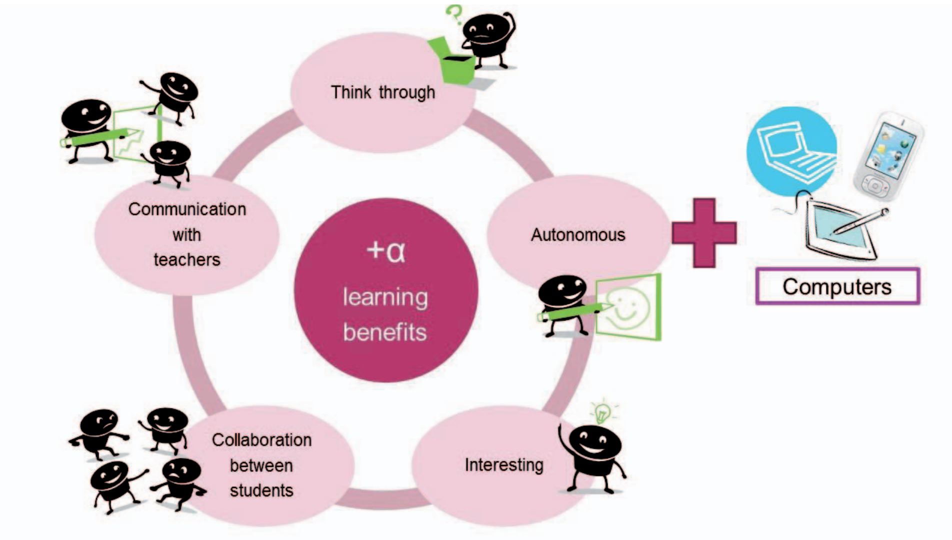

Fig. 1. A^3 learning system concept.

"generic capabilities such as foundational skills to become a member of society" to produce students that can respond to a diverse array of carriers, an educational system that can flexibly respond to the abilities and objectives of individual students is required. That is to say, for students with a variety of objectives, as the required content and size of learning will obviously differ and be constantly changing, the A^3 learning system has moved away from legacy-type learning, in which a fixed quantity of knowledge is crammed in, to achieve a progressive learning system in which the size of learning actively and autonomously changes to fit the objective achievement level depending on the individual student. Furthermore, our A^3 learning system includes an evaluation of both "literacy," which leads to the practical resolution of problems, and "competency," the skill to construct effective relationships with the surrounding environment. In general terms, evaluation with AL uses assessments such as the Collegiate Assessment of Academic Proficiency (CAAP) and Collegiate Learning Assessment (CLA) in the United States and Europe to evaluate ability that differs from academic results; however, these have the drawback of requiring cost and time. Furthermore, there has been little research into whether the standard for the evaluation method can be generally accepted, as the evaluation of student skills conducted using a variety of courses is subjective. Therefore, a PROG test that does not rely on subjective evaluation is used with our A^3 learning system. Both literacy and competency are evaluated by evaluating the growth of each student.

B. A^3 Learning System Lesson Structure

The A^3 learning system consists of the three systems of AL, PBL, and ML. The specific learning forms are as follows.

AL: Lessons that include activities in which students "learn by themselves or with their fellow students," cultivating their "learning skills" while obtaining a deep level of knowledge. Substantial group work (pair work) and discussion is included. ICT devices and electronic materials are used positively, with flip teaching also considered to be effective.

PBL: Cultivates thinking faculties (skills for resolving issues, creativity, etc.) and practical skills (skills for actual manufacturing and resolution using knowledge and technology), as well as foundational skills necessary to complete a project as a member of society. Through the setting of themes in a wide variety of fields, knowledge from each field is merged and deepened, and through setting themes linked to society, an image of philanthropy as a member of a society can be developed.

ML: This is a style of individual learning in which each unit is learned at one's own pace, and once that is fully mastered, there is a transition to the next unit. Lessons consist of individual guidance and face-to-face lessons for support. As there are differences in the understanding speeds for each student, lessons that proceed at the pace of the instructor cannot, in principle, avoid producing students whose understanding cannot catch up and thus have incomplete knowledge. ML is a lesson style that resolves this issue.

