Journal of Technology and Science Education
ISSN: 2014-5349
info@jotse.org
OmniaScience
España

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Journal of Technology and Science Education, vol. 4, núm. 4, 2014, pp. 215-227
OmniaScience
Barcelona, España

Journal of Technology and Science Education

USE OF CHEMISTRY SOFTWARE TO TEACH AND ASSESS MODEL-BASED REACTION AND EQUATION KNOWLEDGE

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Abstract

This study investigated the challenges students face when learning chemical reactions in a first-year chemistry course and the effectiveness of a curriculum and software implementation that was used to teach and assess student understanding of chemical reactions and equations. This study took place over a two year period in a public suburban high-school, in southwestern USA. Two advanced placement (AP) chemistry classes participated, referred to here as study *group A* (year 1), *N* = 14; and study *group B* (year 2), *N* = 21. The curriculum for a first-year chemistry course (*group A*) was revised to include instruction on reaction-types. The second year of the study involved the creation and implementation of a software solution which promoted mastery learning of reaction-types. Students in both groups benefited from the reaction-type curriculum and achieved proficiency in chemical reactions and equations. The findings suggest there was an added learning benefit to using the reaction-type software solution. This study also found that reaction knowledge was a moderate to strong predictor of chemistry achievement. Based on regression analysis, reaction knowledge significantly predicted chemistry achievement for both groups.

Keywords – chemistry, reactions, chemistry teaching, reaction-types, reaction master

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1 INTRODUCTION

Chemical reactions and the equations which describe them have long been one of the keystones of chemistry. Our understanding of them has largely been associated with the very laboratory settings in which they were discovered. Consequently, their significance to the laboratory has made it so that treatment of chemical reactions in first-year chemistry courses has historically been piecemeal (Cassen & DuBois, 1982). In fact, most first-year texts typically devote little space to chemical reactions and the equations which describe them (Hesse & Anderson, 1992). There is a general assumption, that chemical reactions can be taught throughout the first-year on an as needed basis, and that reactions are somewhat solitary and unrelated throughout the first-year (Cassen & DuBois, 1982). The problem with this approach is that the student's terminology of reactions and equations may be limited to sparse examples, which may hinder the student's ability to conceptualize other chemistry concepts (Ragsdale & Zipp, 1992). For instance, concepts encountered in thermochemistry, electrochemistry and chemical equilibrium all depend on knowledge of chemical reactions and equations.

The learning of chemical reactions and equations requires knowledge an understanding of a variety of facts about chemical properties of substances. It requires chemical knowledge which is knowledge about the resultant different substances and properties typified in a chemical change (Piaget & Inhelder, 1941). It requires conservation reasoning, the knowledge of how mass is conserved in a chemical reaction (Hesse & Anderson, 1992). It also requires theoretical knowledge, like that of atomic molecular theory, and particle theory (Fazio, Battaglia & Guastella, 2012; Hesse & Anderson, 1992; Jaber & BouJaoude, 2012; Treagust, Chittleborough & Mamiala, 2003). In order to understand chemical change, one must view a substance as an "entity" which:

- can change between three states;
- can come into and go out of existence; and
- can be identified by its properties (Johnson, 2002).

And this view must occur at three different levels of representation: macroscopic (experiments and experiences); sub-microscopic (e.g., electrons, molecules, atoms – the particulate nature of matter); and symbolic (e.g., ball & stick models, structural formula, empirical formula, computer models, chemical equations) (Hesse & Anderson, 1992; Jaber & BouJaoude, 2012; Treagust et al., 2003). All three levels of representation are integral in developing an understanding of the chemistry concepts under investigation (Treagust et al., 2003). For example, the experienced chemist will understand chemical change in terms of three levels of representation, while the beginner will be limited to a single representation (Hesse & Anderson, 1992; Kozma, Chin, Russell & Marx, 2000; Treagust et al., 2003). The sub-micro level being the most difficult (Wheeldon, Atkinson, Dawes & Levinson, 2012). This is largely a function of experience, or lack thereof, with chemical change. As the student's experience with chemical change progresses, the student will likely gain capacity to operate between the macro, sub-micro and symbolic representations (Jaber & BouJaoude, 2012; Treagust et al., 2003). Although, early on, it will likely be in a discrete, compartmentalized and inconsistent fashion - what has been called instrumental understanding (Jaber & BouJaoude, 2012; Treagust et al., 2003). On the other hand, the experienced chemist will be able to form multiple representations easily and in conjunction with one another. The ability of learners to shift their representations and reasoning is what has been referred to as emergent process schema (Chi, 2005; Jaber & BouJaoude, 2012), and what has also been termed relational understanding (Jaber & BouJaoude, 2012; Treagust et al., 2003), conceptual understanding (Pyatt & Sims, 2012), holistic understanding (Wheeldon et al., 2012); and model-based understanding (Treagust et al., 2003). Teachers often assume that students can easily transfer from one level to another, when in fact this is not always the case (Robinson, 2003; Treagust et al., 2003).

