2006-2521: A CONSTRUCTIVIST EXPERIMENT IN PARTICLE SETTLING AND CENTRIFUGATION

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Introduction

Particle settling and centrifugation are related rate-based separation techniques. Rate-based, time-dependent separation processes are often difficult to teach in a traditional lecture format.[1] However, simple experiments on particle settling and centrifugation are hard to find.[2] To enhance student understanding of these concepts, a particle settling and centrifugation exercise centered on constructivist learning theory was developed.

Constructivism is a philosophical view on how we come to understand or know.[3] This philosophical view can be characterized in terms of three primary propositions.[3]

1. Understanding is in our interactions with the environment.
2. Cognitive conflict or puzzlement is the stimulus for learning and determines the organization and nature of what is learned.
3. Knowledge evolves through social negotiation and through the evaluation of the viability of individual understandings.

Constructivism does not suggest one particular pedagogy; rather, it is a description of how learning happens. To utilize constructivism in the classroom, this philosophical view must be linked to the practice of instruction. Savery and Duffy propose eight instructional principles deriving from constructivism.[3]

1. Anchor all learning activities to a larger task or problem.
2. Support the learner in developing ownership for the overall problem or task.
3. Design an authentic task.
4. Design the task and the learning environment to reflect the complexity of the environment they should be able to function in at the end of learning.
5. Give the learner ownership of the process used to develop a solution.
6. Design the learning environment to support and challenge the learner's thinking.
7. Encourage testing ideas against alternative views and alternative contexts.
8. Provide opportunity for and support reflection on both the content learning and the learning process.

Critics contend that the constructivist approach stimulates learning only in concepts in which the students have an existing interest.[4] Taken to the extreme, the constructivist view implies the non-transferability of knowledge, and that "knowledge is acquired not by the internalization of some outside given but is constructed from within."[5] Contrast this with an alternative position in learning theory, that "if you want somebody to know something, you teach it to them … if you want somebody to know something and retain it for a long time, then you have them practice it."[6] In addition, Matthews states that "… many, if not most, things in science are beyond the experience of students and the capabilities of school laboratories to demonstrate. The cellular, molecular and atomic realms are out of reach of school laboratories, as is most of the astronomical realm."[7]

This study examines whether constructivism can be used effectively in a chemical engineering setting. Can students construct internal knowledge of chemical engineering concepts using simple demonstrations and experiments? Student mastery of particle settling and centrifugation theory was monitored and compared after exposing students to material through traditional lecture and hands-on experimentation with teacher mediation formats.

Theory

The theory of particle settling is based on a force balance.[8] Three forces act upon a rigid particle moving through a fluid: gravity (acting downward), buoyant force (acting upward), drag force (acting opposite to the direction of particle motion). Developing the force balance and solving for the terminal velocity produces the following expression:

$$v_t = \sqrt{\frac{2g(\rho_p - \rho)m}{A\rho_p C_D \rho}} \tag{1}$$

where v_t represents the terminal velocity, g represents the acceleration due to gravity, ρ_p represents the density of the particle, ρ represents the density of the fluid, m represents the mass of the particle, A represents the projected area of the particle, and C_D represents the drag coefficient. For rigid spheres in the laminar-flow region, Equation 1 can be further simplified to yield:

$$v_t = \frac{gD_p^{\,2}(\rho_p - \rho)}{18\mu} \tag{2}$$

where μ represents the fluid viscosity. Examination of Equation 2 reveals that the driving force for settling-based separations is a density difference. The magnitude of the density difference and the liquid viscosity influence the rate of separation. A simple experiment was designed to illustrate these principles in a hands-on format suitable for lecture classes.

Materials

Two different solids and six different liquid were used in this exercise. The critical solid property is the density; the critical liquid properties are the density and the viscosity.

