Advances in Engineering Education

VOLUME 4 NUMBER 1 – WINTER 2014

The *AIChE Concept Warehouse*: A Web-Based Tool to Promote Concept-Based Instruction

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ABSTRACT

This paper describes the *AIChE Concept Warehouse*, a recently developed web-based instructional tool that enables faculty within the discipline of chemical engineering to better provide their students concept-based instruction. It currently houses over 2,000 concept questions and 10 concept inventories pertinent to courses throughout the core chemical engineering curriculum. These questions are available for faculty use both as in-class concept-based clicker questions (or ConcepTests) and stand-alone concept inventories, and can be accessed in various formats (online or offline) for use in class and on assignments and exams. The design philosophy is to make the tool versatile so that it can be used in the way that best fits with the instructor's teaching philosophy and the program's educational environment. Instructors and students perceive it to catalyze engagement and promote learning. While

domain specificity is critical to the targeted development of tools like the one we describe, we argue that the computer-based approach is generic and could be applied to any engineering discipline. One objective in describing this tool and characterizing our experiences using it is to contribute to such wider adaptation.

Key Words: educational technology; interactive learning environments; teaching/learning strategies

INTRODUCTION

Overview

Many engineering educators and industry partners emphasize the need for students to apply their knowledge to new and challenging problems (*Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, 2005). In order to do so, students must *learn with understanding* (Bransford, Brown, & Cocking, 1999). A lack of conceptual understanding has been shown to severely restrict students' ability to solve new problems, since they do not have the foundational understanding to use their knowledge in new situations (Hestenes, Wells, & Swackhamer, 1992). However, science and engineering classrooms often reward students more for rote learning than for conceptual understanding (Elby, 1999; Felder & Brent, 2005). There is clearly a need for more emphasis on conceptual understanding. In this paper, we refer to *concept-based instruction* as the use of pedagogies and corresponding learning activities whose primary objectives are to make students aware of their need for conceptual understanding and then foster that understanding.

The effectiveness of many forms of concept-based instruction depends critically on the availability of high-quality concept questions. These questions can be time-consuming and difficult to construct, posing one of the biggest barriers to implementing this type of pedagogy (Beatty, Gerace, Leonar, & Dufresne, 2006; Crouch, Watkins, Fagen, & Mazur, 2007; Fagen, Crouch, & Mazur, 2002). As Kay & LaSage (2009, p. 824) state in their review of the recent literature, "Unfortunately there are very few collections of ARS (i.e, audience response system or clicker) questions available in most fields, so instructors have to develop original questions, a process that is very time consuming."

The *AIChE Concept Warehouse* is a web-based instructional tool that decreases this barrier by housing concept questions pertinent to a specific discipline - chemical engineering (ChE). This cyber-enabled infrastructure is maintained through the *Education Division* of the discipline's primary professional society, *the American Institute of Chemical Engineers* (AIChE). Questions are available for faculty use both as in-class ConcepTests and stand-alone concept inventories, and can be used in many ways as best fits with the instructor's teaching philosophy and the programs educational environment.

In this paper, we provide an overview that describes the software architecture of the *AIChE Concept Warehouse*, report on the initial community use of this tool, and investigate instructor and student perceptions about its use. While domain specificity is critical to the targeted development of tools like the one we describe, we argue that the computer-based approach is generic and could be applied to any STEM discipline or community. One objective in describing this tool and characterizing our experiences in using it is to help enable such wider adaption.

Concept-based Pedagogy

The pedagogical methods and instruments to promote concept-based instruction that our tool employs are based on those developed by and studied in the physics education research community for three decades. Two concept-based pedagogical methods and instruments have dramatically reshaped how conceptual teaching and learning are viewed in college physics classrooms: ConcepTests (Mazur, 1997) and concept inventories (Hestenes, Wells, & Swackhamer, 1992). Both require high quality concept questions in order to be effective. High quality concept questions are typically (but not necessarily) multiple choice, conceptually challenging, and require little to no calculation so students cannot rely on equations to reach an answer. In addition, they contain incorrect choices, termed distracters, which are attractive to students because they align with common misconceptions. In the following sections, we provide brief descriptions of ConcepTests and concept inventories.

ConcepTests and Active Learning

In his book *Peer Instruction*, Eric Mazur (1997) describes the use of *ConcepTests* to engage students in conceptual learning during lectures. Mazur developed an active learning pedagogy which he terms *peer instruction* as a way of delivering ConcepTests in class. We illustrate the use of ConcepTests with this pedagogy; however, there are many other ways that instructors have actively incorporated them in concept-based instruction (Beatty & Gerace, 2009; Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996; Kalman, Milner-Bolotin, & Antimirova, 2010; Nicol & Boyle, 2003). Peer instruction includes structured questioning in which the instructor poses a ConcepTest and then all students respond independently, using clickers, smart phones, laptops, or flash cards. Students then discuss their answers with one another in small groups and respond again individually. Peer instruction encourages students to reflect on conceptual problems, think through the arguments being developed, and put them into their own words. It also provides both student and instructor with feedback regarding student understanding of the concept being tested.