Just as multiple representations are important to understanding chemical change, multiple means of explanation are also important. The ability of the student to explain chemical change phenomenon, explanatory knowledge (Treagust et al., 2003), is another import area to consider when determining how to effectively teach chemical reactions. Beginners will typically have ambiguous language and will rely on surface features to classify observations and subsequent representations, whereas experts employ an underlying and meaningful basis for their categorization (Bond, 1989; Kozma et al., 2000). Because of the emergent schema process, students need an understanding of what constitutes an acceptable explanation in chemistry (Hesse & Anderson, 1992). For instance, as the student gets command of particle theory, he/she will be able to explain some of the discrepant events which may have been encountered in studying chemical change. This means that teachers' explanations must be compatible with students' explanation knowledge, or student-centered (Treagust et al., 2003). This requires the teacher to communicate and explain abstract and complex chemical concepts and the students' ability to understand the explanations (Treagust et al., 2003). This can be challenging because, as Stavridou & Solomonidou (1998) showed, the progression the learner makes may be quite different from the progression expected in the curriculum, which has historically given little attention to the appropriate treatment and sequence of chemical reactions (Hesse & Anderson, 1992). For instance, students may utilize one of several types of explanations to reconcile their understanding of chemical change:

- analogical - a familiar phenomenon or experience is used to explain the unfamiliar;
- anthropomorphic - a phenomenon is given human characteristics to make it more familiar;
- relational - an explanation that is relevant to personal experience;
- problem-based - an explanation demonstrated through the solving of a problem; and
- model-based - using a scientific model to explain a phenomenon (Treagust et al., 2003).

The pedagogical implication of this is that students will utilize explanation types with which they are most familiar and support their existing lexicon. Further, the teacher's explanations of chemical change must take into account the terminology the student possesses to explain chemical change. The learning experiences for the students should encourage development of precise vocabulary from direct experience with demonstrations and lab activities that involve chemical change and probing questions (Bond, 1989; Pyatt, 2013a). The role of the teacher is to create experiences which help students develop the necessity for a well-defined and precise vocabulary (Bond, 1989).

Therefore, regarding the teaching and learning of chemical reactions and equations, the following theoretical underpinnings were identified for this study:

- knowledge of chemical reactions and equations is difficult to acquire and retain;
- instruction in such content is largely lacking from most first-year chemistry classes and texts; and
- knowledge of chemical reactions and equations predicates understanding of other chemistry concepts.

The focus of this study was grounded on these underpinnings.

1.1 Objectives

- What challenges do students face when learning chemical reactions?
- What are effective ways reaction knowledge should be taught and assessed?
- How can students achieve mastery of reaction knowledge?
- In what ways might reaction knowledge be related to chemistry achievement?

2 METHODOLOGY AND EMPIRICAL APPLICATION

This study took place over a two year period in a public suburban high-school, in southwestern USA. Two advanced placement (*AP*) chemistry classes participated, referred to here as study *group A* (year 1), *N* = 14; and study *group B* (year 2), *N* = 21. The instructor of record was the same for both years and was an experienced chemistry teacher. The course content of the AP courses was prescribed by the College Board and was equivalent to first-year college chemistry, in the curriculum taught and the laboratory investigations (CollegeBoard, 2010). The curriculum for a first-year chemistry course (*group A*) was revised to include instruction on reaction-types(Cassen & DuBois, 1982). The second year of the study involved the creation and implementation of a software solution which promoted mastery learning of reaction-types.

2.1 Procedures (year 1)

As the literature revealed, beginning students may have difficulty recognizing chemical reactions and equations in a categorical manner (Bond, 1989; Kozma et al., 2000). This can lead to an oversimplified and shallow understanding of chemical change. Therefore, a curriculum was created which focused on reaction-types as a framework to help students categorize the chemical reactions and equations which describe them. It included the following reaction-types:

- combination;
- decomposition;
- single-replacement;
- double-replacement;
- oxygen reactions;
- water reactions;
- acid base;
- complex ion; and
- oxidation/reduction.

