Effects of Managing Element Interactivity on Student Achievement and their Academic Self-Concept in Science

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Abstract

Element interactivity, an essential feature underpinning cognitive load theory, has been identified as a major construct for explaining complexity in learning materials, but is not commonly used by teachers. The main aim of this study was to present some preliminary intervention effects following an in-service workshop that enabled teachers to apply an instructional strategy to manage element interactivity. Results showed that Year 7 students (N=156) benefitted from instruction that reduced element interactivity, not only in terms of their achievement, but also in their self-concept. Teachers who understand and are able to use element interactivity to manage instruction will be more effective in designing instruction that benefits their students, thus progressing teacher education to a new level.

1. Introduction

Presenting students with learning tasks that too easy may under-challenge students' cognitive capacities, while tasks that are too difficult may risk reducing students' self-concept, both of which have negative effects towards students' learning and motivation [1]. The cognitive load involved in learning tasks may be due to the element interactivity in dealing with (a) the nature and complexity of the learning material causing intrinsic cognitive load, and/or (b) sub-optimal instruction that does not contribute to learning causing extraneous cognitive load; and/or (c) the interaction between prior knowledge from LTM and new information in the WM which leads to learning to learning causing germane cognitive load [2]. Knowledge of element interactivity enables teachers to design instruction that is compatible with their students' expertise level. When teachers simplify complex problems into their elements and interactions, essential concepts and procedures are clarified resulting in students being more likely to solve word problems successfully [1]. When students experience success in learning, their self-concept, motivation and potential for higher achievement increases [3].

1.2 The study

In this study, element interactivity in the science topic of Density was reduced by the isolated-elements strategy [4]. Since the students in the study possessed good mathematical skills, including algebraic manipulations, the teachers focused on introducing the conceptual knowledge of density, before introducing the related procedural knowledge (e.g., applying mathematical procedures to solve density problems quantitatively). Within each type of knowledge, teachers designed their lessons using sequential stages of increasing element interactivity. Simple concepts (e.g., mass) were introduced before difficult concepts (e.g., density) and simple procedures (e.g., using the density formula as it is: density = mass ÷ volume) were introduced before difficult procedures (e.g., algebraic manipulations of the density formula: mass = density x volume).

2. Method

2.1 Participants

The participants in this study were four Year 7 science teachers (2 males and 2 females; age M = 35.0 years) and 156 Year 7 students (83 boys and 73 girls; age M = 13.1 years) from a selective school in

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Singapore in a high socio-economic area. English is the medium of instruction in all Singapore schools, so the participants were fluent in the English language.

2.2 Materials and procedure

The experiment consisted of four phases: 1) pre-intervention phase, 2) teacher knowledge acquisition phase, 3) students' knowledge and skills acquisition phase and 4) post-intervention phase. The following section provides details of each phase, followed by the instruments used in the study.

2.2.1 Phase 1: Pre-intervention

Before the intervention, teachers taught science in their usual way, typical of the traditional lecture-based system. For every lesson, the teachers showed PowerPoint slides and the students who were seated passively in the classroom, copying relevant information in their worksheets and notebooks. One of the science curriculum topics taught in this way was Properties of Matter. The pre-test and post-test results on Properties of Matter were submitted to the researchers as part of our analysis. During this time, students also completed a pre-test on Density before the intervention. The Density pre-test was designed by the researchers based on the curriculum objectives of the topic determined by the school, and given to the science teachers for moderation. The pre-test was less complex than the post-test because the students were not asked to perform any topic-related calculations. It was also during this phase that students completed a self-concept pre-test, to measure their science self-concept before the intervention.

2.2.2 Phase 2: Teacher knowledge acquisition

Participating science teachers attended five one-hour workshops conducted by the researchers after school curriculum hours. During the first two workshops, teachers were introduced to information about students' cognitive processes during learning and how to use element interactivity as an approach to: (1) analyze science word problems, (2) design instruction to meet students' learning needs and (3) design word problems that matched students' ability levels. In workshops three and four, the teachers worked with the researchers to design Density lessons using the isolated-elements strategy to reduce element interactivity and to assist novice learners with learning complex materials [4]. In the final workshop, teachers worked with the researchers to design a complex multi-part density problem and analyzed it using element interactivity.

2.2.3 Phase 3: Students' knowledge acquisition

The acquisition phase for the students was based on the Density lessons designed by their science teachers. All four science teachers delivered their lessons using the same Density lesson plans that were finalized at the end of the fifth workshop. Over seven one-hour lessons in three weeks, students were taught (1) the concept of mass, volume and density, (2) that density is a ratio of mass to volume and thus a property of a material, (3) the density formula (i.e., density = mass / volume) and how to apply it to solve problems in mass, volume and density and, (4) the concept of relative density and how it relates to floating and sinking. Some of the lessons were in the form of hands-on activities and some were theory-based instruction in the classroom.