Two separate studies, each with over 5,000 student participants, have found that classes using active learning methods such as peer instruction had on average double the conceptual learning gains (Hake, 1998) and a 25% higher pass rate (Poulis, Massen, Robens, & Gilbert, 1998) than traditional lecture classes. Deslauriers, Schelew, & Wieman (2011) compared the performance of two sections of students studying electromagnetic waves; the section taught by an inexperienced postdoctoral fellow using active learning techniques which focused on concept-based instruction outperformed, by 2.5 standard deviations, the section taught by an experienced professor with a record of high evaluations. Clearly, tools that enable faculty to implement these types of methods show great promise for positively impacting student learning in the classroom.

Concept Inventories

Whereas ConcepTests are used to promote student engagement and enable formative assessment, concept inventories provide a summative assessment tool to evaluate and demonstrate the effectiveness of active learning and other pedagogies. Concept inventories are valid and reliable instruments that consist of high quality concept questions. Validity is a measure of how well the concept inventory measures the intended concepts, as evaluated by experts, student observations, or other means within a single population of students or a variety of populations (Nelson, Geist, Miller, Streveler, & Olds, 2007). Reliability is a measure of the degree to which repeated administrations of the concept inventory produce the same results (Nelson, Geist, Miller, Streveler, & Olds, 2007). Concept inventories are used as an objective pre/post measure of an instructional intervention and have been used to inform instruction by identifying student misconceptions.

The seminal concept inventory, the Force Concept Inventory (FCI), provided an instrument to measure students' fundamental conceptual understanding of Newtonian mechanics (Halloun, 1985; Hestenes, Wells, & Swackhamer, 1992). Since development of the FCI, concept inventories have been created in a variety of engineering subjects, including statics (Steif & Dantlzer, 2005), dynamics (Gray, et al., 2005), and fluid mechanics (Martin, Mitchell, & Newell, 2004). Recently, a web-site has been developed to house concept inventories throughout engineering (Imbrie & Reed-Rhoads, 2011). The set of concept inventories pertinent to chemical engineering include: the Thermal and Transport Concept Inventory (TTCI) (Streveler, et al., 2011; Streveler, Olds, Miller, & Nelson, 2003), the Heat and Energy Concept Inventory (Prince, Vigeant, & Nottis, 2012), the Materials Concept Inventory (Krause, Decker, & Griffin, 2003), the Engineering Thermodynamics Concept Inventory (Midkiff, Litzinger, & Evans, 2001), the Thermodynamics Concept Inventory (Vigeant, Prince, & Nottis, 2011b), and a preliminary Material and Energy Balances Concept Inventory (Shallcross, 2010).

ARCHITECTURE

Overview

The AIChE Concept Warehouse has been developed to provide instructors and their students with a cyber-enabled infrastructure housing conceptual questions that contain content spanning the core chemical engineering curriculum. As of October 2013, approximately 2,000 concept questions (ConcepTests) and 10 valid and reliable concept inventories were available for searching, viewing, and using in courses. Instructor and student interfaces (discussed below) are available for the community at http://cw.edudiv.org, and university faculty can obtain an account through this site.

Design Principles

The design architecture is based on the first and third authors' experience developing a similar system that was institution specific (Koretsky & Brooks, 2008). The challenge we faced in extension to the chemical engineering community was to create an architecture that would be versatile and could serve faculty from many institutions who have a wide range of philosophies, climates, and needs. In order to accomplish this objective, we based design on several overarching principles including:

- Question Quality Principle: Provide faculty a resource of high quality conceptual questions, both as ConcepTests and concept inventories (as available).
- Question Quantity Principle: Provide a large enough question pool so that instructors can find questions pertaining to the specific concept they are teaching.
- Emergent Use Principle: Be versatile in how questions can be deployed in instruction so that instructors can use it in ways that best fit their philosophy and context and these ways can change with increasing participation.
- Familiarity Principle: As much as possible, design the layout of the website to be intuitive and match other common web sites with which users may be familiar.
- Support Principle: Provide multiple ways to technically support faculty who adopt the tool. Such support can be online resources, webinars, workshops, and email.
- Community Contribution Principle: Provide a way for faculty to contribute their own materials and to participate as peer reviewers of content.
- Data Collection Principle: Collect question response data for instructors to use in class and to provide empirical evidence to characterize questions and identify student misconceptions (with informed consent).