The reaction-type curriculum was implemented during year 1 with *group A*. This was the control group. Each week, one to two reaction-types would be presented to students, in conjunction with a demonstration of the representative reaction(s) (Gray, 2009; Herr & Cunningham, 1999; Shakkashiri, 1983, 1985, 1989). The reaction-type presentations gave students opportunities to observe chemical reactions, and helped them reflect on the three levels of visualization: macro; sub-micro; and symbolic (Jaber & BouJaoude, 2012; Robinson, 2003). This approach was consistent with the recommendations found in the literature (Cassen & DuBois, 1982; Hesse & Anderson, 1992; Pyatt & Sims, 2012; Ragsdale & Zipp, 1992; Stavridou & Solomonidou, 1998). Sample practice problems were also provided students, in similar fashion to what was described by (Bond, 1989). The presentations took approximately 15 minutes per week and ran for 16-weeks for each two semesters. Students reviewed and practiced the reaction-types which were introduced that week in preparation for a reaction quiz which was given at the end of each week. Students also logged the time they spent studying reaction-types.

2.1.1 Data Collection Instruments

Students' symbolic understanding of reactions and equations was measured in the form of free-response questions, where students predicted the products for a chemical reaction where only the written form of the reactants was given (CollegeBoard, 1999). For example, students would be given the word equation for the reactants of a given chemical reaction (i.e., Magnesium metal is heated in air). Students would then write the chemical equation describing this process: $Mg_{(s)} + O_{2(g)}$ ---> $MgO_{(s)}$. This format was congruent with the reaction question on the *AP* chemistry exam (CollegeBoard, 1999). Measuring symbolic understanding of chemical reaction and equation knowledge in this way has been an established approach which has been used for many years previous to this study (CollegeBoard, 1999; Ragsdale & Zipp, 1992). Chemical reaction and equation knowledge was measured weekly in the form of timed free-response quizzes. This went as follows. At the end of each week, students were given 10-minutes to complete an eight-item reaction quiz, where they would predict the products for a chemical reaction, given the reactants. Students could retake the quiz on a one-time basis. These quizzes were considered formative because they were designed to gauge student proficiency of chemical reactions and equations in a way that allowed on-going revision and reevaluation. This approach was consistent with the recommendation that students need to frequently confront their conceptual understanding of chemical change, in a manner that allows for reflection, revision and revaluation (Stavridou & Solomonidou, 1998; Treagust et al., 2003; Wheeldon et al., 2012). In this case, the focus was on symbolic understanding of equations and formulas.

Reaction-types instruction took place for 16 weeks during the first semester of year 1. During second semester, students continued practicing reaction-types and were assessed on reaction knowledge, weekly. Students logged the amount of time each week spent studying chemical reactions and equations. An open-ended survey was given to students at the end of each semester to gauge student's perceptions and attitudes towards the reaction-types instruction. Chemical reaction and equation knowledge was measured, along with chemistry achievement, with an end-of year summative exam. The exam chosen was the 1999 released AP Chemistry exam(CollegeBoard, 1999). This exam was part of the normal curriculum where the study took place. The exam consisted of two ninety-minute sections:

- multiple choice and
- free-response.

The chemistry content of the exam was equivalent to a typical first-year chemistry course (CollegeBoard, 1999). One question in particular, free-response question 4 (FRQ4), referred to in this study as the reaction question, assessed symbolic understanding of chemical reactions and equations(CollegeBoard, 1999). Questions were scored based on the scoring guidelines described in the transcripts of the released exam. Scores on FRQ4 were also compared to the overall score on the exam. This was done to see whether chemical reaction knowledge was a predictor of overall chemistry achievement.

2.2 Procedures (year 2)

For year 2 of the study, a software solution was created and implemented which provided instruction and assessment on reaction-types for *group B*. This software was designed as a formative assessment tool for students to practice and assess knowledge of chemical reactions and equations, which was measured weekly with the reaction-type software, for a period of two semesters. A summative assessment was given at the end of second semester (just as done with *group A*) to measure chemical reactions and equation knowledge, and chemistry achievement. Mean scores on the reaction question were compared to *group A*. A *t* Test was carried out to test for performance differences between groups. This approach was consistent with other reported studies(Rejón-Guardia, Sánchez-Fernández & Muñoz-Leiva, 2013; Salas-Morera, Arauzo-Azofra & García-Hernández, 2012). Regression analysis, much like what was described in (Kallas & Ornat, 2012), was also carried out to see if chemical reaction knowledge could predict overall chemistry achievement. All of which are presented in the results section.

