Chang, M. et al. (Eds.) (2019). Proceedings of the 27th International Conference on Computers in Education. Taiwan: Asia-Pacific Society for Computers in Education

Linking the learning processes to learning engagement and learning outcomes: How well did the students learn in modeling-based computer simulation activities?

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Abstract: The purpose of this study was to investigate the relationships between students' different extent of completion of modeling activity and the students' modeling competences and learning engagement. Research participants were 76 11-th grade students in Taiwan. The students participated in modeling-based computer simulation activities (MBCSA). We designed and learning patterns was analyzed through lag sequential analysis (LSA). Research instruments included pre- and post-modeling competence tests, engagement questionnaires, and online students' worksheets. Students' activity logs were also recorded by the computers. The students' online worksheets were scored and used for grouping the students into three levels of completion of MBCSA: the Low-Score Group (LSG), Middle-Score Group (MSG) and High-Score Group (HSG). The results showed that, first, in analyzing the students' pre- and post-modeling competences test, ANCOVA results showed HSG and MSG were significantly higher than LSG on model representation (MR). Second, in analyzing the engagement questionnaires, ANOVA results showed HSG was significantly higher than MSG on positive behavioral engagement and positive social engagement, and LSG was significantly higher than HSG on negative cognitive engagement, negative behavioral engagement and negative social engagement. Third, by using the LSA, six activity patterns were identified in this study. Students in the three groups showed different tendencies of the sequences of completing the modeling activities.

Keywords: scientific modeling, modeling competences, computer simulation, lag sequential analysis

1. Introduction

Models and modeling play a large role in scientific discovery and science learning at all levels of education (Gobert et al., 2011). Modeling has been considered as one of the core disciplinary practices in science and science education (Campbell and Oh, 2015). Model and modeling facilitate students' learning of science concepts, methodological processes and the development of an awareness of how science operates (Hodson, 1993). Science education is growing interest in modeling-based learning to promote students' modeling competences.

Modeling involves an iterative process that uses appropriate representation to capture integral features of a science phenomenon and link the relationship between these features in an attempt to provide mechanistic explanations of the science phenomenon (Sengupta and Clark, 2016). In comparison with textbooks and lectures, a learning environment with a computer simulation has the advantages that students can systematically explore hypothetical situations, interact with a simplified version of a process or system, change the time-scale of events, and practice tasks and solve problems in a realistic environment without stress (Berkum & Jong, 1991). Other researchers also believed that simulations are a key way that students can interact with models (D'Angelo et al., 2014). Simulations are tools which can help students to organize their knowledge of a system, or phenomena, and allow them to reevaluate their ideas with new information (Gouvea & Passmore, 2017).

Empirical research has shown that computer simulations can increase the students' understanding of science concepts and scientific phenomena (Gouvea & Passmore, 2017; Yoon et al., 2017; Windschitl & Andre, 1998). However, a study investigating the effectiveness of integrating computer simulations in science and engineering practices for developing and using models showed that computer simulations were just as effective as traditional teaching methods (Mohondro, T., 2018). The impact of MBCSA on students' modeling competences was inconclusive. Additionally, a review research including modeling-based instruction and modeling software argued that there was no dominant software used for research studies aiming to develop the modeling competence (Nicolaou & Constantinou, 2014). Modeling-based computer simulation activity (MBCSA) in physics domain was rare. Therefore, in this study, our goal is to explore the insights into the impact of MBCSA on students' modeling competences and students' activity patterns in MBCSA.

In this study, we pose three research questions:

1. What is the relationship between students' different levels of completion of MBCSA and students' modeling competences?
2. What is the relationship between students' different levels of completion of MBCSA and students' learning engagements?
3. What patterns of behavior sequences can be identified in completing MBCSA? And how did these patterns relate to the students' levels of completion of MBCSA?

2. Method

2.1 Participants

The participants of the study were 76 11th-grade students (48 female and 28 male) from three classes at two senior high schools in central Taiwan. Before the modeling activity, they had learned the basic concepts of force and friction in the physics courses in their senior high schools. However, they had not learned the concepts that were required to solve the target problem. Therefore, they had to construct the scientific models embedded in MBCSA to solve the target problem. The students were invited to a computer classroom and divided into 36 groups for collaboration. Each group consisted of 2~3 students.

2.2 The Modeling-Based Computer Simulation Activity (MBCSA)

The MBCSA we designed based on Model-Centered Instructional Sequence (MIS) (Baek et al., 2011) and Predict-Observe-Explain (POE). The activity provided a challenging question -- which children touched the ground first when playing on the slides in the playground. The students have to analyze the data presented by the simulation, construct their model of Newton's second law on a frictional horizontal surface and slope, experiment with and test their model, and then use their model to solve the problem. The MBCSA includes the following sessions: Problem, Prediction, Investigation 1, Investigation 2, Final model, and Evaluation. Although the students were encouraged to complete the activities sequentially from "Problem" to "Evaluation", the students could revisit any sessions at any time to review or re-edit the answer. The system kept track of all the editing history.