Modes of Use

The intent of the AIChE Concept Warehouse is to provide a tool that instructors can use that best fits with their teaching philosophy and learning environment. In essence, we want to cultivate emergent uses

Mode of Use		Description
Offline		Download questions via Microsoft Word or PowerPoint to use on homework, tests, or with external clicker systems
Online*	Homework	Used online outside of class through student interface as homework
	In-Class, with Laptops or Cell Phones	Used in class through web browser allowing short answer explanations and confidence follow-up
	In-Class, with Turning Point Clickers	Used in class with Turning Point clickers using the AIChE Concept Warehouse java applet

* requires students to interface with the site

Table 1. Predicted modes of use of the AIChE Concept Warehouse and their description

in which faculty leverage and build their own knowledge and experience rather than to attempt to prescribe a unitary, specific way to implement concept-based instruction (Henderson, Beach, & Finkelstein, 2011). To this end, the tool has been designed to be versatile with four general ways that instructors can use it for instruction (Emergent Use Principle). These four modes of use are supported through *Quick Start Guides* written as step-by-step instructions and available through the instructor interface. In addition there are video walkthroughs for a subset of user activities within the AIChE Concept Warehouse. These resources are intended for new users to facilitate their initial use (Support Principle).

Table 1 provides a summary of these modes of use. At all levels of use, instructors can create a "class" which dedicates workspace for a particular course that they are teaching. Within the class they can select a set of ConcepTest questions to create a "test," which is a collection of questions to be used in a single class meeting or out of class assignment. Also they can assign concept inventories to the students in the class.

Offline Use

Offline refers to faculty downloading questions, either as a Microsoft Word document or PowerPoint slides rather than using the web based infrastructure directly to deliver the questions to students. Examples of offline use include: use on a homework set, test, quiz, or in class with an external clicker system. This form of use does not require students to access the site. Even at the basic level of using offline, instructors already using peer instruction or active learning with concept questions need only make minor changes to current practices and the AIChE Concept Warehouse can save them preparation time by providing easy access to high quality concept questions.

Online Use

If an instructor wants to use more of the features available *Online*, instead of downloading questions they can integrate the use of clickers or have students log in and answer ConcepTests and concept inventories on their laptops or smart phones (either "live" in-class or for homework). A benefit of this mode is that it enables instructors to view results in an aggregated and tabulated format. The results may be archived for later use and can be downloaded in Microsoft Excel format. If instructors solicit responses via laptops or smartphones, they can also prompt students for short answer explanations of their answer choice and ask them to rate their confidence. Such written reflection is perceived by students as helpful to learning (Koretsky & Brooks, 2012). These more-involved features require students to interface with the website.

Online use also benefits the education research community since usage data can be used to inform ConcepTest and concept inventory development (Data Collection Principle). Only aggregate, anonymous data are used, taken from students who agree to participate as acknowledged through their acceptance of the IRB-approved informed consent available on the site. For example, data from student selections could be used for item testing, a critical step in concept inventory development. This synergy will allow the question pool for use in concept inventories to greatly expand.

Instructor Interface

The instructor interface is organized into seven main sections, accessible by their corresponding tabs: Home, ConcepTests, Concept Inventories, Instructional Tools, Classes, Profile, and Support. Table 2 provides a description of the functions available to instructors, organized by submenu sections within each tab.

In order to maximize compatibility and minimize complexity, an effort was made to design the instructor interface to match with the current web experiences of potential adopters, to be similar to other web-based interfaces, and to be user-friendly (Familiarity Principle). One approach to accomplishing this design objective was to predict and accommodate different ways users might leverage the *AIChE Concept Warehouse* in their instruction as previously summarized in Table 1. As an example, we present a screen shot of the ConcepTest search tab that enables instructors to find questions in Figure 1.

In addition, instructors may actively contribute by adding their own questions to the database through a scaffolded web tab, as partially shown in Figure 2 (Community Contribution Principle). Instructors can use any of the questions that they develop solely in their own classes or, alternatively, they can choose to submit a question they have developed for use by the entire community. In the latter case, the questions are incorporated pending peer review (Quality Question Principle). They can create multiple-choice, multiple correct multiple-choice, ranking, and short answer questions. These questions can then be associated with classes, the misconceptions they address, textbooks, topics, and sub-topics. Comments can also be left for instructors when they are searching for or deciding on using questions. These comments can include information about the correct answer, a distractor, or the use of the question.