2.2.1 Design Concept - Reaction-type software solution

Based on the results from year 1, it was determined that further modifications to the reaction-type curriculum were necessary. Specifically, an assessment tool was needed which would measure students' knowledge of chemical reactions and equations, and allow students to practice, test and retake, if necessary; and provide such opportunities outside of class. This goal was consistent with the findings in the literature, that students should be encouraged to recognize their existing understandings, while at the same time, allowing for reorganization, extension and abandonment of existing categories (Stavridou & Solomonidou, 1998). A software program was therefore desired which taught and assessed chemical reactions and equations in a manner that emphasized symbolic understanding of chemical reactions and equations (i.e., where students were given reactants and were asked to predict products for reaction-types). It was postulated that such a program might assist students in the progression of their knowledge of reactions, equations. While there were applications available which taught chemical reactions, none provided instruction on the reaction and equation content in the context that the students needed (e.g., tutorial, customizability regarding reaction-types, drill/practice, and testing format similar to end-of-year exam). Furthermore, many of the available applications were cost prohibitive to students, or were ad-driven with distracting pop-up windows. Therefore, an open software solution was created which had practice, mastery and assessment components for chemical reaction-types. While the focus of this paper was on the use of this software, and not on software design or instructional design, it should be noted that a rapid-prototype-design process was followed (Hannafin, Land & Oliver, 1999; Reigeluth & Carr-Chellman, 2009). A summary of the design, development and implementation for the software solution Reaction Master is described below.

2.2.2 Tutorial

The software solution Reaction Master (Pyatt, 2002, 2013b) was designed to instruct students on reactions, specifically, categorical and symbolic representation of nine reaction-types typically encountered in first-year chemistry. The software was made available online, and could be accessed through a web browser. The opening screen for the software is shown here (Fig 1). From this screen students access the tutorial, practice, or test screens. The tutorial feature allowed students to select which of nine reaction types they wanted to study (Fig 2).

Figure 1. Reaction Master Opening Screen

The opening screen shown here is where students will begin their tutorial, practice or test.

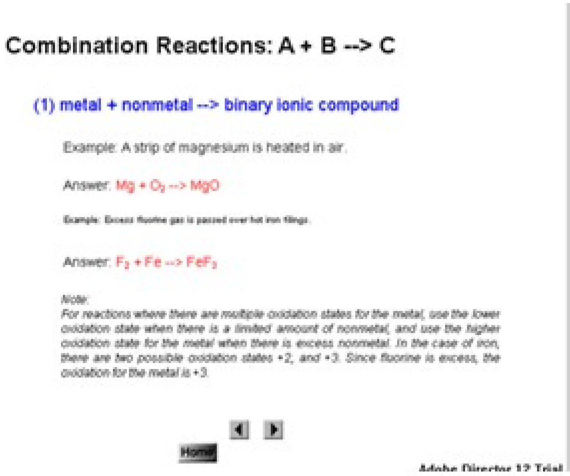

Figure 2. Tutorial Example

Shown here is an example of the reaction-type combination reactions. The tutorial presents chemical reactions categorically in reaction-types.

2.2.3 Practice-utility

Students practice their reaction/equation knowledge with the practice utility. This utility uses a random equation generator (there are over 1500 possible reactions from which the system calls) that displays a word equation, along with formulas for reactants and products.

