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Teaching Simulation on Collaborative Learning, Ability Groups and Mixed-ability Groups

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***Abstract*—In this research, a teaching simulation model is built where the understanding status, knowledge structure, and collaborative effect of each learner are integrated by using a doubly structural network model. The purpose of the model is to analyse the actual conditions of understanding of learners regarding instructions given in classrooms. The influence of teaching strategies on learning effects is analysed in the model. Moreover, the influence of the seating arrangement of learners on collaborative learning effects and ability groups are discussed. As a result of the simulation, the following points were found: (1) the learning effects depend on the difference in teaching strategies, (2) a teaching strategy where learning skills, material structure, and collaborative learning are integrated is the most effective, (3) the seating arrangement affects collaborative learning, and (4) ability groups have adverse effects on learners in collaborative learning.**

I. Introduction

In education, it is important to understand the status of the understanding of each learner and design instruction content according to their understanding status. Additionally, there exist relationships between knowledge and the content to be instructed, and it is important to consider the structural dependency relationship when teaching is done. The effectiveness of the collaborative effect among learners has also been clarified.

In the research field of network models, recently, a new model building method, referred to as a complex doubly structured network model, has been proposed[4]. By using this complex doubly structured network model in this research, we tried to integrate the understanding status, knowledge structure, and collaborative effect of each learner in order to simulate the actual conditions of the learners' understanding for instructions given in a classroom. Moreover, we set and examined the issues described below by applying the simulation method. (1) What kind of influence could teaching strategies have on learning effects? (2) What kind of influence could the seating arrangement of learners have on collaborative learning effects? (2) What kind of influence could ability groups and mixed-ability groups have on collaborative learning effects?

II. In-Class Learning Process Simulation

In this research, we tried to build a simulation with a class consisting of 30 learners, where it was assumed that five instructions, from X1 to X5, are used when teaching them. This simulation was to estimate what material should be taught, in what order and how many times, until all learners in the classroom could give the correct answer. To build the teaching simulation, we used correct answer history data for model estimations, correct answer data in the class, and seating data. Correct answer history data for model estimation has two values, correct/incorrect answers, of all 300 learners for five questions that correspond to the instructions taught from X1 to X5. The history data was gathered from an online learning system where primary school children study arithmetic.

A. Definition of the Internal Network

The internal network is composed with multi-layers combined the understanding probability model of knowledge according to the academic capability of each learner and the learning material structure model. When certain knowledge is taught, based on the understanding probability model, the understanding probability according to the academic capability of each learner is calculated. As for knowledge items, the understanding probability propagates along with the material structure model. In this way, the internal network is defined.

1) Understanding Probability Model: When it comes to the understanding probability model of all knowledge that corresponds to the academic capability of each learner, the item parameter is estimated by conducting the marginal maximum likelihood estimate based on the quasi-Newton's method and the EM algorithm which is an iterative method for finding maximum likelihood in statistical models. The ability parameter is estimated by using the experience Bayesian method. By using these estimated values, the understanding probability model is built. Specifically, this estimation is done by using the correct answer history data for model estimation and the ltm-package for Item Response Theory analyses on software R [18]. The result of this estimation is quantified as the form of Ability. The estimated Ability parameter (item characteristic curve) is set according to the knowledge, and the understanding status for all knowledge of each learner at the point in time before teaching, in order to estimate the understanding probability of knowledge of each learner.

2) The Course Material Structure Model: The material structure model was built by utilizing the structure estimation on the Bayesian network. As for model estimation, the correct answer history data for model estimation was used. The result was estimated with the greedy method on the package deal of software R . This was estimated as formula 1.

$$\begin{aligned} &P(X1, X2, X3, X4, X5) \\ &= P(X1)P(X3|X1)P(X4|X1, X3) \\ &\qquad P(X2|X1, X3, X4)P(X5|X2, X3, X4) \end{aligned} \tag{1}$$

The conditional probability was calculated with the bnlearn package of software R by using the model of formula 1.