Tab	Submenu Sections	Description of Functions
Home		View a brief summary of the latest changes, including: highlights of *AIChE Concept Warehouse* news, added questions, new tutorials and comments about submitted questions.
ConcepTests	Search	View, filter, and search for questions. Then, select question(s) for use in class.
	Manage Tests	Organize, group, download (MS Power Point, MS Word), or assign (via projection in-class or sent to student laptops or smartphones) ConcepTests. Confidence and short answer explanation prompts can be added to questions during assignment.
	Statistics	View information after questions have been answered, including all or a subset of options: question title and text, question images, percent correct, answer choice distribution, average confidence, number of students answered, and pedagogy recommendation.
	New Question	Add new questions. Question information can include: question title, question and answer images, answer options, comments for faculty, and applicable research data. Question types include: multiple choice – single right answer or multiple right answer, short answer, and ranking. Questions can also be tagged by class, misconception, topic, and textbook.
Concept Inventories	Browse	View available concept inventories and select for use in class. Additional concept inventory information is available for viewing, such as: research data, development history, list of individual questions and an answer key.
	Manage Inventories	Assign concept inventories (via projection in-class or sent to student laptops or smartphones), either in complete form or subsections. Confidence and short answer explanation prompts can be added to questions during assignment.
	Statistics	View information after concept inventory questions have been answered, including all or a subset of options: question name, question text, question image, percent correct, answer distribution, average confidence, and number of students answered.
Classes	Class List	Create and delete personal classes and associate personal classes with general classes.
	Manage Class	Manage the class roster and grade sheet. Add students to or remove them from the class roster as well as send students an email instructing them on how to set up an account. View and download the grade sheet, which includes student responses to questions (correct/incorrect, written responses, written explanations, confidence)
Profile	Preferences	Set personal preferences such as: show or hide tooltips, show or hide answer option comments, and show or hide the correct answer indicator in question previews.
	Demographic Information	Report institution, schedule type, approximate first year teaching, and approximate first year using active learning.
	My Clicker	Select clicker type, download clicker integration application, and register clicker receiver.
	User Agreement	Displays the end user license agreement (EULA). Accepting the EULA is a required prerequisite to use of the *AIChE Concept Warehouse* and is displayed upon initial log-in.
Support	Webinars	Register for webinars offered by collaborators (e.g. Getting Started)
	Quick Start	Step-by-step instructions available online or as a download (PDF) for the four modes of use. Each mode of use is summarized to help faculty determine which mode best suits their current teaching philosophy.
	Intro to Pedagogy	View a collection of journal articles and videos to facilitate the integration of concept-based pedagogy into their classes.
	Tutorials	Watch videos to help instructors use the *AIChE Concept Warehouse*.
	Chat Forum	Interact with other community members through a bulletin board. This includes a forum for frequently asked questions (e.g How do I search for concept questions?)
	Helpful Links	Links to external resources on concept-based pedagogy, and active learning.
	News Archive	View the full history of the news about the *AIChE Concept Warehouse*.

Table 2. Summary of instructor interface functions organized by sub menu sections within each tab

