

# ENHANCING PEDAGOGY WITH CONTEXT AND PARTNERSHIPS: SCIENCE IN HAND

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## Abstract

*Two activities, one on heat/work and one on dynamic equilibrium, are described for three high school classes (n=55) in the USA. The curriculum addressed showcases strategies to use with science, technology, engineering, and mathematics (STEM) students. The two lessons described follow the context ACS method (Application, Career opportunities, and Societal impact). ACS, or real-world context application, relies on a strong foundation of teaching concepts while developing enhanced learning experiences for K-12 students. The research described probes the problem of student engagement and content learning in STEM coursework and provides evidence for the potential of utilizing context ACS. The activities demonstrate how to use ACS to maximize student engagement and emphasize formative assessment during lesson implementation. Analysis of the data shows that students exposed to ACS lessons drawing from partnerships to connect real-world applications to core content make gains of 17% in aggregate.*

**Key words:** context learning, engineering, partnerships, science education, STEM education.

## Introduction

The problem of influencing students to want to truly understand content in the sciences can be daunting. To address this problem, a partnership team composed of a high school teacher, National Science Foundation (NSF) Fellow, education instructor, and various engineering advisors at the University of Cincinnati (UC) developed two activities as subcomponents of lessons designed for high school chemistry and biology classes. Science, technology, engineering, and mathematics (STEM) lessons created and implemented by partnerships in the same program (Project STEP) can be accessed free of charge at [www.eng.uc.edu/STEP](http://www.eng.uc.edu/STEP).

The chemistry lesson (heat/work) addressed a chemistry curriculum taught to advanced chemistry students throughout the USA as part of the Advanced Placement (AP) system and the biology lesson (dynamic equilibrium) addressed a biology curriculum taught to high school students as part of the national standards. The lesson design followed the ACS method (created by the Project STEP primary investigators at UC), which stands for A – application of the content, C - career connections, and S - societal impact. ACS relies on application of content through real-world experiences and lays a strong foundation for teaching abstract concepts and developing enhanced learning experiences through career connections and a focus on the impact on society. ACS is a modification of what are commonly termed context-based approaches

or conceptualized approaches (Belt, Leisvik, Hyde, & Overton, 2005; Holman & Pilling, 2004; Tsaparlis, 2007; Yaron, Karabinos, Lange, Greeno, & Leinhardt, 2010). The authors provide research examples of how the team used ACS and enhanced pedagogy to maximize student engagement with the content and emphasize formative assessment during lesson implementation.

The AP chemistry teacher at the high school (where the Fellow helped to implement lessons), stated, “My students don’t like [enthalpy]! They have a really hard time...” Her comment referred to an upcoming lesson on Hess’s Law and Calorimetry, and real-world context was needed. According to the teacher, all of the students required help with physics concepts as well as the theoretical definition of “energy.” Difficulties with enthalpy often arise from misconceptions about the nature of energy and its mathematical representation, specifically when students must differentiate forms of energy. For example, “the motion energy of a book sliding across a table is transformed into thermal energy, not into a force” was only answered correctly by 33% of high school students (AAAS, 2013) in the USA. Accordingly, students seldom equate the effort of lifting a load with that of heating a liquid. Thus, the partnership team chose to find an example from everyday life to show the students how a chemist or an engineer might describe the concept of work in terms of the release and use of energy. This would give the students the necessary background to understand the definition of enthalpy as heat loss and pressure-volume work. After much consideration, the partnership team decided to focus on food preparation processes that were familiar to the students and involved energy conversion.