B. Definition of the Teaching Simulation Model

When it comes to the classroom network, in order to build a model, we assumed an all-together (brick-and-mortar) classroom lecture consisting of one teacher and 30 learners, where collaborative learning would be done between each of learners sitting left to right. Learners were allocated according to seating data. If it was found according to correct answer history data that either those learners on the left or those on the right understood the targeted knowledge taught, he/she should conduct collaborative learning when the teacher teaches that knowledge so that the other learners could also understand the knowledge taught.

Based on the complex doubly structured network model consisting of an internal network and a social network, this agent-based simulation estimates the progress of understanding status of the learner when teaching is done.

III. Experimental Results and Discussion

A. Experiment 1: Evaluation of Teaching Strategies

In the experiment, we tried to discuss the issue of what kind of influence teaching strategies could have on learning effects. In this experiment, we move our discussion forward by applying the following four teaching strategies for the class pattern 1 in which students are seated randomly, and then by comparing the average time of teaching sessions and the attainment degrees.

- TS 1 Teaching along with the complex doubly structured network method
- TS 2 Teaching by selecting items to teach in a random manner
- TS 3 Teaching an item where many learners gave wrong answers
- TS 4 Teaching by moving to next item when all learners understood an item by order of the highest correct answer rate according to each model question

TABLE I
The average teaching time.

Teaching Strategy(TS)	Teaching time
TS 1	22.5
TS 2	42.9
TS 3	32.3
TS 4	23.4

As the result of conducting 10 simulation sessions, the average teaching time is shown in Table I. This result confirmed that learning effects depend on teaching strategies. When observed from the viewpoint of the average teaching time, in both teaching strategy 1 and 4, the teaching time was less than 24 times. We can consider that these strategies had higher learning effects. From the viewpoint of the attainment degree, teaching strategy 1 has a tendency where the initial growth was higher than the other strategies. For example, when the attainment degrees after the fifth teaching session are compared with the degree of each strategy, teaching strategy 1 was 0.70, 2 was 0.59, 3 was 0.42, and 4 was 0.49. Therefore, this shows that the teaching strategy 1 had the highest attainment degree.

B. Experiment 2: Evaluation of Collaborative Learning

In this second experiment, preparing three different environments for the lecture model, the left-and-right collaborative learning model, and the group collaborative learning model, we compared the results. The left-and-right collaborative learning model is a model where the seating arrangement is the same as the lecture model and collaborative learning occurs between left and right seats as shown in Fig. 1. On the other hand, the group collaborative learning model is a model where the seating arrangement is grouped in a class room and collaborative learning occurs in the groups as shown in Fig. 2.

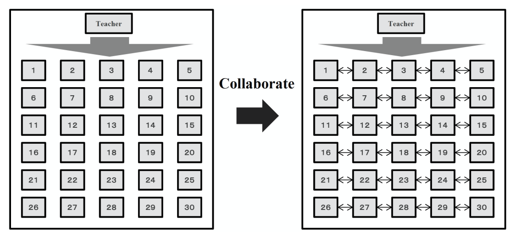

Fig. 1. Placement of the left-and-right collaborative learning model

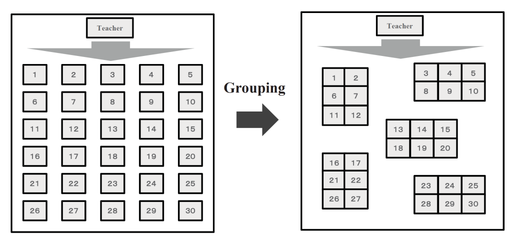

Fig. 2. Placement of the left-and-right collaborative learning model

We conducted 10 simulation sessions. Table II shows the average number of teaching of the simulations. In any of environments for the lecture model, the average number of teaching decreases in order of the lecture model, the left-and-right collaborative learning model, and the group collaborative learning model. Therefor, it is obvious that the collaborative learning models has a positive effect on leaners more than the lecture model, and the wider the range of collaborative learning is, the more the effect on learners is. On the other hand, the attainment degree did not reach 1 in any of teaching strategies of 1, 2, 3, or 4. In the group collaborative learning model, the teaching strategy 4 has virtually the same effect as the strategy 1 in terms of the average number of teaching times. This result means that the teaching strategy 4, which is the teaching method in order of the highest correct answer rate, is the second best strategy for a newly-appointed teacher, because she or he has difficulty teaching while understanding their knowledge structure, ability and collaborative relations.