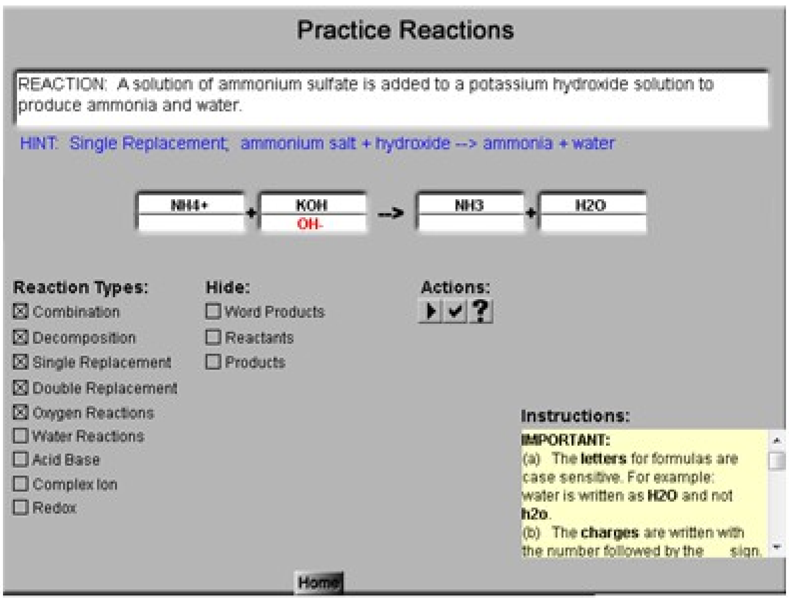

Figure 3. Practice Reactions Screen

Shown here is a practice reactions screen. The top field is where word equations appear. The boxes below are for equation inputs for reactants or products. The user dictates which reaction type(s) to practice, and can choose the HIDE option(s) to hide/show reactants, products, and word products. There is also a HINT button that displays pertinent information about the current reaction. The CHECK function enables the user to check the whether or not the response is correct.

2.2.4 Test-utility

Once students are familiar with a given reaction-type, they test their knowledge with the test-utility. Students select reaction-type(s), select a time (i.e., 10 min) and begin their test. The random-reaction-generator builds a 5-item assessment based on the reaction-types selected. Students then input their responses (Fig 4). Once students have completed their entries, they select to have their entries scored. Their entires are scored and students are shown which entries were correct (Fig 5).

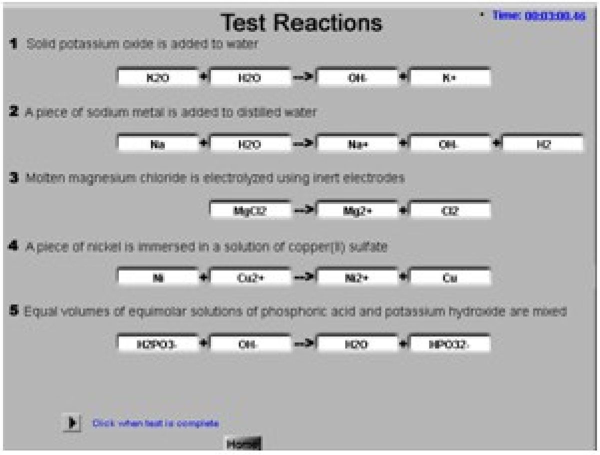

Figure 4. Test Screen with Example Inputs

Shown here is an example test screen where five reactions have been randomly generated and a student input formulas for reactants and products.

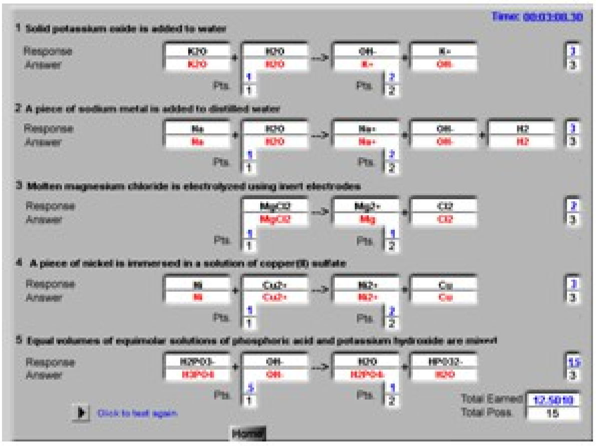

Figure 5. Test Screen with Completed Evaluation

Shown here is an example evaluate test screen where the inputs for a sample test have been scored.

2.2.5 Implementation

The reaction-type software solution, Reaction Master, was implemented at the beginning of year 2, with *group B*. This was the experimental group. The procedures described in year 1 were followed. The only difference was that students in *group B* were provided access to the reaction software at the beginning of first semester. Students took weekly reaction quizzes outside of class which were administered and scored by the reaction software. Students submitted their reaction-types quizzes at the end of each week to their instructor for recording. This routine took place for 16 weeks in the fall semester and again for 16 weeks throughout the second semester. Students logged time spent each week studying reactions and equations. An open-ended survey was given to students at the end of each semester to gauge student's perceptions and attitudes towards reaction-types instruction. At the end of the second semester, students from *group B* were given a summative exam – the same exam given to *group A* the previous year.

3 RESULTS

The performance data on chemical reaction knowledge that were gathered over a two year period are shown below. The data were gathered from formative and summative assessments, as well as student practice-time logs. These data are reported in Table 1.