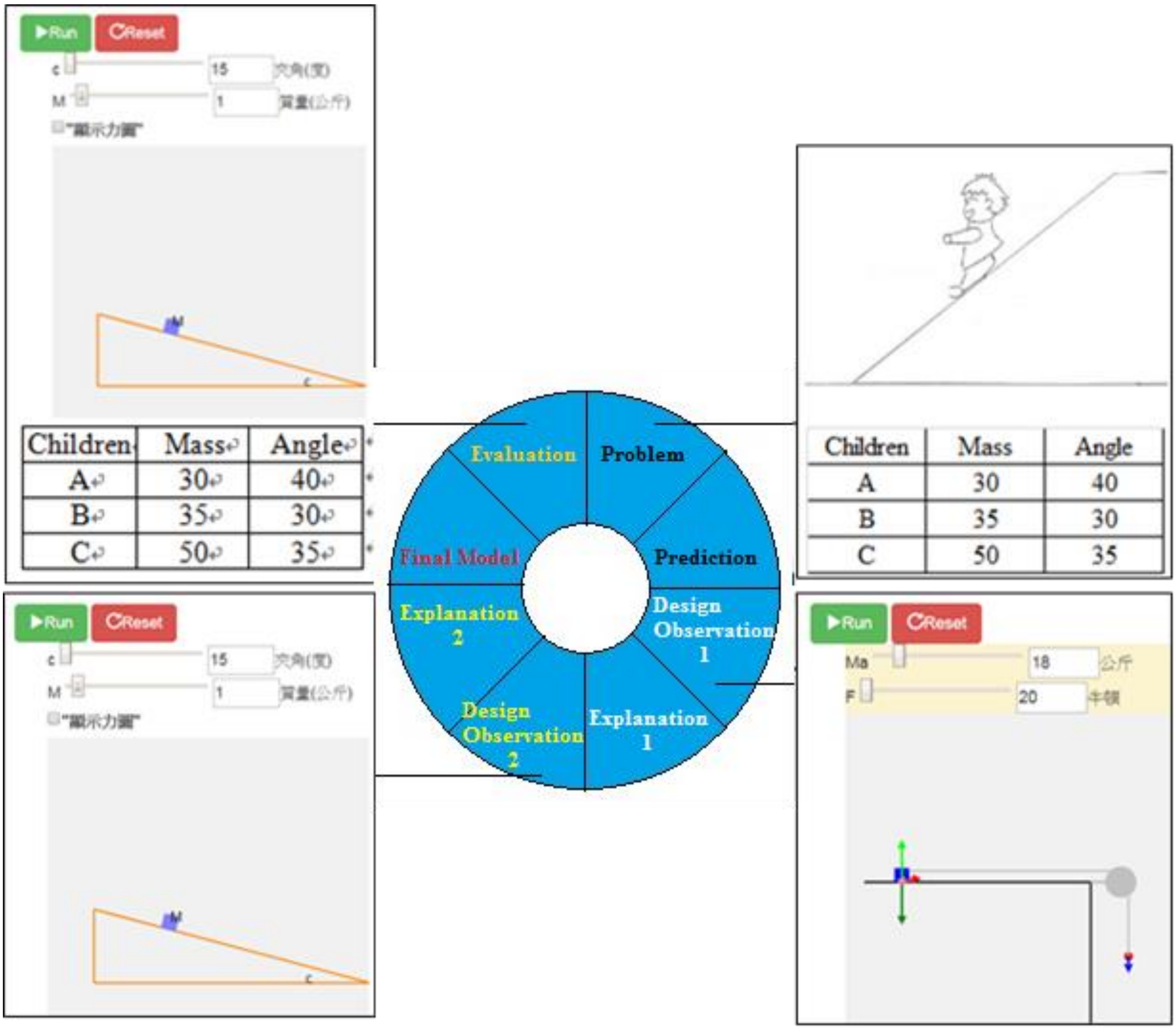

Figure 1. The MBCSA

2.3 Data Collection

2.3.1 Modeling Competence Test

Modeling competence test includes twelve modeling items (Wang and Lee, 2018). The test focuses on assessing the students' understanding of modeling products based on three modeling-oriented assessments (MOA) dimensions (Namdar & Shen, 2015), namely, model construct, model representation and model coherence. The scientific content in the assessment covers “simple machines" and "Newton's second law".

2.3.2 Engagement

The Math and Science Engagement Scale (Wang et al., 2016) were conducted after the MBCSA to analyze students' engagement. This questionnaire includes four subscales: cognitive engagement, behavioral engagement, emotional engagement, social engagement. The four sub-scales are further divided into positive and negative dimensions. A five-point Likert scale (i.e. 1 = strongly disagree, 2 = disagree, 3 = not sure, 4 = agree, and 5 = strongly agree) was used with all the items.