TABLE II
THE AVERAGE TEACHING TIME.

Teaching Strategy(TS)	1)	2)	3)
TS 1	22.5	8.20	6.0
TS 2	42.9	17.7	13.6
TS 3	32.3	11.8	8.3
TS 4	23.4	9.30	6.0

C. Experiment 3: Evaluation of the seating arrangement on learning effects

The third experiment considered what kind of influence the seating arrangement of learners could have on collaborative learning effects. In this experiment, preparing four different environments for the social network, concentrated arrangement and dispersed arrangement on the left-and-right collaborative learning model and the group collaborative learning model, we conducted 10 simulation sessions by using teaching strategy 1. Afterward, we compared the results. The concentrated arrangement is a model where learners with high academic capability are gathered in one place. The dispersed arrangement is a model where learners with high academic capability next to those learners with low academic capability. About the left-and-right collaborative learning model, we created particular situations with the concentrated and dispersed arrangements by changing the seating arrangement of learners as shown in Fig. 3 and Fig. 4. We compared both situations for discussion. In this experiment, we estimated the academic capability of each learner by using IRT based on the correct answer history of the learner. According to the estimated value, we determined those learners with high academic capability. Determining those learners that have above a certain estimated value to be excellent learners, we structured the concentrated arrangement and the dispersed arrangement by changing the seating arrangement of those excellent learners. As for the average teaching times, the concentrated arrangement was 9.5 and 8.4 times, while the dispersed arrangement was 7.7 and 5.6 times as shown in Table III. While the average teaching times increased in the concentrated arrangement, it decreased in the dispersed arrangement. Through this result, we were able to confirm that learning effects vary by making changes in the seating arrangement for learners and the dispersed arrangement could enhance teaching effects.

TABLE III
AVERAGE NUMBER OF TEACHING IN EXPERIMENT 3

Collaborative type	Centralized	Dispersed
1) Left-and-right	9.5	7.7
2) Group	8.4	5.6

1) the left-and-right collaborative learning model
2) the group collaborative learning model.

