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USE OF APPARATUSES IN SCIENCE LABORATORY

Developmental Characteristics of Didactical Interactions

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KEY WORDS

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ABSTRACT

Teaching and learning through the use of tools is evolving in response to new developments in pedagogy that aim to enhance students' high-order thinking skills. This paper presents results from part of a research project investigating innovative teaching pedagogy, engaging with active learning through students' manipulation of apparatuses in a series of mathematics lessons conducted in a science laboratory. The findings of the study include illustration of the development of didactical interactions, a modified framework yielding multi-directional transitions of interactive activities. This serves not only to promote interactive learning activities, including various active forms of productions, but also embraces innovation in STEM education.

GLOBAL KNOWLEDGE ACADEMICS

1. Introduction

Innovative teaching and learning that enhances creativity is a significant advance in education research, conducted for the purposes of demystifying the developmental considerations of cognition, pedagogy and other critical issues in teaching. In traditional classrooms, some teachers implement lesson via authoritative and deductive approaches, unidirectionally transferring knowledge in the process (Lei & Leung, 2017). Students are offered few opportunities to construct knowledge in an interactive way as would be the case in a student-centred learning environment that has the potential to foster their capacity to develop high-order thinking.

Manipulatives, such as teaching aids made in physical form, apparatuses available in laboratories, ICT applications installed in tablets, etc., are frequently utilized by teachers aiming to allow students to not only solve certain technical problems, but also construct knowledge teachers have intentionally integrated into the problems (Lei & Leung, 2017). Lei et al. (2018) reveal that one role of manipulatives is to convert the authority of teaching and learning process into advocate student-centred learning, facilitating students to construct knowledge more independently. In addition, a laboratory approach to learning mathematics helps students' visualize mathematical concepts and ideas through concrete materials (Loh, 1984). This process particularly enables slow learners to enjoy mathematics learning throughout this process.

This paper reports on findings of an explorative study examining didactic implementation of a series of mathematics lessons conducted in a science laboratory, consisting of apparatuses available to students.

2. Theoretical Framework

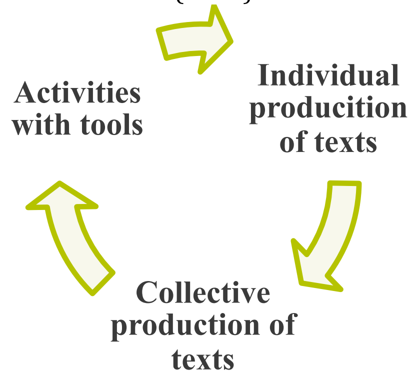
Teaching and learning with manipulatives is associated with tool-based task design and its implementation (Bartolini Bussi, 1998). Didactical considerations through the use of tools are essentially being studied in various epistemological aspects, e.g., cognitive development, pedagogical content knowledge, innovative teaching and learning, etc.

In the study, didactical cycle (Mariotti, 2012) is adopted as the main analytical framework, having a strong and unique value and constituting pedagogical structure in tool-based teaching and learning environment.

2.1. Didactical Cycle

Bartolini Bussi (1998) promotes the idea of a mathematics discourse aimed at fostering development of shared meanings, converging to meet the didactic goals of a lesson. Inspired by the theory of tool of semiotic mediation (Bartolini Bussi, 2008) which cultivates the evolution of signs in a tool-based environment, manipulatives play a crucial mediation role in the development of mathematics knowledge. Mariotti (2009; 2012) further develops didactical cycle into a pragmatic practice, stressing the connection between signs having different semiotic levels of states.