The concept of the A^3 learning system is shown in Fig. 1. As shown in the figure, through AL, PBL, and ML, learning is achieved through active and autonomous student learning and through communication among students and between students and instructors, bringing +α learning benefits to legacy learning content.

III. PRACTICE OF THE A^3 LEARNING SYSTEM

A. Overview of the Practice of the A^3 Learning System

In regard to the proposed A^3 learning system, computing education has also adopted a curriculum design and practiced specializing in software education. In concrete terms, foundational learning in software/hardware information and PBL from the software design stage to the system implementation stage were conducted using AL and two methods, respectively, by individual students and by a group.

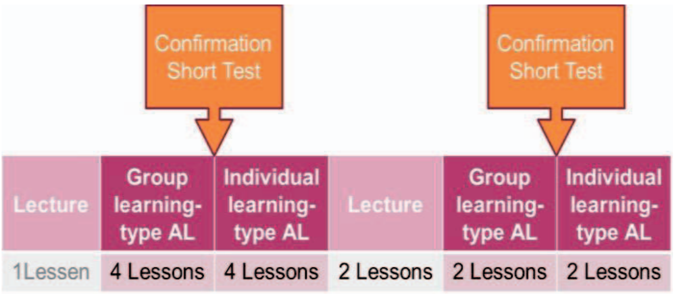

Fig. 2. Example of course design with AL in knowledge engineering.

B. AL practice: Software-related subjects

As a software-related subject, the AL A^3 learning system was introduced in the knowledge engineering course. With the aim of providing an introductory education on artificial intelligence and knowledge engineering, this consisted of an overview of artificial intelligence, search methods, expert systems, production systems, and the latest trends.

In this subject, as shown in Fig. 2, group learning- and individual learning-type AL have been mutually adopted. More specifically, survey learning, which adopted group learning-type AL, was conducted for part of the previous important lecture-based courses that students struggled with or found difficult to understand. With group learning-type AL, there is positive discussion and inter-teaching among students, encouraging understanding among all students. In particular, with learning of a “rule set” in production systems, group learning-type AL was conducted in which expert knowledge was summarized as a rule set. The target themes were not specified by the instructor but determined by discussion among the students in each group, and autonomous learning among the students was stimulated through practical learning of the themes in which the students themselves were interested. There are a wide variety of themes from animation on television to cooking recipes, and this was approached enjoyably and earnestly by all the groups. The rule sets completed by each group were firmly in place, and it was considered that the content to be learned had been sufficiently understood. Furthermore, in the case of content having a broad range of fields to study that students often take an interest in and where a variety of different answers, such as recent trends related to information technology, can be expected by each student, separately performing survey analysis through individual learning-type AL can result in a wide variety of answers. For example, in the case of AL based on the theme “learning,” individual learning is conducted on the field that each person finds interesting, and through the use of learning methods from the most recent research trends to learning via social network software and games, a wider range of content can be handled than when it is prepared by the instructor alone. In this way, learning can be broadened and deepened through the use of individual learning-type AL.

After survey learning such as that described above, through presentation of the surveyed content and lively discussion based on it, it is possible to come into contact with a diverse array of answers and understand them in a broader, deeper manner, reaching conclusions that reflect each other’s opinions. In addition, not specifying the presenter until immediately before beginning enables all students to fully conduct their presentation preparations, thereby further enhancing understanding.

Unit1	Unit2	·····	Unit6	Unit7
6 Lessons	2 Lessons	·····	6 Lessons	2 Lessons

(a) One year

Confirmation of the knowledge	Lecture	Training· Exercise	Conclusion
10 min.	40 min.	50 min.	10 min.

(b) One lesson

Lecture	Individual work	Group work
20 min.	5 min.	5 min.

(c) One lecture

Fig. 3. Example of course design with AL in the digital circuits.