2.2.4 Phase 4: Post-intervention

During this phase, students completed a Density post-test designed by the teachers and researchers, as well as a survey measuring their science self-concept after the intervention. The Density post-test questions covered the targeted concepts and procedures in the curriculum which were: (1) density is a ratio of mass to volume and thus a property of a material, (2) applying the density formula (i.e., density = mass ÷ volume) to solve problems in mass, volume and density and (3) applying the concept of relative density to determine whether an object floats or sinks in a liquid.

2.2.5 Test scores

The pre-tests and post-tests of the two science topics, Density and Properties of Matter, were assigned 5 marks each, one mark per question. Any error in a question resulted in zero mark assigned to the student for that question. All test questions were marked and awarded scores by the teachers. The researchers were then given the same students' work to score and had an inter-rater agreement of 100%. Students' achievement was determined from these test scores. Comparisons were made between the pre-test and post-test scores for each topic to study students' achievement gain before and after the topics were taught. If students' improved more significantly from pre-test to post-test in the topic of Density (where element interactivity management was present), than in the topic of Properties of Matter (where element interactivity management was absent), then it could be an indication that managing element interactivity during students' learning process had a role in the students' higher achievement.

2.2.6 Science self-concept

Each student was given a survey in which they rated on a scale of 1 (strongly disagree) - 6 (strongly agree) how much they agreed with each of four statements describing their sense of competence in science (e.g., "I have always done well in science") [5]. The same survey was administered to the students before and after the intervention.

2.3 Statistical analysis

A paired-samples t-test was conducted to compare students' scores on the pre-test and post-test on the science topics of Density and Properties of Matter. This was also done for students' science self-concept, before and after the topic Density was taught. The purpose of the test was to find out if the post-test scores were significantly higher than the pre-test test scores for each measure. Cohen's d [6] was used as a measure of effect size for the t-test, whereby d = 0.2, 0.5, and 0.8 could be interpreted as small, medium, and large effects respectively [6].

3. Results

The results of our experimental study are summarized in Table 1. Mean comparisons indicate that students did better in the post-test compared to the pre-test for each measure. A paired-samples t-test found that students performed significantly better ($p < 0.01$) in the *Density* post-test compared to the *Density* pre-test with a reasonably large effect size of $d = 0.78$. These results suggest that the element interactivity intervention had positive effects on students' achievement. For the *Properties of Matter* science topic, which had no intervention, the gain was small ($d = 0.15$) and not statistically significant ($p > 0.05$). This could imply that the instructional strategies employed by the teachers, which did not address element interactivity, were not as effective in helping students attain optimal achievement.

Table 1. Comparing Pre-test and Post-test Scores

	Pre-test		Post-test		99% CI				Cohen's
	Mean	*SD*	*Mean*	*SD*	LL	UL	*t*(155)	*p*	*d*
Density	2.22	1.54	3.56	1.33	0.98	1.70	9.68	0.00	0.78
Properties of Matter	2.43	1.58	2.71	1.21	-0.04	0.26	1.93	0.06	0.15
Science Self-Concept (Density)	3.77	1.29	3.98	0.89	-0.04	0.19	1.69	0.09	0.14

Note. *N* = 156; CI = confidence interval; LL = lower limit; UL = upper limit.

For science self-concept, we found high reliabilities of alpha >.94 and >.85 for the pre-test and post-test respectively. This indicates that the four statements are a good measure of science self-concept before and after the *Density* topic was introduced. The difference between the pre-test ($M = 3.77$, $SD = 1.29$) and post-test ($M = 3.98$, $SD = 0.89$) was not statistically significant ($p > 0.05$). However, this slight gain ($d = 0.14$), albeit non-significant, is pleasing, considering the typical decline of students' science self-concept in this age group [7]. Specifically, our results suggest that when element interactivity is effectively managed, students could have improved achievement and maintained self-concept.

4. Discussion

The results of the study indicate positive effects on students' achievement and self-concept when teachers consciously use element interactivity as a construct to manage instruction. Given the limited resources of the human working memory [2], science learning provides inherent challenges when handling complex learning tasks such as science problem solving [2]. Progress in cognitive load theory has enabled us to understand the nature and consequences of each type of cognitive load [2]. Knowledgeable teachers who devise optimal instruction practices to facilitate students' learning using cognitive load theory and who analyze element interactivity inherent in the learning material (i.e., intrinsic cognitive load), or the methods of learning (i.e., extraneous cognitive load), or the facilitation of schema construction and retrieval (i.e., germane cognitive load) will optimize their students' learning potential [1]. When students experience success in their science learning, they may be more motivated to engage in further science learning, thereby situating science education within a positive learning paradigm.

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