Figure 1. The didactical cycle. Adapted from Mariotti (2012)



Didactical cycle consists of three stages, shown in Figure 1. The first stage consists of activities with tools which are generally a starting point, enabling students to operate manipulatives in purposive ways. The aim of the activity, in the first stage, is to provoke the emergence of tool-based production that is notated in the next stage. The second stage is individual production of texts, engaging students to undertake different semiotic activities that individually concern, mainly, the written texts. Individual production is not contradictory towards group work, however, it places emphasis on the mediation of manipulatives between concepts and the manipulator. The production emerging in the second stage is purposively advocated to solve a problem requiring the use of manipulatives. Thus, the texts are, in general, ordinary and primitive in this context. The third stage is collective production of texts, the core of a semiotic process orchestrated by teachers to promote the evaluation of meaning construction in a process of creating knowledge. The individual production of texts by students in the previous stage, collectively, is shared and discussed with various solutions for analyzing, commenting and elaboration. The educational goal in this stage is to enable students to construct knowledge based on an evolved production. The iteration of the stages is expected to be repeated as a cycle so that the stages are sequentially transited for the evolution of texts in a context of manipulatives. Without loss of generality, the terminologies used for apparatuses, manipulatives and tools are interchangeable in the study.

3. The Case

A single intrinsic case study approach (Yin, 2012) was adopted in the study, an in-depth, multi-faceted exploration of a bounded situation in real-life settings (Stake, 2010). This qualitative research allowed the case undertaken to illustrate a unique phenomenon of integration between mathematics knowledge and scientific learning approaches in the context of an apparatuses-based learning environment. The uniqueness of the phenomenon relates to the professional academic background of the teacher as participant in the study, designing an apparatuses-based learning mathematics environment for her secondary one students (i.e., grade 7). A problem-based task design for a series of lessons and its pragmatic implementation was the unit of analysis.

3.1. The Teacher

An experienced mathematics and science teacher, who was also the panel head of a science department in a secondary school, was the participant in the study. Her teaching duties focused on integrated science and mathematics in junior secondary levels. Thus, her knowledge in mathematics was harmonized with science knowledge so that her teaching of mathematics strategies and skills was inseparable from science knowledge. Therefore, she was able to embed the learning mathematics experience into a science learning environment which promoted integration of the two key knowledges.

3.2. The Lessons

The case consisted of a series of five consecutive lesson conducted over the course of two weeks. The teacher designed the lessons in the sequence of (1) introduction and planning; (2) planning and carrying out the experiment; (3) implementing and recording the experiment; (4) jigsaw presentation and (5) reflection.

The lesson plans show that the learning aims of the lesson were to understand estimation and errors through hands-on measurements with the help of apparatuses. Students' prerequisite knowledge consisted of some basic concepts of capacity and volume in terms of measurements learnt in primary school. Based on this, the concept of errors and related mathematics knowledge, e.g., problem-solving protocol, were the learning objectives in the design of the lessons.

In the implementation of the lessons, the students were divided into groups for the estimation activity. Discussion between the teacher and students was videotaped and transcribed, while some of the discussion within groups was also video-recorded.

3.3. Data Collection

Finiteness of the data collection is critical for assessing the boundedness of a topic (Merriam and Tisdell, 2016). Therefore, the boundary of the study is defined as a tool-based mathematics lessons involving interactions between teacher, students and manipulatives. Useful information emerging in the case should be collected for analysis.

Four main methods employed by Travers (2001) were adopted in the study, including interviewing both teacher and students, observation in the field, discourse analysis and textual analysis. A pre-lesson interview with the teacher was conducted for establishing the teacher's views of tool-based task design and perceptions of manipulatives. Post-lesson interviews with the teacher and selected students were conducted to evaluate implementation of the lessons and to gather the students' understanding of certain mathematics knowledge respectively. A series of five lessons was videotaped and transcribed for analyzing didactical flows of activities implemented in the lessons. Fieldnotes were made during the lesson observation to supplement and raise the reliability of the findings produced from the analysis. Students' work, for example, worksheets completed and presentation slides, was gathered to triangulate the data simultaneously collected in the field, illustrating the didactic transition of the activities.