Deciding to use context and ACS was directly related to increasing interest in the STEM content. Recent literature points to student difficulty with STEM content. Yaron, Karabinos, Lange, Greeno, and Lenhardt (2010) state, “chemistry concepts are abstract and can be difficult to attach to real-world experiences” (p. 584). Struggling to find real-world examples is common in STEM classes, and one answer to this problem is teaching in context (Belt, Leisvik, Hyde, & Overton, 2005; Burrows, Herfat, Truesdell, & Miller, 2013; Cooper & Cunningham, 2010; Holman & Pilling, 2004; Tsaparlis, 2007; Yaron, Karabinos, Lange, Greeno, & Leinhardt, 2010). Additionally, STEM subjects are not viewed or taught as interdisciplinary subjects (Coll, Gilbert, Pilot, & Streller, 2013). This research provides more evidence of how real-world contextual experiences influence day-to-day life, and thus ACS can influence classroom content and redirect student interest to that material.

## Methodology of Research

This was a mixed methods study conducted during lesson implementations in 2008-2009 where qualitative, informal interviews and quantitative, open-response questionnaires were used to gather data. The informal interviews occurred during class as the high school students engaged in the activities while the open-response quizzes were given at the beginning and the ending of the classes. Three classes of 55 total students participated in the chemistry and biology ACS activity research study. The authors collected the data and used a sociocultural/social constructivist (Vygotsky, 1978) theoretical lens to analyze the data. Therefore, the authors consider learning as a process of interactions with peers and teachers co-engaged in context stimuli (involving the STEM content). The two activities (heat/work and dynamic equilibrium) implemented by the teacher and Fellow are described to elucidate the classroom situation.



**Figure 1: Bodum Santos™ Vacuum Coffee Pot used in the heat/work lesson (left) and students engaged in the “Molecular Mixing” activity (right).**

A vacuum coffee pot relies on the conversion of mechanical energy into heat and pressure-volume work (Figure 1). This apparatus has a completely open, hands-on process, making an ideal example for the front of the classroom. The brew process initiates by heating water in the lower chamber (e.g. via Bunsen burner). The water expands and rises into the upper chamber. Prior to this, the Fellow passed out some brewed coffee to catch the students’ attention and then presented a quiz to gauge the students’ prior knowledge of the target content (Table 1).

Following completion of the quiz, the brew process was initiated in parallel with a class discussion: “Where does the heat from the flame go?” This probing, “then-what?” exercise interactively traced the path that the heat took. “Once the heat enters the pot, where does it go?” Students grappling with this question elicited responses over a range, from attesting no knowledge to noting from experience that heat speeds evaporation. Students then watched the coffee pot as water rose into the brew chamber, leaving the lower volume completely empty. Confirming this development (the heat entered the water) as the correct response, the Fellow asked students what “job” the heat did other than expanding the water. This elicited silence until one student connected the heat input and the upward movement of water, giving the Fellow an opportunity to elaborate that the energy added to the system had changed form. The hot water *moved* without any additional input other than the flame of the Bunsen burner. A short review and statement of the definition of the terms “heat” and “work” followed to recapitulate the target content, specifically that energy changes form from heat to work in processes extremely common to daily social experience.

To reinforce the content and simultaneously conduct a formative assessment of mastery, students were required to apply this concept to understand two newly introduced equations:

$$\text{Definition of Enthalpy: } h \equiv u + pv$$

$$\text{Hess's Law: } \sum \Delta h_{\text{reactants}} = \sum \Delta h_{\text{products}}$$

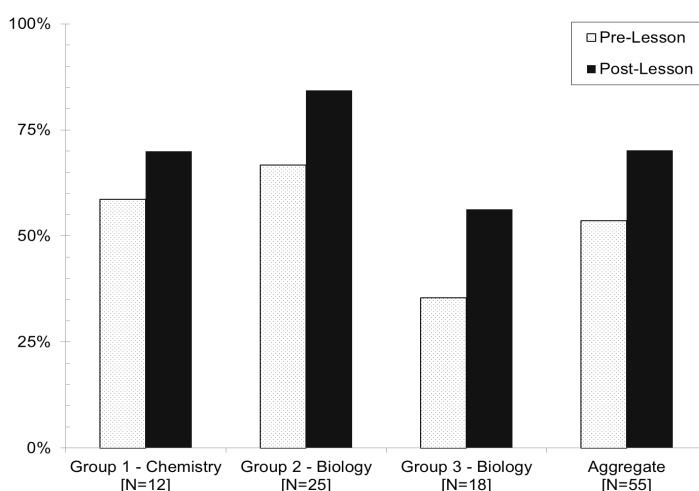
The ACS context approach was designed to assess and reinforce the content at a deeper level of cognitive engagement and connection. Students could describe the work going on in the coffee brewing system and the energy being absorbed by or released from/to the surroundings, but had difficulty with the mathematical representation of the system. In retrospect, it is recommended to familiarize students with the mathematical properties of the equation itself as a basis for their initial attempt to represent the example system symbolically.