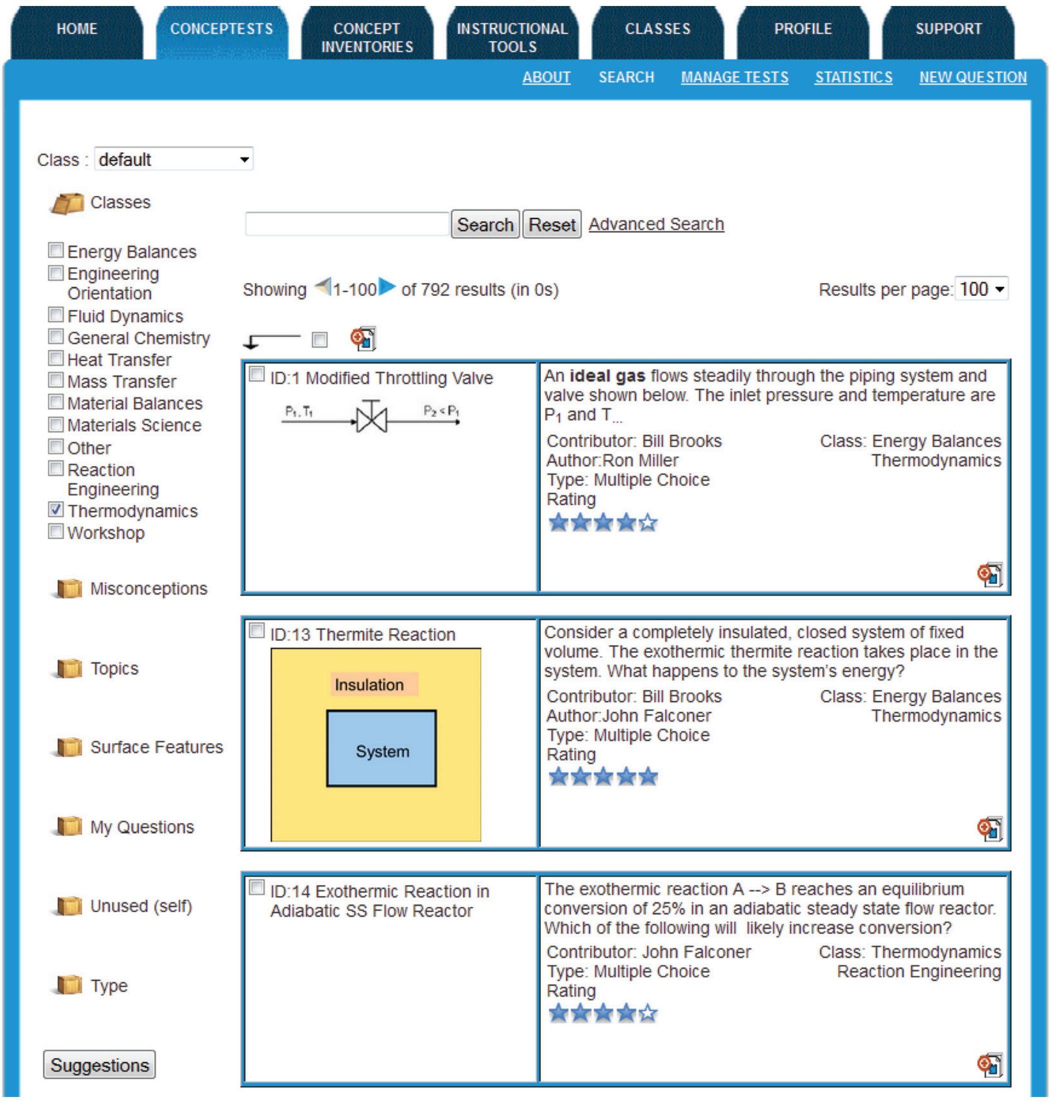

Figure 1. Screenshot of the ConcepTest search tab in the instructor interface of the AIChE Concept Warehouse

Instructors who use the tool in the *Online* mode, have access to student performance data as shown in Figure 3. An instructor receives summary data for all questions assigned in a class (as shown in the main tab), and has historical data and can retrieve student response data from previous classes. In addition, instructors can access student explanations in two ways, as shown in the insets. First, the entire response set is available to the instructor as a word cloud. Second, a sortable, anonymous list of individual written responses for each question is available together with the multiple-choice

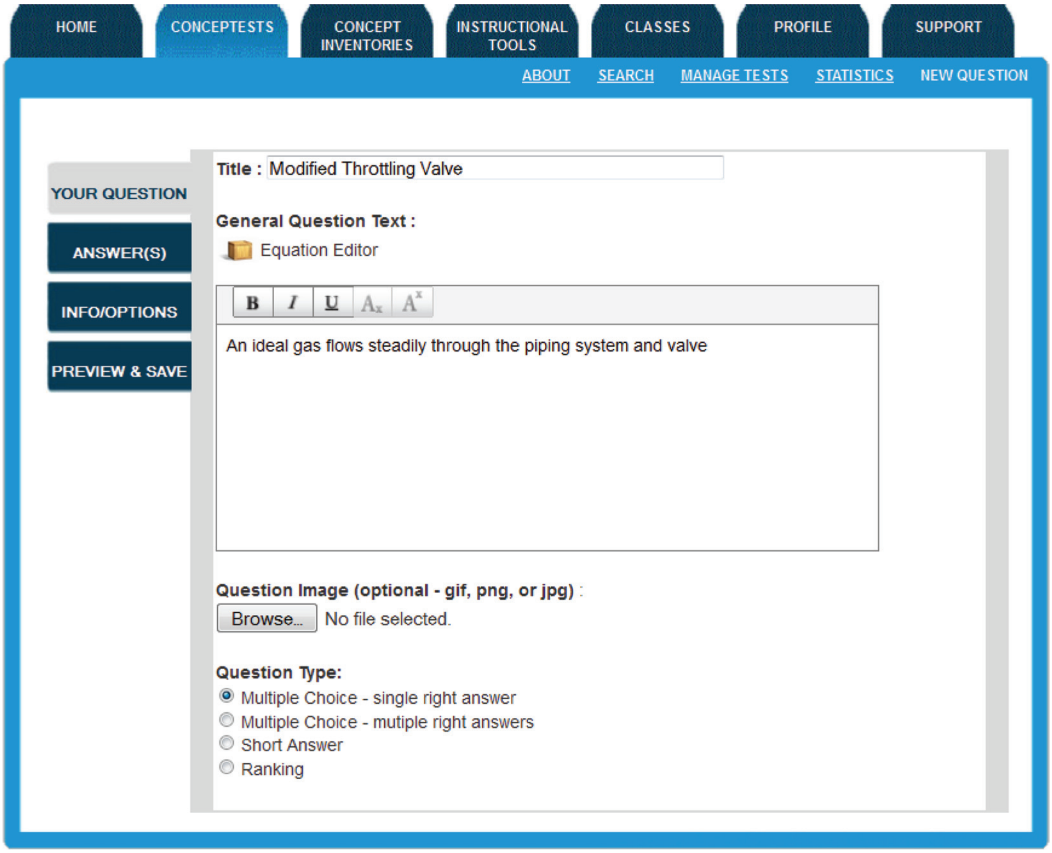

Figure 2. Screenshot of the question input tab in the instructor interface of the AIChE Concept Warehouse

response selected and the selected confidence rating. This data can provide instructors rich information about the level and distribution of their students' conceptual understanding.

Student Interface

The student interface is simpler than the instructor interface and has only three tabs: Home, Questions, and Profile. The tabs, submenu sections, and function descriptions are presented in Table 3. The questions tab, shown in Figure 4, shows the highest priority concept-based assignment for a selected class. Here students can answer questions from in-class activities or homework assignments. Also depicted in Figure 4 is the student view of three question components: a multiple-choice question, a short answer written explanation, and a confidence selection. A sample (incorrect) student answer is also shown.