Furthermore, as a trial for ML, we confirmed the extent to which the learning content had become established through short tests on the important areas of the course. In particular, a short test was administered on the important points each time after conducting group learning-type AL for handling important learning content. For all of the content for which group learning-type AL was performed, the fact that all of the content to be learned had been sufficiently learned was confirmed by students achieving an average score of eight to nine points out of ten on the tests. It was confirmed in this way that the autonomous learning of students could be encouraged by introducing the elements of AL and ML into previous lecture-centric courses. Furthermore, it was confirmed that the ML method is effective as a method of confirming levels of understanding using short tests for students on important areas.

C. AL practical: Hardware-related subjects

The A^3 learning system was also used in a digital circuit course as a hardware-related subject. In spiral education, which we have being using until now, experiments, training, lectures, and exercises are linked in an organic and systematic manner, and the curriculum is considered to be based on these concepts. As the course design for these subjects, we designed the AL course to utilize the merits of spiral education.

For this subject, multiple units related to digital circuits were prepared. In previous courses, the structure has been such that a number of practical sessions were conducted together after multiple lectures had been successively taken. With this design, there are concerns that the quality of education might suffer owing to the gap of a week or more between the lecture and the practical sessions. For this reason, in the digital circuit course in which we aimed to practice the A^3 learning system, we planned lessons that proceeded in a spiral shape, with reviews, lectures, training, and exercises taking place in relation to one another in one lesson within one unit, and we introduced these into the course as necessary. The course design shown in Figs. 3, (a), (b), and (c) represent one year, one unit, and one lecture, respectively. The lessons progressed within a single unit, adopting group learning-type AL and using the approach of students teaching one another to avoid the “one-way” type of lessons in which students’ awareness of the objectives tends to decrease. One unit consists of a confirmation of the knowledge acquired up to that point; lectures, training, and exercises for learning new knowledge; and a conclusion. Within the lectures, time for the individual to think (individual work) and time for a pair or group to learn from one another (group work) are provided, and where necessary, this occurs multiple times within the time frame. In addition to improving the students’ abilities of thinking and acquiring knowledge, this aims to increase students’ communicative ability. The intention of the aforementioned framework is not only to enable listening to the opinions and thinking of other students within the group, thus deepening the thinking of the students themselves, but to further engrain knowledge in a deep manner through the use of inter-teaching among the students. Furthermore, the plan included improving student activity by intentionally increasing this inter-teaching among students.

Reviews at an early stage are effective in further increasing the understanding and retaining of course content. Keeping this in mind, elements of ML have been introduced and the content of the practical elements and exercises conducted in the second half of the lesson was linked to the lecture conducted to confirm the level of understanding. Reviews that occur through practical training immediately after the lectures are effective in promoting the establishment of a knowledge level.

In addition, as the content of the lecture itself can be experienced through practical exercise, this is considered to be extremely effective in understanding the content of the lecture and retaining this knowledge. Furthermore, as practical training involves approaching problems by forming pairs within the lecture group, the knowledge required for the practical training is shared within the pair. This ensures a high level of communication between students within the lecture time. For this reason, the framework is such that the inter-teaching within the group during lectures is also utilized for practical training. In fact, with practical training, it is often the case that inter-teaching among students is seen to occur without any encouragement from the instructor, suggesting that both AL and ML are functioning.

When trial lessons with this lesson structure were conducted, communication among students progressed very smoothly, and it was felt that lessons had become livelier than before. It was also seen during the practical training that issues were being tackled with more vigor than before. The activity level of students appeared to increase, and the level of understanding and entrenchment of specialized content appeared to improve. It was also felt that introducing AL into the course not only entrenched specialist knowledge but also promoted improvements in the students’ autonomous learning and communication abilities.

D. Group-type PBL practice: Software design development

A group-type PBL A^3 learning system was put into practice in a software design development course. The objective of this subject is to learn the object-oriented development method, with the course structure consisting of two parts: learning the object-oriented analytical design method using Unified Modeling Language (UML) and practice in the software development process. A PBL for actual application development was introduced in this second half of the development process practical.

