Students' understanding of mathematics in the context of chemical kinetics

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Abstract: This work explores general chemistry students' use of mathematical reasoning to solve quantitative chemical kinetics problems. Personal constructs, a variation of constructivism, provides the theoretical underpinning for this work, asserting that students engage in a continuous process of constructing and modifying their mental models according to new experiences. The study aimed to answer the following research question: How do non-major students in a second-semester general chemistry course and a physical chemistry course use mathematics to solve kinetics problems involving rate laws? To answer this question, semi-structured interviews using a think-aloud protocol were conducted. A blended processing framework, which targets how problem solvers draw from different knowledge domains, was used to interpret students' problem solving. Preliminary findings describe instances in which students blend their knowledge to solve kinetics problems.

Keywords: Rates, Problem Solving, Blended Processing, Chemistry, Kinetics

Understanding fundamental concepts in chemistry is intrinsically tied to understanding mathematical symbolism and operations, as well as translating between equations and physical realities. Because of this reality, studies in science education have begun to focus on students' understanding of and use of mathematics in scientific contexts (e.g. Becker & Towns, 2012). Findings from such studies allow researchers and practitioners to find ways to enhance students' abilities to interpret and use mathematical expressions in conjunction with conceptual understanding, rather than blindly applying routine mathematical procedures.

Research on quantitative problem solving investigates students' abilities to solve the problem correctly (e.g. Wilcox, Caballero, Rehn, & Pollock, 2013), to understand and set up the problem (e.g. Bodner & McMillen, 1986), or to execute problem-solving steps (e.g. Reif & Heller, 1982). However, such studies rarely examine how individuals *use* equations (Kuo, Hull, Gupta, & Elby, 2013). Because of the great importance of mathematics in chemistry, it is of the utmost importance to understand *how* equations are used and understood by chemistry students. Kuo et al. (2013) propose that equations could be used in two ways, where the second is more sophisticated and expert-like: 1) as computational tools to obtain an answer or 2) as holding meaning when blended with conceptual understanding.

This study explores undergraduate chemistry students' quantitative problem solving in the context of chemical kinetics because it is an anchoring concept of the undergraduate chemistry curriculum that requires the use of mathematics to understand and solve problems (Holme, Luxford, & Murphy, 2015; Holme & Murphy, 2012; Murphy, Holme, Zenisky, Caruthers, & Knaus, 2012). It has the power to provide insight into the nature of chemical reactions and processes, because it ties observable phenomenon with theoretical aspects of chemistry that are modeled mathematically (Çakmakci, Leach, & Donnelly, 2006). In addition, studies in this content area are understudied when compared to other topics in chemistry education research (CER) (AUTHOR, 2016, submitted).

The aim of this study is to identify how undergraduate chemistry students understand and use equations to solve kinetics problems. The guiding research question for this work is: How do non-major students in second-semester general chemistry and a non-majors physical chemistry course understand and use mathematics to solve kinetics problems involving rate laws? This study will provide insight into the mathematical processing stage of quantitative problem solving, providing instructors with an understanding of how students studying kinetics understand and use both the concepts and mathematics involved.

The theoretical framework for this study is personal constructs, a variation of constructivism, a framework that presents individuals as making sense of their experiences by inventing knowledge constructions and continually modifying them as they encounter more experiences (Bodner, 1986; Bodner, Klobuchar, & Gleelan, 2001). Specifically, Kelly's (1955) theory of personal constructs, a combination of personal and social constructivism, argues that while individuals differ in their knowledge constructions, one individual's constructs can be similar to another's, due to social interaction. A cognitive framework called blended processing is used to help describe and analyze problem solving. Blended processing describes a cognitive process that explores and models human information integration (Coulson & Oakley, 2000; Fauconnier & Turner, 1996, 1998, 2002). It provides a way to describe and understand individuals' mental spaces (or knowledge constructions) and their interactions (Bing & Redish, 2007; Hu & Rebello, 2013). In the context of science education research, blended processing can describe the "opportunistic *blending* of formal mathematical and conceptual reasoning *during* the mathematical processing stage" (Fauconnier & Turner, 2002; Hull, Kuo, Gupta, & Elby, 2013; Kuo et al., 2013; Sherin, 2001).

The primary data source for this study is individual semi-structured interviews with undergraduate chemistry students, which are conducted using a think-aloud protocol (Becker & Towns, 2012). This interview technique has students perform a task while explaining their thought process out loud. During these interviews participants solve kinetics problems involving rate laws, tables of data, and graphs. The written work is recorded physically on Livescribe™ paper and digitally by a Livescribe™ smartpen that captures both audio and writing in real time. The protocol is adapted from Kuo et al. (2013) to use a chemical kinetics context. It contains equations that the participants are asked to explain and problems they would be asked to solve in a general chemistry or upper-level undergraduate physical chemistry course.

The participant sample was selected using a homogenous sampling technique (Patton, 2002). Student participation is voluntary. Fall 2015 data collection yielded 21 individual interviews with second-semester general chemistry students. Spring 2016 data collection is ongoing with both second-semester general chemistry students and physical chemistry students. For completing the interview, students are compensated with a $10 iTunes gift card.

Audio data is transcribed verbatim following the interviews. To condense our data in a way that is conducive to answering our research question, we organized interviews into problem solving maps. To make the maps, we identified problem solving "steps" in large tables, where all data from the interview corresponding to each step were categorized with a brief descriptor, such as "highlights purpose of the equation." Keeping in mind a conceptual framework of blended processing, an open coding approach was used to analyze the problem solving maps. Frequently, codes were assigned to excerpts of data as they were organized into steps in the map, which meant that a problem-solving step received one code. However, there were also instances where multiple codes were assigned to all the data in one step or different codes were assigned to different parts of the data in one step. Preliminary thematic findings will be presented and discussed. Evidence of blended processing will be explored, in conjunction with evidence of other modes of reasoning.

This study holds the promise of developing a better understanding of how non-major chemistry students understand chemical kinetics, but more importantly how they use and understand mathematics in chemistry contexts.

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