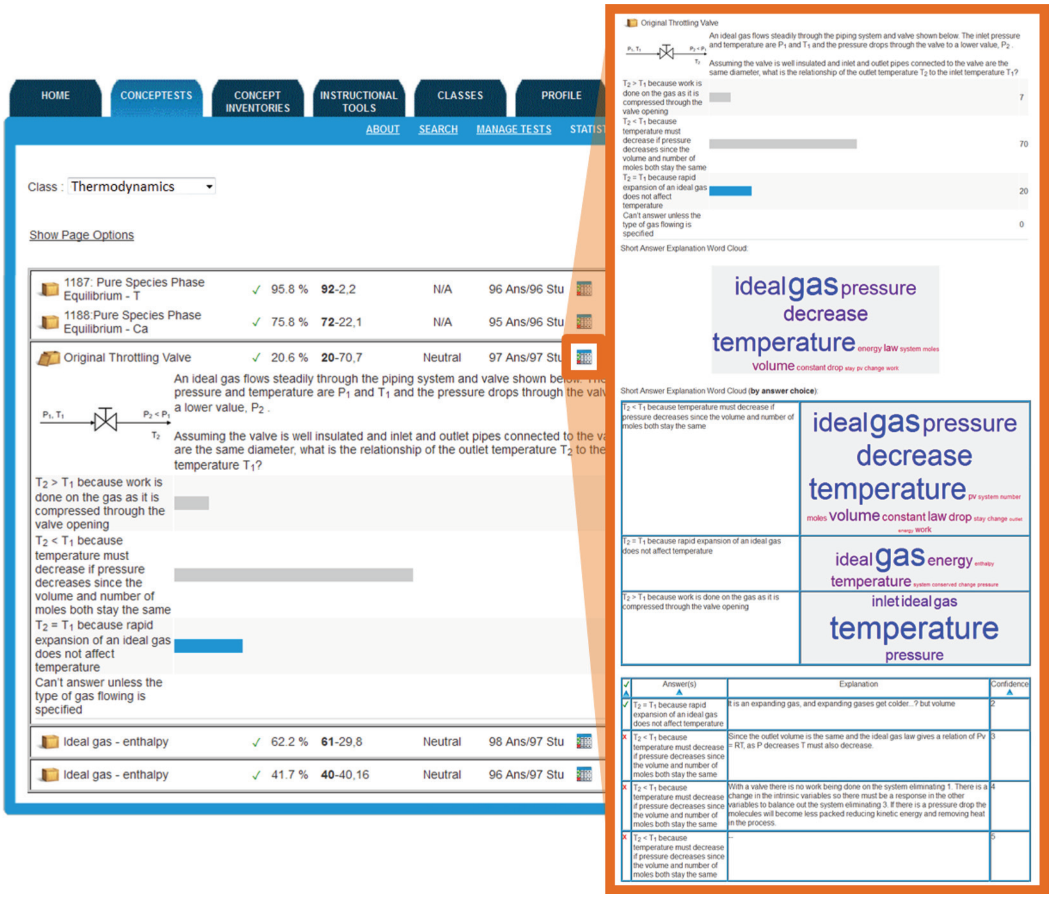

Figure 3. Statistics tab in the instructor interface of the AIChE Concept Warehouse showing question response data for a single class. The insets show more extensive information available for written responses.

To obtain an account, students provide their email address and click the "log in" button, while leaving the password field empty. A link is then emailed which allows the students to create a password. The same process is used to reset forgotten passwords. Student email addresses and passwords are encrypted using a one-way hash; therefore password reminders cannot be sent. After an account is set up, students can log in for the first time and are greeted with a prompt to provide voluntary user information and an opportunity to provide informed consent to allow their anonymous responses to be incorporated into aggregate data for research purposes, as shown in the profile tab in Table 3 (Data Collection Principle).

Technology use in the classroom, in the form of laptops (Efaw, Hampton, Martinez, & Smith, 2004; Griffin & Walker, 2005), tablet PCs (Cromack, 2008; Koile & Singer, 2006), and clickers (Duncan,

Tab	Submenu Sections	Description of Functions
Home		Alerts students to the number of concept-based assignments with unanswered questions, categorized by class.
Questions		View the highest priority concept-based assignment for a selected class. Students can answer questions from in-class activities or homework assignments.
Profile	Demographics	Report voluntary demographic information (e.g., birth year, first year at the university, gender, race, and major).
	Informed consent	Students can allow or deny the use of their response data for research purposes.
	Clicker registration	Aligns clicker responses with the student's account.

Table 3. Summary of AIChE Concept Warehouse Student functions organized by tab and sub menu sections

2005) has been well documented. The use of internet-capable cell phones is also emerging as a learning tool, seen in a recent study on active learning (Koretsky & Brooks, 2012) and as evidenced by audience response system companies creating cell phone applications as an alternative to purchasing separate hardware (eInstruction, 2013; i>clicker, 2013; Inc., 2013; Turning Technologies, 2013). The student interface was designed with these considerations in mind.

Material and Methods

This mixed methods study aims at characterizing initial community use of the AIChE Concept Warehouse and determining faculty and student perceptions of the challenges of using the tool and the benefits it affords.