Sodium chloride and Polyarmor® G17 were selected as the solids. Ethanol, hexanol, octanol, chloroform, 2,2,4-trimethylpentane (isooctane) and polypropylene glycol 2000 mw were selected as the liquids. Densities, viscosities, and possible vendors are listed in Table 1. Proper safety precautions should be observed when handling these materials (suitable protective clothing and gloves, eye protections). Other liquids and solids with suitable properties may be substituted.

Table 1. Physical properties of solids and liquids

Material	**Density (g/mL)**	**Viscosity (cP)**	**Vendor**
Sodium chloride	2.17	n/a	Fisher BP358
Polyarmor® G17	0.94	n/a	www.innotekpowdercoatings.com
Chloroform	1.49	0.58	Acros 158210010
Ethanol	0.79	1.2	Aldrich 459828
Hexanol	0.81	5.7	Aldrich H13303
Octanol	0.83	9.2	Fisher A402
Polypropylene glycol, 2000 mw	1.01	301.5	Aldrich 202339
2,2,4-trimethylpentane	0.69	0.47	Aldrich 360597

Samples were prepared in clear 1.5 mL microcentrifuge tubes (Fisher 05-408-10). For the centrifugation portion of the exercise, an Eppendorf 5415D microcentrifuge with 24-place rotor (Fisher 05-40-100) was used. Alternative tubes and centrifuges may be substituted.

Sample Preparation

Samples were created by placing a small amount (0.1 mL) of one solid into a tube. One of the liquids was added until the total sample volume was 1.0 mL. The microcentrifuge tubes were capped and shaken, vortexed, or mixed by rotary inversion to suspend the solid in the liquid.

To insure that sufficient samples were available, samples were prepared at a ratio of one set of for six students. A complete set of samples consists of both solids suspended individually in each of the liquids (12 total samples). Sodium chloride will sink in all six of the liquids. Polyarmor® G17 will sink in four of the liquids. The variety in density differences and liquid viscosities provides a wide range of settling behavior.

In-Class Exercise

This exercise was implemented in a second-semester course on separation processes, taken by juniors during the spring semester. Since constructivism relies on cognitive conflict or puzzlement as the stimulus for learning, efforts were made to illustrate the appeal, relevance, and utility of the technical material before beginning the exercise.

Supporters believe that posing problems of emerging relevance is a guiding principle of constructivist pedagogy, and that this relevance can emerge through teacher mediation. To develop relevance, teachers should begin with a good problem. Greenberg identified four elements of a good problem.[9]

1. It demands that students make a testable prediction (preferably testable by the students).
2. It makes use of relatively inexpensive equipment.
3. It is complex enough to elicit multiple problem-solving approaches from the students.
4. It benefits from (as opposed to being hindered by) group effort.

An exercise focused on these four elements was developed. Student teams were asked to make a testable prediction by agreeing on one physical property that would influence particle settling speed. Answers included solid density, liquid density, and liquid viscosity. When they had arrived at this prediction, the teams came forward to test their prediction by selecting a few samples. For instance, if the students believed that solid density influenced particle settling speed, they selected samples of two different solids suspended in the same liquid (e.g. sodium chloride in chloroform, Polyarmor® G17 in chloroform).

Many of the samples displayed rapid settling, requiring a minimum of equipment. For more difficult samples (similar liquid and solid density, or viscous liquid), a vortex and microcentrifuge were provided to speed the process. Student summaries of their experiments, such as "the denser particle settled faster," provided the rationale for subsequent development of the underlying theory.

Take-Home Exercise

For the following class session students were asked to bring a sample from home that would display interesting separation behavior in a centrifuge. The students responded by supplying a wide spectrum of samples. A few examples include spicy brown mustard, which was separated into four layers (from the bottom: spices, dense yellow liquid, clear liquid, light yellow liquid); Mountain Dew, where a yellow solid begins to accumulate at the bottom; and uncooked scrambled egg, which easily separates into two liquid layers.

