# AC 2011-2155: COLLABORATIVE RESEARCH: INTEGRATION OF CONCEPTUAL LEARNING THROUGHOUT THE CORE CHEMICAL ENGINEERING CURRICULUM


**Milo Koretsky, Oregon State University**

Milo Koretsky is an Associate Professor of Chemical Engineering at Oregon State University. He currently has research activity in areas related to thin film materials processing and engineering education. He is interested in integrating technology into effective educational practices and in promoting the use of higher level cognitive skills in engineering problem solving. Dr. Koretsky is a six-time Intel Faculty Fellow and has won awards for his work in engineering education at the university and national levels.

**David L. Silverstein, University of Kentucky**

David L. Silverstein is the PJC Engineering Professor and an Associate Professor of Chemical & Materials Engineering at the University of Kentucky. He is assigned to the College of Engineering's Extended Campus Programs at Paducah, Kentucky. Silverstein received his B.S.Ch.E. from the University of Alabama in 1992, his M.S. in Chemical Engineering from Vanderbilt University in 1994, and his Ph.D. in Chemical Engineering from Vanderbilt in 1998. He is the 2007 recipient of the Raymond W. Fahien Award for Outstanding Teaching Effectiveness and Educational Scholarship.

**Ronald L. Miller, Colorado School of Mines**

Dr. Ronald L. Miller is professor of chemical engineering and Director of the Center for Engineering Education at the Colorado School of Mines where he has taught chemical engineering and interdisciplinary courses and conducted engineering education research for the past 25 years. Dr. Miller has received three university-wide teaching awards and has held a Jenni teaching fellowship at CSM. He has received grant awards for education research from the National Science Foundation, the U.S. Department of Education FIPSE program, the National Endowment for the Humanities, and the Colorado Commission on Higher Education and has published widely in the engineering education literature. His research interests include measuring and repairing engineering student misconceptions in thermal and transport science.

**Dr. John L. Falconer P.E., University of Colorado, Boulder**

# Collaborative Research: Integration of Conceptual Learning throughout the Core Chemical Engineering Curriculum

## Overview and Objectives

We will report on the progress of the first 9 months of a recently funded CCLI project. The goal of this project is to create a community of learning within the discipline of chemical engineering (ChE) focused on concept-based instruction. The project plan is to develop and promote the use of a cyber-enabled infrastructure for conceptual questions, *the AIChE Concept Warehouse*, which ultimately could be used throughout the core ChE curriculum (Material and Energy Balances, Thermodynamics, Transport Phenomena, Kinetics and Reactor Design, and Materials Science). Conceptual questions, both as Concept Inventories and ConcepTests, will be available through an interactive website maintained through the Education Division of the American Institute of Chemical Engineers (AIChE), the discipline's major professional society. The overall objective is to lower the activation barrier for using conceptual instruction and assessment so that many more chemical engineering faculty will incorporate concept-based learning into their classes.

The specific objectives of this project are to:

1. Develop the AIChE Concept Warehouse, a flexible database-driven website for conceptual questions in the core chemical engineering sciences. Features of the AIChE Concept Warehouse include:
    a. Making concept questions available in different formats to facilitate widespread use.
    b. Allowing integration of questions within a course and from different courses so students can link concepts to one another and form a more cohesive cognitive structure.
    c. Populating the site with conceptual questions that are submitted and reviewed by faculty, and are catalogued, rated and linked for ease of use.

2. Develop and deliver workshops that explain and promote conceptual learning in Chemical Engineering.
    a. Present workshops at the ASEE Chemical Engineering Faculty Summer School, the Fall AIChE Annual Meeting, and the Summer ASEE Annual meeting.
    b. Present workshops to faculty and future faculty through department site visits.
    c. Assess the participant's perception of the workshops and follow up with faculty to determine the extent of curricular integration of concept questions.