Variable	*Group*			
	A		*B*	
	M	*SD*	*M*	*SD*
Weekly reaction score	*13.74*	*1.24*	*14.38*	*1.39*
Weekly practice time	*1.68*	*0.89*	*1.95*	*1.03*
Final reaction question (FRQ4)	*4.36*	*2.68*	*7.71*	*3.54*
Chemistry achievement	*37.6*	*9.0*	*66.1*	*16.6*

Note: $^{a}N = 14$; $^{b}N = 21$. *The data included here were derived from: (1) mean formative reaction scores; (2) mean weekly practice times; (3) mean reaction question scores; and (4) mean chemistry achievement scores for group A and group B. The maximum score for the weekly reaction quiz and the reaction question was 15.*

Table 1.Performance data for group A and group B

3.1 Hypothesis Testing (*t* Tests)

To investigate whether differences existed in reaction and equation knowledge between *group A* and *group B*, a series of *t* Tests were conducted. *T* Tests were also conducted to determine differences in chemistry achievement between groups, as well as weekly practice time. The following assumptions were tested and met:

- groups were similar in size;
- the variances of the two populations were equal;
- observations were independent; and
- the dependent variable was approximately normally distributed.

3.1.1 Limitations

Because of the relatively small sample size of each population, there could be validity concerns in terms of variance. However, these concerns should be eliminated so long as the following assumptions are true (Leech, Barrett & Morgan, 2008). For *t* Tests:

- groups were similar in size;
- the variances of the two populations were similar;
- observations were independent; and
- the dependent variable was approximately normally distributed.

For regression analysis, assumptions of linearity and normal distributions were checked and met. Another limitation of this study is in the generalizability of the findings based on the relatively small sample size.

3.1.2 Is there a difference between *group A* and *group B* reaction knowledge?

A *t* Test was conducted for this sample to determine whether significant differences existed between mean scores on the final reaction question, FRQ4, for *group A* and *group B*. There was a statistically significant difference between *group A* and *group B* in reaction knowledge, *t*(33) = 3.02, *p* = 0.0049, *SE* = 1.113. *Group A* (*M* = 4.36, *SD* = 2.68) scored lower than *group B* (*M* = 7.71, *SD* = 3.54). The confidence interval for the difference between the means was 5.62 to 1.09. A *t* Test was also conducted for this sample to determine whether differences existed between the mean weekly reaction scores for *group A* and *group B*. There was no statistically significant difference between *group A* and *group B* in weekly reaction quiz scores, *t*(36) = 1.51, *p* = 0.1410, *SE* = 0.427. *Group A* (*M* = 13.7, *SD* = 1.24) scored similarly to *group B* (*M* = 14.38, *SD*= 1.39). The confidence interval for the difference between the means was 1.507 to 0.223.

3.1.3 Is there a difference between *group A* and *group B* weekly practice time?

A *t* Test was conducted to determine whether significant differences existed between the mean weekly practice times for *group A* and *group B*. There was no significant difference between *group A* and *group B* means for weekly practice time, *t*(33) = 0.8465, *p* = 0.4029, *SE* = 0.311. *Group A* (*M* = 1.68, *SD* = 0.89) had similar times to *group B* (*M* = 1.95, *SD* = 1.03). The confidence interval for the difference between the means was -0.89 to 0.37.

3.1.4 Is there a difference between *group A* and *B* in overall chemistry achievement?

To investigate whether differences existed in chemistry achievement between *group A* and *group B*, a *t* Test was computed. There was a statistically significant difference between *group A* and *group B* in overall chemistry achievement, *t*(33) = 3.52, *p* = 0.0013, *SE* = 8.065. *Group A* (*M* = 37.6, *SD* = 9.03) scored lower than *group B* (*M* = 66.1, *SD* = 16.6). The confidence interval for the difference between the means was 44.82 to 12.00.

3.2 Regression

Simple linear regression was computed to investigate whether reaction knowledge predicted chemistry achievement. This was carried out for *group A* and *group B*. Assumptions of linearity and normal distributions were checked and met. Reaction knowledge for *group A* (I = 4.36, *SD* = 2.68) significantly predicted chemistry achievement (*M* = 37.6, *SD* = 9.0), *F*(1,13) = 0.4798, *p*< .001, adjusted *R*2 = 0.42, as shown in Figure 6. According to Cohen (1988) this is a moderate relationship.