Assessing Student Understanding

This exercise was incorporated into two 75-minute lecture periods devoted to particle settling and centrifugation. The lecture material followed the course textbook.[8] No homework problems related to this material were assigned. Therefore, all student knowledge of this material was created through the hands-on exercise, lecture material, and independent studying from the text.

A problem similar to one of the text examples (Geankoplis example 14.3-3) was included on the final exam.[8] In this problem, a mixture of galena and silica were settling (galena is denser). Particle size ranges, solid densities, liquid density, and liquid viscosity were provided. Three quantities were requested: i) the terminal velocity of the fastest-settling galena particle (40% of credit); ii) the terminal velocity of the fastest-settling silica particle (20% of credit); iii) the size range of galena particles that settle faster than all silica particles (40% of credit).

Student performance was exceptional, with an average score of 95% on this problem. Whether student understanding was created through this hands-on exercise, the lecture material, or independent studying from the text is unclear. However, it is clear that the mandatory material (hands-on exercise and lecture) did not interfere with student learning. The impact of the hands-on exercise will be examined during the spring 2006 semester, when students will be split into two cohorts and exposed to two different five-step sequences (Table 2).

Table 2. Proposed sequence of student activities during spring 2006 semester.

	Step 1	Step 2	Step 3	Step 4	Step 5
Cohort A	Pre Test	Exercise	Mid Test	Lecture	Final Test
Cohort B		Lecture		Exercise	

In this manner, the effectiveness of student exposure to lecture-only, exercise-only, and combined instruction can be measured. In addition, the effect of activity sequencing can be determined. Results of this experiment are not available at this time, but will be included in the presentation.

Extensions

This short, hands-on exercise is suitable for courses that include rate-based separations. In addition, the exercise could be used to illustrate the utility of force balances and dimensional analysis in introductory physics, fluid mechanics, and dynamics courses.

This exercise could also serve as an introductory example before moving to hindered settling or full-scale laboratory experiments on sedimentation.[10]

Summary

A short, hands-on, low-cost particle settling and centrifugation exercise was developed. This exercise generated genuine student excitement for the course material. The "take home centrifugation" portion created a sense of competition among the students as they attempted to provide the "most interesting" sample. By creating hands-on, visually-appealing exercises centered on constructivist learning theory, student interest and understanding is enhanced.

References

1 Wankat, P. (2001). Teaching separations: why, what, when, and how. Chem. Eng. Ed. 35, 168-171.

2 Halsall, H.B. and Wermeling, J.R. (1982). Sedimentation coefficient, frictional coefficient, and molecular weight: a preparative ultracentrifuge experiment for the advanced undergraduate laboratory. J. Chem. Ed 59, 1076-1078.

3 Savery, J.R. and Duffy, T.M. (1996). Problem based learning: an instructional model and its constructivist framework. In B. Wilson (ed.), Constructivist Learning Environments: Case Studies in Instructional Design, Englewood Cliffs, NJ, Educational Technology Publications.

4 Brooks, J.G. and Brooks, M.G. (1993). In Search of Understanding: The Case for Constructivist Classrooms. Association for Supervision & Curriculum Development.

5 Osborne, R.J. and Freyberg, P. (1985). Learning in Science: The Implications of Children's Science, London, UK, Heinemann.

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6 Geary, D.C. (1995). Reflections of evolution and culture in children's cognition: implications for mathematical development and instruction. American Psychologist 50, 24-37.

7 Matthews, M.R. (2000). Constructivism in Science and Mathematics Education. In National Society for the Study of Education, 99th Yearbook, edited by D.C. Phillips. Chicago, IL, University of Chicago Press, p 161-192.

8 Geankoplis, C.J. (2003). Transport Processes and Separation Process Principles (Includes Unit Operations). 4th ed. Upper Saddle River, NJ: Prentice Hall PTR.

9 Greenberg, J. (1990). Problem-Solving Situations, Volume 1. Grapevine Publications, Inc.

10 http://www.unb.ca/che/Undergrad/lab/sedimentation.pdf. Last visited on 03-06-06.