## Concept Inventories

Most tools and methods to assess engineering student learning focus on either procedural knowledge (e.g., solving specified classes of problems, designing a process or artifact, using appropriate engineering tools, oral and written communication) or development of affective and behavioral characteristics (e.g., teamwork, life-long learning, professional and ethical responsibility). Beginning in the 1970's, education researchers and educators began to identify conceptual shortcomings in students and the propensity for students to carry with them stronglyheld misconceptions describing how the world around them worked.[1] Based on this perspective, Halloun and Hestenes developed the Force Concept Inventory (FCI), an instrument to measure students' fundamental conceptual understanding of Newtonian mechanics.[2,3] The FCI led to a transformation in physics education in which a renewed focus on conceptual understanding replaced some of the emphasis on routine problem-solving.

As the positive effect of the FCI on physics education has become more widely known, Concept Inventories have emerged in many science and engineering fields. Inventories are now available or under development in electric circuits,[4] electromagnetic waves,[5] fluid mechanics,[6] heat transfer,[7] materials engineering,[8] signals and systems,[9] statics,[10] statistics,[11] strength of materials,[12] and thermodynamics,[13] among other fields. These Concept Inventories have been created using a variety of methodologies and have been subjected to varying degrees of validity, reliability, and bias testing.[14]

In chemical engineering, the most developed instrument is the Thermal and Transport Concept Inventory (TTCI).[15,16] A large Delphi study using 31 engineering professors was completed to identify important but widely misunderstood concepts in thermal and transport science (heat transfer, thermodynamics, fluid mechanics), and 12 concepts were identified as meeting the criteria of high importance but low conceptual understanding. These items included key topics in thermal science and transport disciplines such as the 2$^{nd}$ law of thermodynamics including reversible vs. irreversible processes, conservation of fluid momentum, viscous momentum transfer, several energy-related topics (heat, temperature, enthalpy, internal energy), and steady-state vs. equilibrium processes. Items were then developed for the TTCI assessment instrument,[17] using a seven-step process recommended by Downing.[18]

1. Drafting open-ended questions about the concept
2. Collecting student response data orally (think-aloud problem solving sessions) and in written form
3. Using the responses to convert the open-ended questions to multiple choice items with distracters describing plausible but incorrect answers
4. Beta testing the drafted items on groups of engineering students
5. Collecting expert reviews on each item (to establish content validity)
6. Revising the items based on statistical performance and expert feedback
7. Collecting additional beta test data.

The present version of the instrument (version 3.04) had consistently demonstrated reliabilities of 0.7 or higher for each of the sub-instruments, heat transfer, thermodynamics, fluid mechanics. Nearly 400 students at more than 20 engineering schools have used at least one of the three TTCI instruments.

The flexible nature of the database developed in this project will allow student response data, such as those in steps 2 and 4 above, to naturally become available as the concept questions are used in other forms, such as in an interactive electronic ConcepTests. This synergy will allow the question pool for use in Concept Inventories to greatly expand.

**ConcepTests**

Numerous studies in physics, chemistry, and biology classrooms have shown that active learning pedagogies such as peer instruction (students discussing answers in small groups) that are based on concept questions (ConcepTests) are more effective for student learning than traditional lecture.[19-22] A recent paper in *Science*[23] showed that this instructional technique significantly improved students' ability to answer a second, isomorphic ConcepTest on the same concept, immediately after the first ConcepTest, even though the instructor did not supply the correct answer to the first ConcepTest. For difficult questions, where only about 20% of the students answered the first question correctly on their own, approximately 55% answered the second question correctly on their own. This improvement demonstrates the value of ConcepTests and peer instruction for improved learning.

Questions that reflect the core concepts of a discipline are believed to be most effective in promoting conceptual change, especially when answer choices reflect common student misconceptions. Eliciting those misconceptions is believed to be a requisite step in the development of scientific concepts, especially because the meanings of words and concepts in everyday settings are often quite different from meanings in the specialized languages of science and engineering. McDermott[24] stated that students must be allowed to apply their own ideas, so that when they fail, students are more likely to learn the correct concepts. She found that “an effective instructional approach is to challenge students with qualitative questions that cannot be answered through memorization”. There is a great need for these concept questions in science and engineering courses because students often solve quantitative problems by memorizing an algorithm; as a result they do not obtain a functional understanding, which means they cannot use their knowledge in new situations.