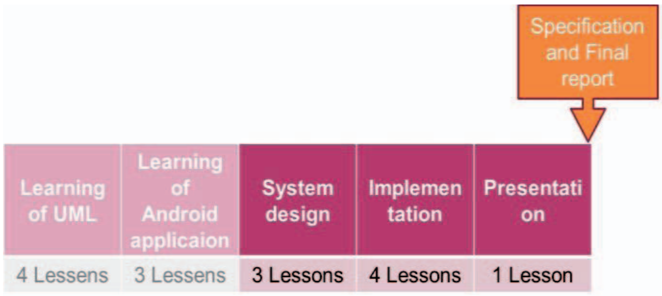

Fig. 4. The example of course design with PBL in the software design development.

In this PBL, as shown in Fig. 4, the theme is an Android application, and this is developed in the three phases of specification research (three times), implementation (four times), and presentation (one time). Each group consisted of four or five members chosen in consideration of aptitude for software development and communication abilities.

The flow of the practical training is as shown below. At the beginning of the training, a sample Android application is proposed by the instructor. Development of the application entails adding functionality. First, during the specification research phase, a sample is analyzed using the UML method learned in the first half, and specifications such as class diagrams or sequence diagrams are created. The functions to be added to this are discussed, and in addition to creating the external specification, the specification is revised using UML. Next, the program is created during the implementation phase based on the revised specification. Despite the fact that there are differences in programming ability among the students, all students are encouraged to participate in the program creation as much as possible. Finally, the program is completed and the results of the development are presented.

The execution of PBL was seen to bring about an increase in academic ability as a result of improvements in communication and inter-teaching within the group. In general terms, an issue in software-related subjects is that there tends to be a clear difference in ability between students compared to other subjects; however, it seems that the use of PBL deepened the understanding of a large number of students. Selecting PBL themes that would attract the attention of students contributes to enlivening a large number of students. When PBL was used this time, choosing the subject of an Android tablet application that would attract the interest of students encouraged students’ positive participation. Furthermore, we heard from those reporting that as there are disparities in development skills within the group, contributions were made to the project from all standpoints through a division of roles.

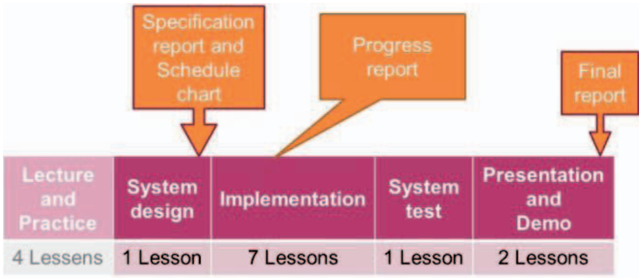

Fig. 5. Example of course design with PBL in the CG application development.

E. *Individual-type PBL practical: Computer Graphics (CG) Application development*

In the Computer Graphics (CG) course, a practical software application subject, the A^3 learning system was put into practice with an individual-type PBL. With the objective of understanding CG programming and theory, this consisted of lectures on the theory of CG and CG projects freely created by each student.

For this subject, an individual-type PBL was adopted to allow each student to experience the full software development process. In concrete terms, the software to be developed is determined by the students themselves, and all of the processes from creating a software requirements specification to design are implemented and tested by each student. The CG projects are completed at the student's own pace. In particular, as practical training is based on the image of software developed at a company rather than as simply a subject within a course, for the important points of the training, the results are presented in an actual report document rather than just a simple report. As shown in Fig. 5, submission of this report is a function of ML, and is important in confirming the progress of each development process and the level of understanding.

With the production of this CG project, having students themselves create the work themes breeds student creativity. Furthermore, by completing design and development themselves, every student can benefit by experiencing the entire development process. In software development, it is necessary to understand the entire process, and having the PBL conducted by individual students themselves rather than by the group provides all students a valid experience of all of the processes. Additionally, with the introduction of ML elements, training can proceed at each individual student's own pace. This approach potentially prevents having a stereotypical course.