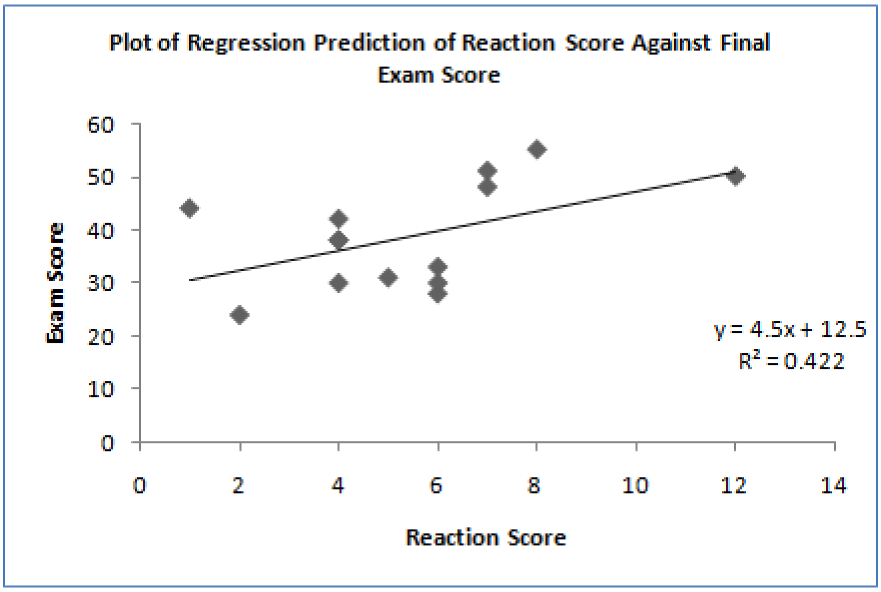

Figure 6. Regression Analysis for group A Reaction Score vs. Exam Score

Shown here is a linear regression for *group A* where reaction knowledge as measured on FRQ4 is related to chemistry achievement, as measured on final exam score.

The linear regression for *group B* (Fig 7) is shown below. The regression analysis showed that reaction knowledge for *group B* (M = 7.71, SD = 3.54) significantly predicted math achievement (M = 66.1, SD = 16.6), $F(1,20) = 23.38$, $p < .001$, adjusted $R2 = 0.56$. According to Cohen (1988) this is a strong relationship.

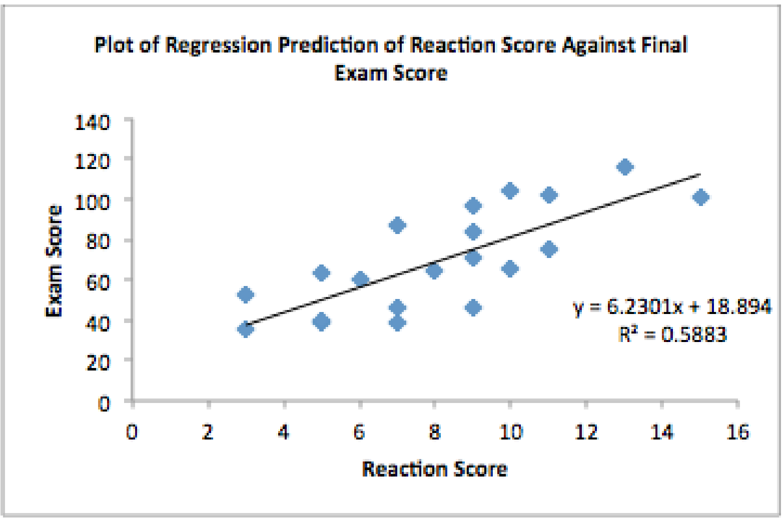

Figure 7. Regression Analysis for group B Reaction Score vs. Exam Score

Shown here is a linear regression for *group B* where reaction knowledge as measured on FRQ4 is related to chemistry achievement, as measured on final exam score.

4 DISCUSSION

The effectiveness of the reaction-type curriculum in promoting conceptual change and mastery of reaction knowledge was determined. The results of these measures demonstrated that the reaction-type curriculum promoted learning and conceptual change of reaction knowledge. For instance, the mean weekly reaction score for *group A* was (M = 13.74/15, SD = 1.24) or 92%, which demonstrated proficiency on reaction knowledge. Based on formative assessment alone, this indicates that the reaction-type curriculum helped students be successful in mastering chemical reaction and equation knowledge. However, even though *group A* showed mastery on reaction knowledge, it was not retained to the extent expected. For instance, the summative assessment data that measured the extent to which reaction knowledge was retained showed *group A*'s overall mastery of reaction knowledge to be (M = 4.36/15, SD = 2.68) or 29%. This indicates *group A* did not retain the level of reaction knowledge for which they had earlier become proficient. Therefore, while *group A* students reached a proficiency of over 90% on reaction knowledge, this did not directly translate to mastery of reaction knowledge as revealed in the summative assessments. Therefore, the reaction-type curriculum was effective at promoting student proficiency on reaction knowledge to approximately 90%, yet this did not equate to mastery of reaction knowledge.