3.4. Data Analysis

Section 2 captured the theory of didactical cycle grounded in a tool of semiotic mediation illustrating pedagogical flow of the activities, embracing development of texts from contextualized situation to abstraction mathematics knowledge, mediated through the uses of manipulatives. Theorizing the data (Marriam & Tisdell, 2016) was one way of moving towards developing a theory explaining some aspects of practice. Thus, the ideas of didactical cycle were adopted and served as an analytical tool to describe the implementation of the mathematics lessons in the presence of rich manipulatives. A coding scheme grounded in didactical cycle was created for assigning designations to various aspects of data, so that specific pieces of the data could be easily retrieved (Marriam & Tisdell, 2016). Three activity stages indicated in didactical cycle discerned critical actions taken in classroom teaching, contextualizing uses of manipulatives. Three corresponding codes, therefore, were generated in the coding scheme, indicating pragmatic implementation of the research lessons. The coding scheme was applied to analysis of transcribed lessons. There were two major purposes in the adoption of the coding scheme, (1) describing 'how' the interactions in the lessons fitted into the analytic frame; and (2) conceptualizing and modifying the theory of didactical cycle in a data-driven situation.

In the data analysis process, the transcriptions were analyzed by assigning the codes generated from the three activity stages, which were A1 (referring to activity with tools); A2 (individual production of texts); and A3 (collective production of texts).

4. Findings

The results illustrate two major findings, which were that dual-directional transitions emerged in the implementation of the mathematics lessons and enhancement of the activity stages described in didactical cycle. The findings thus contribute to the development of ideas of didactical interactions.

4.1. Dual-directional transition

The theory of didactical cycle presents a unidirectional flow of activity stage from 1) activity with tools, 2) individual production of texts, and 3) collective production of texts. The activity stages captured in didactical cycle were notably identified in the analytical processes of the research lessons. In addition, the iterations of the activity stages were detected as reversible throughout the implementation processes of the lessons. Two major reverse transitions of the activity stages are presented as follows.

Table 1. Transition of activity stages (Activity with tools & Individual production of texts)

	Verbatim	**Code**
Student 1	There're some spaces inside [the large flask]	A2 (verbal, spaces)
Student 2	Every marble has space [between marbles]	A2 (verbal)
Student 1	If we use the small flask to estimate the large flask, there will be errors, since there're spaces between marbles.	A2 (verbal, small flask, method)
	[Students are holding small flasks to compare with the large flask.]	A1 (manipulation with flasks)
Student 2	Height [of the large flask] is twice of the height of small flask.	A2 (verbal, ratio)

Table 1 shows an episode illustrating a mixture of activities between A1 and A2, which are activity with manipulatives and individual production of texts. A group of students was generating verbal production (captured as A2), contextualized in the tool-based learning environment that the generated texts were based on, relating to the apparatuses the students were using. In the first part of the episode, the students were manipulating the flasks in such a manner that specific terminologies, e.g., space, estimation, and height, were verbally generated. These terminologies, viewed as texts, were used to further elaboration and calculation. This generation of texts was typically analysed as *Individual production of texts* (A2). While the students had some ideas about the ways they were going to solve the problem, they had started to estimate the volume of the conical flask by using a smaller one to compare heights. The students re-started manipulation of the apparatuses. This action was categorized as activity wit2018h tools (i.e., A1). The situation went back to the students generating information or data after the manipulation with the flasks, which was viewed as an example of the individual production of texts. By applying the activity stage codes of didactical cycle as analytical themes, the episode demonstrated that students were discussing methods to solve the problem, and at the same time, conducting experiments to generate data to support their ideas. Therefore, individual production of texts obviously emerges during the process of manipulation of apparatuses. It shows that stages of 'A1' and 'A2' are intertwined. In fact, it is difficult to discern the two stages from each other.

Table 2. Transition of activity stages (Activity with tools & Collective production of texts)

	Verbatim	**Code**
	[Discussion among teacher and students]	
Teacher	Okay. Now. Do you know we can have different ways [of estimating volume of a marble]? This lesson, you have a choice. If you still continue using the original approach, then you try to reduce the error. Do you know, reduce the error. Now your textbook consists of a page talking about how to reduce error.... [Teacher reviews Chapter 5 regarding estimation and error with students.] ...	A3 (error, ways to reduce errors)
Teacher	Now you may try, you have twenty minutes. You can go to see the apparatuses at the back. [Students started second round of experiments]	A1 (instruction, apparatuses)

Table 2 shows an episode during which the teacher was wrapping-up some ideas she observed in the first lesson. She prompted the students to focus on errors in the estimation processes linking the prior knowledge that they had learnt to the experiments they were planning to conduct. The collective activity of texts, which was known as A3, was orchestrated by the teacher, who had gathered verbal and written texts from the students in previous lessons. It shows further that the students were asked to continue the experiments or modify them according to the mathematics knowledge (i.e., errors and methods to reduce errors) discussed. This action was analysed as tool manipulation conducted by the students (i.e., A1). Therefore, the activity stage of collective production of texts was carried out followed by the activity with tools as the start of the second round of the experiment.