Both types of software development PBL, the group-type PBL in 1) and the individual-type PBL, enhance students' awareness of the development process in a company, and allow them to experience the entire process from requirements analysis/design to implementation and delivery. This has the benefit of entrenching the importance of document creation and deadlines in students, contributing to the nurturing of the foundational skills necessary for them to become members of society.

IV. Method of Evaluating the Benefits of the A^3 Learning System

A. *An approach to nurturing foundations and measuring abilities*

To measure the foundational abilities of the students without relying on subjective evaluation of such abilities through the practice of the A^3 learning system, we conducted a continuous evaluation using the PROG test, a generic measurement test. The PROG test has a track record of being tested on more than 110,000 university students and by treating the data of young leaders active in actual society as an instructor model has shown the possibility of applying this evaluation standard more widely. That is to say, through this test, it is possible to measure "literacy," the practical ability to resolve problems, and "competency," the ability to build effective relationships with the surrounding environment. Consequently, we measure the benefits of the A^3 learning system through a periodic PROG test evaluation of the students using this system for their studies.

B. *Analysis of measurement results*

As a trial of this evaluation method, the PROG test was administered on a total of 64 students, consisting of 29 nineteen year olds and 35 twenty year olds, in October 2014.

The average for literacy and competency as a whole is shown in Table 1. The target student group achieved higher scores than university students as a whole. In particular, general literacy showed an exceptionally high score. If we analyze this literacy element in detail, "the power of imagination" (ability to consider various conditions and restrictions, examine/select a resolution and put this into a concrete policy) of the target students showed a very high value compared to other university students. For general competency, the 19-year-old student group achieved a higher value than the 20-year-old student group. As shown in Table 2, in the 19-year-old student group, there was a strong trend toward the interpersonal foundational skill of "affinity" and the personal foundational skill of "emotional control." On the other hand, inter-subject foundational scores of "planning skills" were low compared to the science and technology-based university students, and when analyzed in detail, the scores for "setting of objectives," "scenario construction," and "plan evaluation" were low. Furthermore, the students who were targeted for the test had a tendency to be weak in terms of "planning."

C. *Analysis results*

Although expressing the characteristics of the test target students on the basis of the results from one test is insufficient, numerous results were recorded. To analyze the growth (development) of any of the abilities of students in any year as the results of education after entering university, it will be necessary to continually perform measurement tests every school year. We plan to administer measurement tests aimed at all students in all school years, and we are eagerly awaiting the results of this analysis.

V. Conclusion

In this paper, we propose an A^3 learning system as an educational system using next-generation ICT devices that drastically revises the traditional form of education systems in

TABLE I. PROG TEST RESULTS (GENERAL)

(The respective abilities are shown as average values evaluated in seven stages)

	19 year olds	20 year olds	All university students
General literacy	5.6	5.6	3.8
General competency	3.8	3.3	3.2

TABLE II. COMPETENCY – EXCERPTS FROM LARGE/MEDIUM-SIZED CLASSIFICATIONS

(University students/engineering/science & technology/information engineering majors)

		19 year olds	20 year olds	University 3rd year	University 4th year
Interpersonal foundational skills average		4.0	3.4	3.4	3.5
Personal foundational skills average		3.9	3.5	3.5	3.7
Inter-subject foundational skills average		3.8	3.7	3.9	4.2
Interpersonal	**Affinity**	4.4	3.2	3.5	3.6
Personal	**Emotional control**	4.0	3.5	3.4	3.7
Inter-subject	**Planning skills**	3.4	3.3	3.6	3.9

order to maximize the potential of individual students, meet the demands of society for the nurturing of human resources, and achieve a form of education that is aware of the capabilities in students required by society and objectively understands its current state. Furthermore, we discussed the practices and methods for evaluating our A^3 learning system.

As future work, in addition to performing a more detailed evaluation of the A^3 learning system through further practical trials, we will conduct additional surveys on trends in student literacy and competency.

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