The second year of this study involved the creation and implementation of a software solution which facilitated practice, mastery, and assessment for chemical reaction-types. For *group B*, the weekly practice and reaction quizzes were handled within the software environment. The data show that reaction knowledge *group B* (M = 14.38/15, SD = 1.39), or 96%.This was similar proficiency to *group A* (M = 13.74/15, SD = 1.24), or 92%. Furthermore, the mean weekly practice times (measured in hours) were also similar: *group B* (M = 1.95, SD = 1.03); and *group A* (M = 1.68, SD = 0.89).This showed that there was no difference between groups – reaction proficiency was about the same throughout the year. However, the retention of reaction knowledge was largely different between groups, as was chemistry achievement. Upon review of reaction knowledge retained, it was found that *group A* scored (M = 4.36/15, SD = 2.68), and for *group B* scored (M = 7.71/15, SD = 3.54). These were significant differences. *Group A* retained 29% of reaction knowledge, while *group B* retained

51%. By comparison, the mean score for *group A* on reaction knowledge was lower than the national average 6.36/15 or 42%, while the mean score for group B was much higher (CollegeBoard, 1999). This pattern likely transcended chemistry achievement as well. For instance chemistry achievement for *group A* was (*M* = 37.6, *SD* = 9.0), and for *group B* (*M* = 66.1, *SD* = 16.6). These findings suggest, even though reaction proficiency between groups was similar, the mastery of this knowledge was not. Given that the only differences between *group A* and *group B* was the use of the reaction-type software, these findings suggest an added learning benefit to using this software solution. This study also found that reaction knowledge was a moderate to strong predictor of chemistry achievement. Based on regression analysis, reaction knowledge significantly predicted chemistry achievement for both groups. For *group A* it was a moderate predictor (i.e., $R2 = 0.42$) and for *group B* it was a strong predictor (i.e., $R2 = 0.56$). These data confirm what has been reported in the literature regarding the importance of reaction knowledge as a foundational concept in the chemistry classroom (Usak, Ozden & Eilks, 2011).

5 CONCLUSION

A likely reason for these performance differences rests in the possibility that the software successfully supported learners in forming a model-based understanding of chemical reactions and formulas (Stavridou & Solomonidou, 1998). In this case the conceptual model was reaction-types, and understanding chemical change from this perspective may have helped students predict products for a given reaction. This may have promoted mastery of chemical reactions and equations and, consequently, chemistry achievement. This supports the notion that model-based understanding is related to the student's ability and experience with gathering and interpretation of relevant information about chemical phenomena (Pyatt & Sims, 2012). Further, without many examples of reaction-types, students will have limited ability to predict products for chemical processes (Cassen & DuBois, 1982). In such instances, students may have little grasp of reaction knowledge and may have only an instrumental understanding (Jaber & BouJaoude, 2012; Treagust et al., 2003) where they understand how to write chemical formulas they have memorized for word equations, but will not be able to predict products. While memorizing formulas is an important element of overall reaction knowledge, it is not a model-based understanding. Therefore, based on this analysis, fewer students in *group A* reached model-based understanding of reactions, while more students in *group B* formed model-based understanding through support of the software solution. The results of this study have also revealed that there is a link between reaction knowledge and chemistry achievement. As was proposed earlier, chemical reactions are a keystone of chemistry, and therefore represent a foundational concept that transcends many other topics encountered throughout a typical first-year curriculum. For these reasons, a recommendation is made here that first-year chemistry courses should include reaction-types as an integral curriculum component that promotes student understanding of reaction and equation knowledge and consequently promotes overall chemistry achievement.

ACKNOWLEDGEMENTS

I would like to thank Regis University and my spouse for their generous support in my research endeavors. I would also like to say thank you to my students who have always and always will inspire me to find effective ways to teach.

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Citation: Pyatt, K. (2014). Use of chemistry software to teach and assess model-based reaction and equation knowledge. *Journal of Technology and Science Education (JOTSE), 4(4), 215-227.* http://dx.doi.org/10.3926/jotse.110

On-line ISSN: 2013-6374 – Print ISSN: 2014-5349 – DL: B-2000-2012

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Published by OmniaScience (www.omniascience.com)

Journal of Technology and Science Education, 2014 (www.jotse.org)