Middle School Students' Learning through Modeling Chemical Reactions with the Much.Matter.in.Motion Platform (Short Paper)

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Abstract

This research seeks to explore and promote the development of science students' conceptual understanding of chemical reactions through computational thinking (CT) and modeling practices using the Much.Matter.in.Motion (MMM) platform. According to NGSS standards, chemical reactions should be understood in terms of collisions between molecules resulting in rearrangements of atoms into new molecules. However, many students view chemical processes as a simple connection between molecules rather than an interaction of breaking and forming chemical bonds. To support learning, we designed and developed a learning platform that integrates CT and a complex systems perspective. The MMM enables defining molecules' properties, actions, and interactions through block-based coding while emphasizing the existence of collisions, removing, and adding substances. A first round of research with six middle school students was conducted to study the impact of learning to program a variety of chemical reactions on understanding them. Findings demonstrated increases in students' understanding of chemical reactions after learning with integrated CT activities. Students learned about physical and chemical change, collisions between molecules as a condition for a reaction, and reactions as breaking or forming bonds. This paper presents the first round of study with the MMM platform, the analysis of its results, discussion, and conclusions.

Keywords: Chemical reaction, Collisions, Bonds breaking and forming, Computational thinking, Simulation.

Introduction

This study is part of a larger project that seeks to advance science learning by having students construct computational models while developing computational thinking (CT) and system thinking (Authors, 2021). Specifically, this study addresses students' difficulties in understanding chemical reactions and investigates their learning with a novel learning design.

Chemical reactions, their rates, and whether or not energy is stored or released should be understood in terms of the *collisions* of molecules and the *rearrangement* of their atoms forming new molecules (NGSS, 2013). However, students do not perceive chemical reactions in terms of the particulate model of matter (García & Taber 2009). They think that substances are attached or modified into products in a one-step process rather than a process of bond breaking and forming involving many particles (Andersson, 1990).

To address challenges such as these, we designed and developed a platform MMM (Figure 1, Levy et al., 2018), whose design is based on an integration of CT with a complex systems perspective. Wing (2006) defines CT as a basic skill to solve problems and design systems. It includes converting complicated problems into smaller ones that can be solved, pattern finding, abstraction, and decomposition. Applying to chemical reactions, the MMM design supports students in decomposing the process into steps of collisions, breaking and forming bonds. Moreover, the learning design involves modeling various chemical reactions with the same building blocks, supporting students in generating patterns and abstracting the principles underlying reactions. The complexity framing for scientific systems promotes understanding of a system's behavior as emerging from the interactions between its constituent entities (Bar-Yam, 2003). When students observe their model, the system's emergent behavior such as rates of reaction becomes apparent.

The Learning Environment

With the MMM platform, students program models in chemistry and physics with a block-based interface. MMM includes a NetLogo (Wilensky, 1999) model and a NetTango (Horn et al., 2020) block-based interface. The chemistry learning environment also includes an activity guide on physical and chemical changes, chemical reactions, and mass conservation.

To model chemical reactions, students define the participating molecules, using separated coding units. Each molecule has a separate coding unit. Coding is done by dragging blocks into one of three cavities: properties (e.g., shape), actions (e.g., move forward), and interactions (e.g., collide). The model they construct visually demonstrates that chemical reaction involves interactions between numerous molecules that are in constant motion, breaking and making bonds.

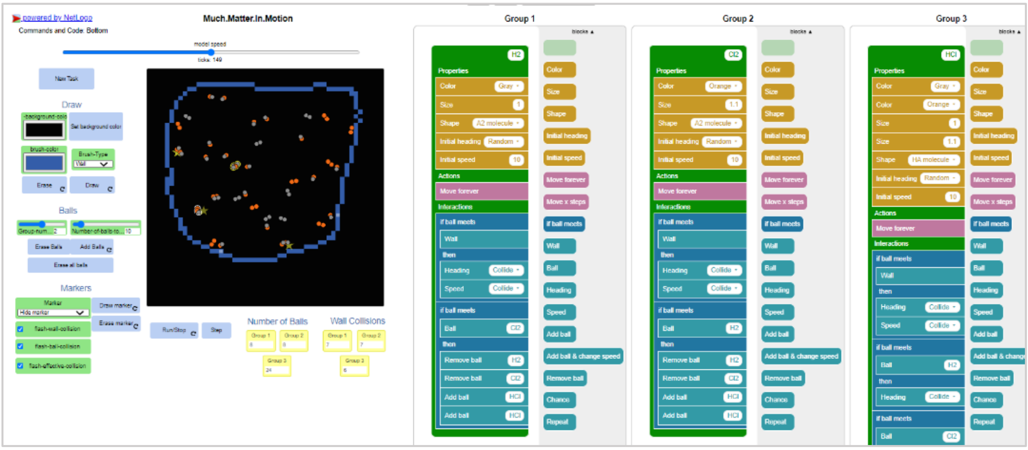


Figure 1. MMM interface, an example of an HCl production model. Painting tools are on the left side of the interface, and block-based coding is on the right side.