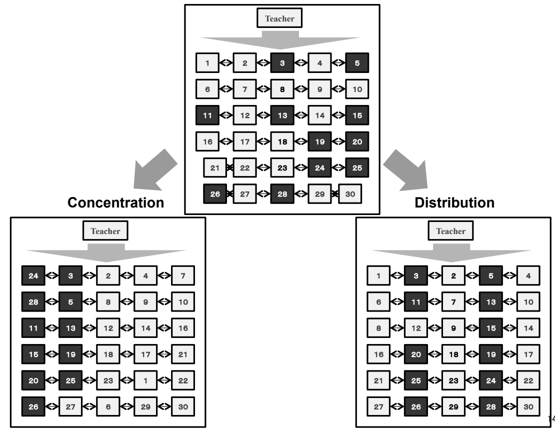

Fig. 3. Placement of the left-and-right collaborative learning model

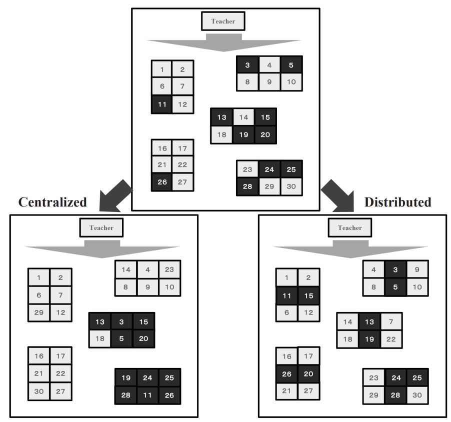

Fig. 4. Placement of the group collaborative learning model

D. Experiment 4: Evaluation of the effects of grouping according to ability

The fourth experiment considered the issue of ability groups in a school. Ability groups mean that children are divided up into groups according to their ability levels to be taught. In this experiment, preparing two different environments for ability groups and mixed-ability groups, we conducted 10 simulation sessions by using teaching strategy 1. The environment of ability groups has three classes divided by their ability level of the answer data on online learning. Although the environment of mixed-ability groups has also three classes, all the learners are mixed by ability randomly. The total number of teaching times in three classes of the lecture model, the left-and-right collaborative learning model and the group collaborative learning model are shown in Table IV. And the results of the average number of teaching times in ability groups are shown in Table V.

When observed from the viewpoint of the teaching time, the number of teaching times for the ability groups is less than the mixed ability groups in the lecture model. On the other hand, the number of teaching times for the ability groups

TABLE IV
TOTAL NUMBER OF TEACHING FOR MIXED-ABILITY AND ABILITY GROUPS

	Mixed-ability groups	Ability groups
1) Lecture	67.5	60.7
2) Left-and-right	23.1	25.5
3) Group	16.8	19.9

1) the lecture model
2) the left-and-right collaborative learning model
3) the group collaborative learning model.

TABLE V
AVERAGE NUMBER OF TEACHING IN THREE ABILITY GROUPS

	All	High*	Medium**	Low***
1) Lecture	60.5	17	20	23.7
2) Left-and-right	25.5	7.8	8.4	9.3
3) Group	19.9	6	6.9	7

*high ability group, **medium ability group, ***low ability group

is more than the mixed ability groups in both the left-and-right collaborative learning model and the group collaborative learning model. The results indicates that ability groups have adverse effects on learners in collaborative learning.

E. Discussion

We utilised the simulation for in-class learning processes considering academic capability, learning material structure, and collaborative relationship. In the first experiment, using four teaching strategies, we quantified the teaching procedure selected by each teaching strategy and the learning effect status, visualised them in chronological order, and compared the influence of each teaching strategy on learning effects. By so doing, we were able to evaluate the educational effects of each teaching strategy.

In the second experiment, we modelled three different environments for the lecture model, the left-and-right collaborative learning model, and the group collaborative learning model. Comparing the results, it is obvious that the collaborative learning models have a positive effect on leaners more than the lecture model, and the wider the range of collaborative learning is, the more the effect on learners is.

In the third experiment, we arranged learners using a concentration arrangement and a dispersed arrangement, quantified the learning effect status, and compared both arrangements. By so doing, we were able to evaluate the influence of seating arrangements on learning effects. Through these evaluations, we confirmed that teaching would work more effectively where there is a dispersed seating arrangement, not a concentrated seating arrangement in collaborative learning.

The fourth experiment considered the issue of ability groups in a school. The environment of ability groups has three classes divided by their ability level of test results on online learning. The environment of mixed-ability groups has also three classes, and all the classes has 30 learners mixed by ability randomly. The results of the experiment indicates that ability groups have adverse effects on learners in the collaborative learning models, while ability groups are more effective than the mixed ability groups in the lecture model.

According to these experiments, ability groups in a school possibly have negative effects to learning because they reduce diversity in a class. Homogeneity between learners on collaborative learning has the risk to take away diversity from learners and make collaborative effect fall into decline.

IV. CONCLUSION

Traditional approaches to analyse the learning effect have focused on the internal knowledge structure or collaborative effect between learners respectively. On the the hand, this study aims to integrate these approaches to analyse the knowledge structure, each learner's state and their collaborative effect simultaneously on the single agent based model.

The purpose of this research was to clarify the actual conditions of understanding of teaching done in a classroom. As a means to do so, we proposed a simulation for in-class learning processes with consideration given to academic capability, learning material structure, and collaborative relationships. We built an agent-based teaching simulation model on an internal network by estimating the understanding probability network by the use of IRT and estimating the learning material structure model with the use of the Bayesian network. We were able to quantify the teaching effects in the classroom and conduct simulations to determine effects.

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