## Results of Research

The qualitative responses from the students included comments such as, “I’ve been drinking coffee since middle school” and “Are we really learning about enthalpy here?” While these remarks alone do not relate to successful pedagogy, the emphasis of these lessons was increased engagement through context ACS learning, implemented with a heavy dose of formative assessment. These types of comments, elicited while students engaged with the content, showcase the connection between the activities, everyday lives of the students, and the STEM content. The discursive instruction and informal interviews gave an overall picture of student engagement. In a quantified sense, all three implementations presented here show a marked increase in the rate of correct responses. The 12 AP chemistry students engaging in the coffee pot demonstration were able to answer heat/work questions correctly about 10% more of the time. Figure 2 underscores the previous observation around the mathematical lesson component where prong C addressed the equation and showed no improvement, while A and D addressed concepts and terms and showed increases of more than 20%. Both biology classes (totaling 43 students) showed an increase in correct answers of greater than 15%, where improvement was less pronounced where initial scores were higher. In aggregate, analysis of student responses to pre/post questionnaires (probing content knowledge in these two ACS context activities) show an increased rate of correct answers of 17% (Figure 2).

**Table 1. Open response questions and rubric used for the heat/work activity with correct answer rates.**

Prong	Question Text	Grade Rubric			Correct Answer Rate	
		Correct	Partial	Incorrect	Pre [%]	Post [%]
A	1. How do you define work?	Force applied over distance or a change in system pressure/volume ( $W = \Delta PV$ ) are work	Link among pressure, volume and work (or force, distance, and work) without clarity	Failure to link heat, pressure, volume and work without additional support to demonstrate understanding	8	33
B	2. Is the heat energy in your coffee doing any work?	No or Yes where justified by the upward motion of vapor		Yes	42	42
C	3. If your coffee holds 38 units of energy and I add cream, which has -8 units, how many units of energy are left in my coffee? How about if I use the heat to do 20 units of work?	30,10 or 30,18	One correct numeric answer or good logic only.	Other numeric answers and/or support with erroneous logic, blank answers	58	58
D	4. What single measure might a thermo-chemist use to describe changes in the energy of the coffee cup system?	“Enthalpy” or $\Delta H$	Partial statements of Hess’s Law or supporting logic that links heat and work	Erroneous logic or blank	33	92



**Figure 2: Correct open responses for heat/work (Group 1) & dynamic equilibrium (Groups 2 & 3).**

## Discussion

To be clear, ACS is a specific type of context learning where there are subparts to the context that include application, careers, and societal impact. The main contribution of this work is to add to the research which shows the success of context based approaches while specifically targeting the blend of applications in everyday life, career connections, and societal impacts to effectively create a strong context for the students to delve into the STEM content.

The results obtained by this heat/work ACS activity display greater increases in student knowledge gains than the results of traditional teaching in previous years, as reported by the chemistry teacher. Later in the year, the teacher asked the Fellow to exemplify dynamic equilibrium with ACS, and reflected that the results were comparable to the heat/work activity. As with energy/heat/work, since students cannot easily see dynamic equilibrium happening in a chemical reaction, a concrete, practical example from daily life could develop the students' understanding of the concept. The Fellow utilized an activity that could be used in classes such as biology or chemistry to emphasize the role of molecules in diffusion.