The concepts that are important in chemical engineering are extensions from concepts in physics, chemistry, and biology. Thus, the same methods that are effective in physics, chemistry, and biology for improved learning are also effective in engineering. Although their use has increased in recent years, ConcepTests have been used less often in engineering classes.[25-28] This project will facilitate the use of these active pedagogies by providing a resource of high quality concept problems for instructors to use.

**Software Development Plan**

This poster will present the preliminary design of the interactive AIChE Concept Warehouse software. An innovative approach is planned to allow conceptual questions to be developed, linked, and integrated on an item-based level. The software will allow interactive electronic use, as well as PowerPoint, Word, and pdf formats to be automatically generated so that conceptual learning and evaluation can be incorporated into instruction in various forms: in-class ConcepTests with student response (clickers, laptops, cell phones), concept inventories to evaluate student learning (or student preparation for a course), exam and homework problems. A key element to this approach is to provide a context for conceptual learning that reflects the richly interconnected and interrelated knowledge structures of experts. The pedagogy includes cross development and testing between items on a Concept Inventory and in ConcepTests.

The first step in the design process is understanding user needs. The primary purpose of the concept warehouse is use as a curricular tool; however, a secondary aspect is to provide researchers a tool which they can use in order to perform educational research. Faculty with strong backgrounds in ConcepTests and concept inventories have been surveyed in order to compile a list of important features and to better understand the necessary ease of accessibility for those features. Relevant literature was explored to compile example questions and a list of question types and forms of use. Websites and software that potential users may be familiar with were surveyed to gather ideas for the user interface. The goal while surveying websites was to understand the flow of commonly used websites in order to incorporate that information into the AIChE Concept Warehouse. Once data were collected regarding the user needs an initial list of features and functionality was made and a draft website was constructed. The draft website was then used in focus group testing. Feedback from the focus group was then incorporated into the revised draft website.

## Acknowledgements

The authors gratefully acknowledge support from the National Science Foundation's Course, Curriculum and Laboratory Improvement Program, under the grant NSF 1023099, "Collaborative Research: Integration of Conceptual Learning throughout the Core Chemical Engineering Curriculum." Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

**References**

1. Duit, R. (2009). Bibliography: Students' and Teachers' Conceptions and Science Education. Kiel, Germany: Institute for Science Education. Available at http://www.ipn.uni-kiel.de/aktuell/stcse/ *Accessed 10 January 2010.*
2. Halloun, I. and Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics* **53**, 1043.
3. Hestenes, David, Wells, Malcolm, and Swackhamer, Greg. (2002). Force Concept Inventory. *The Physics Teacher*, **30**,141.
4. Evans, D. L., Gray, G. L., Krause, S., Martin, J., Midkiff, C., Notaros, B. M., et al. (2003). Progress on concept inventory assessment tools. *Proceedings of the 33rd Annual ASEE/IEEE Frontiers in Engineering Conference,* Boulder, CO.
5. Rhoads, T. R., and Roedel, R. J. (1999). The wave concept inventory-a cognitive instrument based on Bloom's taxonomy. *Proceedings of the 29th Annual ASEE/IEEE Frontiers in Engineering Conference,* San Juan, PR.
6. Martin, J. K., Mitchell, J., and Newell, T. (2004). Work in progress: analysis of reliability of the fluid mechanics concept inventory. *Proceedings of the 34rd Annual ASEE/IEEE Frontiers in Engineering Conference*, Savannah, GA.
7. Jacobi, A., Martin, J., Mitchell, J., and Newell, T. (2003). A concept inventory for heat transfer. *Proceedings of the 33rd Annual ASEE/IEEE Frontiers in Engineering Conference*, Boulder, CO.
8. Krause, S., Decker, J. C., and Griffin, R. (2003). Using a materials concept inventory to assess conceptual gain in introductory materials engineering courses. *Proceedings of the 33rd Annual ASEE/IEEE Frontiers in Engineering Conference,* Boulder, CO.
9. Wage, K. E., Buck, J. R., Wright, C. H. G., and Welch, T. B. (2005). The Signals and Systems Concept Inventory. *IEEE Transactions on Education* **48**, 448.
10. Steif, P. S., and Dantzler, J. A. (2005). A Statics Concept Inventory: Development and Psychometric Analysis. *Journal of Engineering Education*, **94,** 363.
11. Stone, A. D. 2006. A Psychometric Analysis of the Statistics Concept Inventory. Ph. D. dissertation, University of Oklahoma.