Methods

The participants were three pairs of volunteer students: one each from 7th, 8th, and 9th grade. The procedure involved three meetings: two individual 1-hour meetings for identical pre- and post-semi-structured interviews and questionnaires, and one 2-hour meeting in which each pair of students followed a guided activity filling worksheet.

The interviews included questions about everyday chemical and physical changes – the water cycle, rusting, and wood combustion. Students were asked to describe the processes, state whether the change is physical or chemical, and whether new substances were created. The questionnaires were composed of ten questions regarding chemical knowledge, one CT question, and one transfer question. The worksheets included instructions and explanations, questions, and CT challenges.

Students' interviews were video-captured. Their hands-on activities were screen-captured and audio-recorded. The transcripts of the interviews were coded to detect the emergent common concepts. Questionnaires were coded and their scores were compared.

Findings

Questionnaires. The average post-test score was higher ($M = 69$) than the pre-test score ($M = 51$). The topics that showed improvement were mainly the effect of collisions and density on the pressure and rate of reaction.

Interviews. There was a meaningful positive change in students' verbal explanations (Table 1). Their pre-test answers were vague and lacked scientific terms. Regarding physical or chemical change, for example, they either did not state the type of change or when they did, they misapplied scientific explanations:

> "The water cycle is a chemical change because everything related to molecules relates to chemistry. If at first, the molecules were together and during the evaporation they are separate, it means it is chemical" (Student-5).

The tools to distinguish between the changes were missing. In the post-test, the explanations included more scientific concepts such as collisions and molecules, and were more mechanistic.

"The water cycle is a physical change because the composition of the water molecule does not change, it remains H2O; only the phase of matter changes" (Student-5).

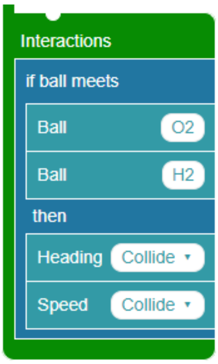
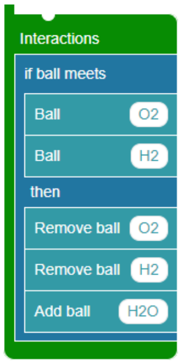
Table 1. Concepts, descriptions, and frequencies of use

Concept	**Description**	**Number of mentions**	
		Pre-interview	**Post-interview**
Collision	Molecules meet each other	6	18
Movement	Molecules are in motion	7	8
Break apart	Chemical bonds are broken	7	14
Connect	Chemical bonds are formed	17	11
Within	Molecules that are within other molecules, or part of them. Example: "H_2 molecule is within H_2O molecule"	7	2
Chemical bond	Atoms are bonded	5	14

Table 1 shows that after the activity students (1) mentioned the concept of *collision* three times more than before activity; (2) referred to *breaking bonds* twice more; (3) replaced the concepts of *connect* with *chemical bond*; and (4) less perceived molecules as *within* other molecules. A similar rate of describing *motion* is observed showing that the dynamic aspect was understood from the start.

Worksheets. As an example of CT challenges, we present a challenge emphasizing the different steps required for each type of change. Table 2 shows how student-4 uses the MMM blocks to distinguish between the changes – elastic collision in physical change compared to substances added and removed in a chemical change.

Table 2. Student-4's answers to a CT challenge about the type of change

	Change A	**Change B**
Block-based code		
Type of change	Physical	Chemical
How did you define the type of change?	The composition does not change	Chemical bonds are broken and formed. A new substance was created
What do you think the programmer meant to make the model show?	That the molecules will meet and continue moving	To create a new molecule of H_2O

Discussion and Conclusions

This paper describes the first study into students' learning of chemical reactions through a learning environment that integrates CT and modeling practices. The design of properties, actions, and interactions addresses the main difficulties in understanding the principles of the topic. By defining the participating molecules and setting their *properties*, students understand that atoms are rearranged, that they are conserved, and that the products are new substances having different properties. By setting the *actions,* students refer to the constant motion of the particles learning about the particulate model. By coding the *interactions,* students realize that the process is a sequence of steps including collisions, bond breaking, and forming. Finally, running their models enables students to observe the emergent nature of chemical reactions. Our results showed that learning with MMM provided students with the concepts and tools that are required to shift to a more scientific explanation. From a naïve perception of attached substances, they shifted to the more scientific explanation based on collisions and interactions between molecules.

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