2.3.3 Modeling Processing Scores

Students' answers for the "Design and Observation 1", "Explanation 1", "Design and Observation 2" and "Explanation 2" sessions (8 short answers in total) were scored. Students' answers were recorded automatically by computer. Scoring was based on rubrics developed in this study.

2.3.4 Activity Logs

The raw activity logs record detail actions that each student performed in a chronological form. The raw activity logs were then processed and mapped to the MBCSA activities.

2.4 Data analysis

To discuss whether students with different modeling processing scores have a difference on modeling competences and engagement. 36 groups were divided into Low-Score Group **(LSG)** which has 10 groups, Middle-Score Group **(MSG)** which has 14 groups and High-Score Group **(HSG)** which has 12 groups according to their modeling processing scores. One-way ANCOVA was conducted to analyze the students' modeling competences among **LSG**, **MSG** and **HSG**. The pre-test scores of modeling competence served as the covariate in our analysis of covariance (ANCOVA) when comparing the students' post-test scores of modeling competence after participating in the MBCSA. Additionally, the ANOVA was conducted to analyze the students' differences of engagement in MBCSA among LSG, MSG and HSG.

2.4.1 Pattern of Modeling Behavior

The students' activity logs were analyzed through lag sequential analysis (LSA). The LSA utilizes the transition diagram to represent how the students transited among different types of activities to develop their learning models. The transition diagram contains only the significant transitions to display the students' activity patterns in the modeling activity (Wen et al., 2018). We interpreted the different patterns of modeling based on the different LSA diagrams.

3. Results

3.1 Students' modeling competence and modeling processing scores

Results indicated that there is significant difference on model representation (MR) among three groups, ($F(2,66)=7.21$, $p < .01$) of large effect (eta square = .18). The strength of effect measured by eta square values of .01, .06, and .14 can be considered to be small, medium, and large, respectively (Cohen 1988). Post-hoc comparisons using the LSD test revealed that **HSG** and **MSG** were significantly higher than **LSG**, but there was non-significant difference between **HSG** and **MSG**.

3.2 Students' engagement and modeling processing scores

An ANOVA was conducted to analyses the students' engagement among **LSG**, **MSG** and **HSG**. Results indicated that positive behavioral engagement and positive social engagement are significantly different among **LSG**, **MSG** and **HSG** ($F(2,65)=4.17$, $p < .05$, $F(2,65)=4.85$, $p < .05$). Post-hoc analyses revealed that **HSG** were significantly higher than **MSG**. Negative cognitive engagement, negative behavioral engagement and negative social engagement are significant different among the three groups ($F(2,65)=5.14$, $p < .01$, $F(2,65)=6.72$, $p < .01$, $F(2,65)=8.82$, $p < .001$). Post-hoc analyses revealed that the **LSG** was significantly higher than the **HSG**. The results showed no association between the students' level of completion of the students' performance in the modeling process and emotional engagement.

3.3 Students' modeling behavior and modeling processing scores

Each group's activity log was analyzed independently to reveal the activity patterns of each individual group in the MBCSA. Six activity patterns emerged from the LSA data. These activity patterns are (1) Step-by-step (SS), (2) Prediction-focused (PF), (3) Between investigations (BI), (4) Investigations to evaluation (IE), (5) Evaluation-centered (EC), (6) Final model to evaluation (FE).

The result showed that students in **LSG** tended to focus on the prediction session (i.e., PF pattern) and revisit the process from investigation to evaluation in MBSCA. In terms of **MSG**, except for the SS, the majority of groups belong to **BI, IE, and EC** behavioral patterns, and none belong to **FE**. In other words, the **MSG** students probabl**y** more focused on investigation and evaluation activities in MBSCA. In terms of **HSG**, most of the groups showed behaviors of PF, IE, EC, and FE pattern. Especially **FE** activity pattern only was found in **HSG**. Compared to the other two groups, some of the HSG students' emphasized reflecting from final model session to the evaluation session.

4. Conclusions and suggestions

This study illustrated the importance of looking into the students' learning process in terms of levels of completion of the modeling tasks and their behavior patterns in a computer simulation environment. This study showed that the computer simulations and the modeling activities can promote the students' competence in model representations if the students can correctly complete more than half of the activities. We also found that students' engagement in the learning activities were associated with the students' levels of completion. Future studies can use more complex statistics models to build the relationships between engagement, completion of activities, and modeling competence. Also, there is a need for designing modeling-based activities of good quality as well assessment items for promoting and evaluating modeling competence in future studies (Nicolaou & Constantinou, 2014).

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WORKSHOP 3 - Emerging Technologies for Teachers' Professional Development at Scale

THE DEVELOPMENT OF A TEACHER'S GUIDE FOR ENGLISH PROFICIENCY GAMES 86

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