Use Data

Use data is available from the tool's central database and has been analyzed to characterize the engagement of the chemical engineering faculty community over time. Data include identification of faculty users, their institutions, and how they became aware of the tool. The use statistics identify users both in the online and offline modes. For the online mode, the number of questions, number of students, and number of unique answers submitted are reported. For the offline mode, the only information available from the database is the number of questions downloaded. However, no information is available about how and the extent to which faculty use these questions, nor is there a record of faculty who use questions from the database, but retrieve them in other ways. Finally, use data is segregated by class type for the classes available: material balances, energy balances, thermodynamics, transport phenomena, chemical reaction engineering, materials science, chemistry, and physics.

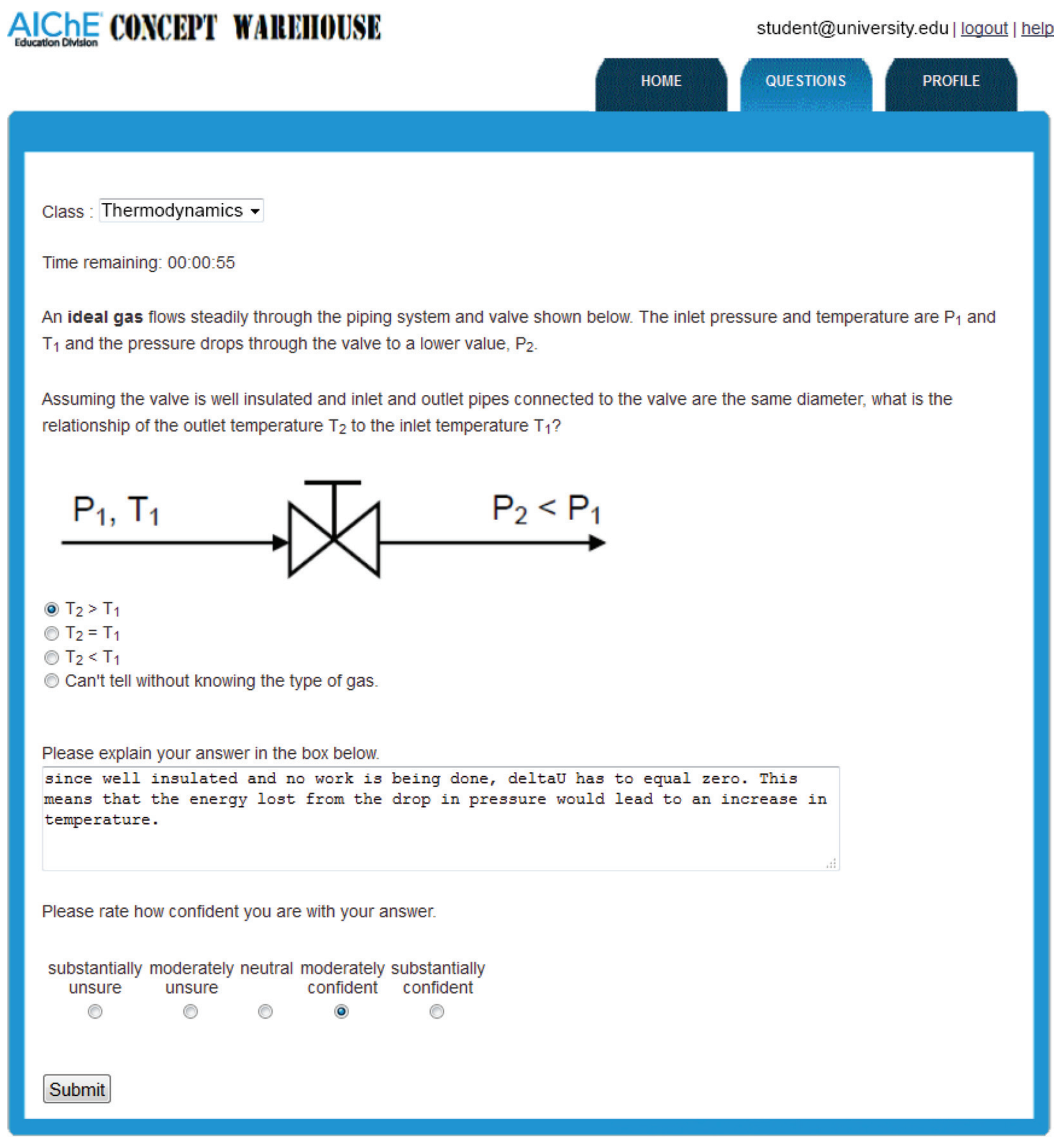

Figure 4. Screenshot of a student's (incorrect) answer from the questions tab from the student interface

User Perceptions

Faculty

Ten faculty members who were early adopters were interviewed to investigate their perceptions of the AIChE Concept Warehouse. Three were beta testers that tested the website when it was in the early stages of development, seven had attended the Summer School Workshop where it was made generally available to the community, and one heard about it from a colleague but did not attend the Workshop and was not a beta tester. One beta-tester also attended the workshop.