12. Richardson, J., Steif, P., Morgan, J., and Dantzler, J. (2003). Development of a concept inventory for strength of materials. *Proceedings of the 33rd Annual ASEE/IEEE Frontiers in Engineering Conference*, Boulder, CO.
13. Midkiff, K. C., Litzinger, T. A., and Evans, D. L. 2001. Development of Engineering Thermodynamics Concept Inventory instruments. *Proceedings of the 31st Annual ASEE/IEEE Frontiers in Engineering Conference*, Reno, NV.
14. Santiago Román, A. I. (2009). Fitting Cognitive Diagnostic Assessment to the Content Assessment Tool for Statics. PhD dissertation, Purdue University, West Lafayette, IN.
15. Streveler, R.A., Olds., B.M., Miller, R.L., and Nelson, M.A. (2003). Using a Delphi Study to Identify the Most Difficult Concepts for Students to Master in Thermal and Transport Science. *Proceedings of the American Society for Engineering Education Annual Conference* (electronic), Nashville, Tennessee.
16. Streveler, R. A., Litzinger, T. A., Miller, R. L., and Steif, P. S. (2008). Learning conceptual knowledge in engineering: Overview and future research directions. *Journal of Engineering Education* **97**, 279.
17. Streveler, R.A., Miller, R.L., Santiago Roman, A.I, Nelson, M.A., Geist, M.R. and Olds, B.M. (2010). A rigorous methodology for concept inventory development: using the assessment triangle to develop and test the thermal and transport concept inventory (TTCI). *International Journal of Engineering Education*, in press.
18. Downing, S. M. (2006). Twelve steps for effective test development. In *Handbook of test development*, edited by Downing, S. M. and T. M. Haladyna, 3-26. Mahwah, NJ: Erlbaum.
19. Caldwell, J. E. (2007). Clickers in the Large Classroom: Current Research and Best-Practice Tips. *CBE Life Sci Educ*, **6**, 9.
20. Crouch, C.H. and Mazur, E. (2001) Peer Instruction: Ten Years of Experience and Results. *American Journal of Physics*, **69**, 970.
21. Duncan, D. *Clickers in the Classroom*, Addison Wesley, San Francisco (2005).
22. MacArthur, J. R and Jones, L. L. (2008), A review of literature reports of clickers applicable to college chemistry classrooms, *Chem. Educ. Res. Pract.*, **9**, 187.
23. Smith, M.K., Wood, W.B. Adams, W.K. Wieman, C. Knight, J.K. Guild, N. and Su, T.T. (2009) Why Peer Discussion Improves Student Performance on In-Class Concept Questions. *Science*, 323, 122-124.
24. McDermott, L.C. (2001). Oersted Medal Lecture 2001: Physics Education Research-The Key to Student Learning", *American Journal of Physics*, **69**, 1127.
25. Falconer, J.L. (2004). Use of ConcepTests and Instant Feedback in Thermodynamics. *Chemical Engineering Education*, **38**, 64.
26. Falconer, J.L. (2007). Conceptests for a Chemical Engineering Thermodynamics Course. *Chemical Engineering Education*, **41**, 107.
27. Koretsky, Milo and Brooks, Bill. (2010). The Effect of Peer Instruction on Students' Construction of Conceptual Understanding in Thermodynamics. *Proceedings of the Annual Conference of the American Society for Engineering Education*.