Briefly describing the dynamic equilibrium activity will allow for repetition of this exercise. "Molecule Mixing" required about fifteen minutes and provided a visual model in the same way as in the vacuum pot example. Each student started with a beaker containing 200 ml of water. Clear water filled all but two beakers. One of these beakers had 200 ml dark blue waters and the other had 200 ml of yellow colouring. The class became a living example of dynamic equilibrium, which occurs in chemical reactions and in cells. Each student moved at a constant speed and in a straight line. When two students came close to each other, the students were to stop, exchange water in the beakers through a back and forth pouring motion (Figure 1), then change directions and continue to walk at a steady pace until bumping into the next person. The Fellow would stop the experience to ask questions periodically.

Formative assessment during this activity was paramount. After a few seconds of walking and mixing the Fellow would ask the class to "freeze!" The students halted and everyone raised his or her beaker for others to see. "What happened?" The students could observe that the blue and yellow colors "diffused" through the beakers in the class. The Fellow asked the students to predict what would happen after some time. The class predicted that all the water would soon be the same color green. After a very brief time, the color was evenly dispersed through the beakers held by the students, and the students confirmed the prediction made earlier. The Fellow started the activity again. The students recognized that although everyone con-

tinued moving and mixing, the color distribution did not change after the original mixing. The Fellow explained to the students that dynamic equilibrium in a chemical reaction replicates this type of movement - everything moving (bonds breaking and reforming) but no visible changes (concentrations remain constant). Figure 2 illustrates the improvement on pre/post test answers that the biology classes made in relation to dynamic equilibrium.

Context learning is critical, and Tinker and Krajcik (2001) sum up the problem when they refer to bringing the world into the students' classroom that appears to have no relevance outside the classroom. It is unacceptable that students gain only isolated knowledge that they cannot relate to real world problems. They suggest taking students out of classroom and into the field to explore science education. However, with heat/work and dynamic equilibrium topics, bringing the real world *into* the classroom (e.g. making coffee) makes the topics relevant. Thus, the right tools for the situation are essential. One of those tools is ACS.

## Conclusions

Although both activities were successful, there were limitations to this study. The research study was conducted at one high school during one academic year with only two types of science classes. The sample size was too small in individual classes to assess significance to the pre/post test scores. The teachers working with the Fellow had volunteered for the Project STEP program and thus were the type of teachers to explore new methods of teaching and embrace the ACS method. Despite these and other limitations, context teaching is essential.

These two activities (heat/work and dynamic equilibrium) meet the standards for the ACS approach and enhance STEM pedagogy because of the contributions of the partnership team in each of the ACS areas. The first activity linking a vacuum coffee pot with heat/work was rooted in application (A) through a practical example of making coffee. It was directly connected to career connections (C) through engineers designing household appliances that use chemistry and physics concepts. The social impact (S) explored the social economy of the coffee commodity. The dynamic equilibrium activity included a model of application (A) through discussion of room capacities and spoke to careers (C) in chemistry, structural biology, and process engineering. Societal impact (S) included discussion on people mingling in public spaces and how the system remains dynamic though the people rest.

Both activities also involved important features for effective pedagogy. Partnerships were used to create activities and lessons with multiple perspectives. The first activity, vacuum coffee pot heat/work, required little set-up time and provided an engaging real-world demonstration. The students saw, heard, and smelled the workings of the coffee pot and energy transfer. The vacuum coffee pot made a good starting point for learning about enthalpy. Although quite simple, Molecule Mixing involved all of the students with the dynamic equilibrium content in an industrious design. The students literally took the STEM concept in hand, walked around holding a beaker of water, and shared it with classmates while observing dynamic equilibrium taking place. Each student had to stand up, move, talk and actively participate and verify the predictions. For the teacher and the Fellow, enhanced learning pedagogy, in the form of a partnership, founded the basis for a context ACS (application, careers, and social impact) approach that created learning experiences where abstract concepts transformed into interesting, practical and useful information with relevance in the real-world. The ACS of STEM content can also help experienced teachers design new lessons that engage students in context and yield in-process information on student progress.

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