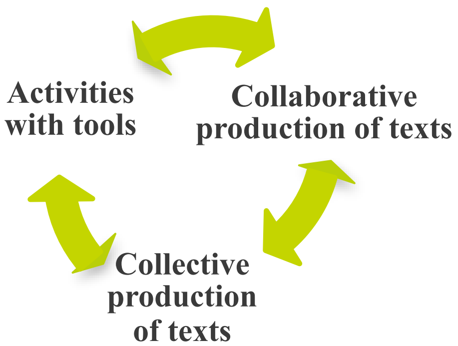
In short, the two episodes support the reversible transitions of activity stages aspect of the theory of didactical cycle. The transitions observed in the lessons generally comply with the critical proposes, for example, supporting data as evidence to prove a hypothesis the student put forward in the plan. Thus, the three activity stages are closely bonded and interact with each other. An updated network is introduced to modify the didactical cycle, which is named as *didactical interactions* with reversible transitions between the activity stages. Figure 2 shows didactical interactions with reversible arrows between the three activity stages.

4.2. Modification of activity stages

In the analysis of the activity stage of individual production of texts (i.e., A2), the students' actions captured in the implementation of the lessons showed high bonding with manipulation processes. Each student individually interacted with manipulatives to generate certain ideas. That means the students were stimulated by the manipulatives when they were using them. Therefore, activity with tools, in general, embeds the generation of individuals' productions. Moreover, in the social setting, where the students worked in groups, ideas generated by individual students were influenced by others. Thus, the manipulations of the apparatuses yielded individual students' productions of texts followed by collaborative productions. Therefore, the activity stage of individual production of texts is reflectively considered in a broader way, that collaborative production of texts is a modified constitution in the theory of didactical interactions.

The activity stage of *collaborative production of texts* proposes a situation of students working in groups or pairs in order to generate ideas in the manipulation process. The generated ideas, in addition, could be well organized in tasks for further elaboration and revision. Teachers should remind students to concentrate on certain productions which are critically related to the development of mathematics knowledge. Students should, on the one hand, manipulate the apparatuses in order to solve the problem, and on the other, refer to the task that stimulated them to generate data. Throughout the stage, the groups of students should legitimate their work in order to produce consensual ideas which represent the whole group. It clarifies the specific interactions that emerged in the implementation process which enhance the original theory of didactical cycle by optimising the activity stage.

Figure 2. The didactical interactions for the mathematics lessons conducted in the science laboratory with apparatuses as manipulatives



5. Concluding Remarks

To conclude, this paper has duly presented the development of transitions of activity stages through unlocking its reverse directional transition between two stages. The interrelationship between the stages is thus highlighted, and in-depth investigation is proposed for developing the theory of didactical interactions. In addition, pragmatic implementation of activity stages is analyzed, modified as collaborative work between teachers and students. It assists mathematics teachers to flexibly design activity stages with reversible directions. It also conforms with the development of students' generic skills. Furthermore, the study demystifies practical integration of mathematics and science through the implementation of teaching and learning mathematics contextualized in a science-based environment; a model of STEM education, named context integration (Roebrig et al., 2012), aiming to teach the ideas of multiple contents through a problem-solving approach, selecting relevant contexts from other disciplines. Ng et al. (2019) purposed an analytical way of integrating innovative teaching with hands-on experience in a multidisciplinary learning and teaching environment. This study could be extended to further explore pedagogical considerations specifically in STEM education which aim to synthesize mathematics and science content knowledge overarching between the two domains.

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