Semi-structured interviews were conducted using an initial list of questions as a guide. Interview questions were designed around Rogers' Theory of Diffusion of Innovations (Rogers, 2003). Interviews were conducted by two graduate student researchers. Participants were asked to provide IRB approved informed consent. Interviews averaged approximately 50 minutes. At the beginning of the interview, participants were told what the purpose of the interview was and that they should feel comfortable giving any comments or criticism. All interviews were audio recorded and transcribed. An emergent thematic coding process was performed on all transcripts (Braun & Clarke, 2006).

Students

A survey of student users was conducted for two cohorts in one of the classes in which the AIChE Concept Warehouse was used. The survey instrument consists of eight (1=strongly disagree to 5=strongly agree) Likert-scale statements and two questions which require written comments. It is described in detail elsewhere (Koretsky & Brooks, 2012). The students surveyed were in a junior-level class of approximately 100 students. While all students were asked to respond to the survey, only those who signed IRB approved informed consent forms were included in the analysis for this study.

In this class, the tool was used in the online mode with students providing answers by laptops (mostly) and smart phones. Most students in the class had used the AIChE Concept Warehouse (or its predecessor) in at least two classes previously. Additionally, the class was taught by one of the primary developers of the tool. Thus, the responses reported in this study represent a specific case and are not intended to be comprehensive of the varied ways this tool is used throughout the community.

To provide a richer view of students' perception, the free response written comments were further analyzed. Questions focused on students' technology problems and the perceived benefits, as follows:

1. Describe any problems specifically based with **technology** that you encountered when the AIChE Concept Warehouse was used in class.
2. Describe any benefits of using the AIChE Concept Warehouse in class.

A coding process was used to identify common responses. The questions were coded by two graduate student researchers using an emergent process to develop categories. Once the categories were identified, agreed upon and described, each researcher independently coded the student responses. The Cohen's kappa was 0.98 indicating high reliability between researchers.

RESULTS AND DISCUSSION

Preliminary Use

The *AIChE Concept Warehouse* was made available to the chemical engineering community at the ASEE Chemical Engineering Summer School in July 2012. In the following year, over 300 faculty from over 100 institutions have registered for accounts. It has been actively used in both *Online* and *Offline* modes. In the online mode, over 2,800 questions have been answered by over 4,000 student users and over 125,000 answers have been submitted. For use offline, faculty have downloaded over 2,200 questions. This number represents a lower bound since interviews show some instructors have copied questions directly from the interface rather than using the download feature. Although there is no way of telling how many individual questions have been answered, a conservative estimate scaling from online use would be well over 200,000 total from both modes. From these usage statistics it appears that the tool is rapidly being adopted and used by the chemical engineering academic community.

Figure 5 shows the relative percentage of use by class type for questions asked online (Online Question %), answers submitted online (Online Answer %), and questions downloaded (Offline

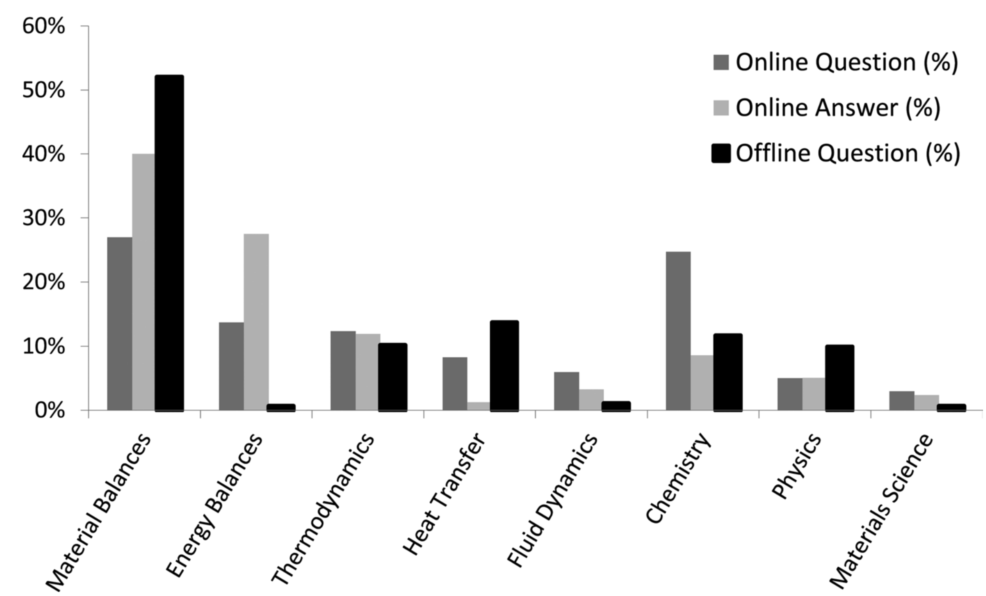

Figure 5. Plot of use percentage for different types of class available in the AIChE Concept Warehouse. Online use shows percentage of concept questions asked and percentage of student answers, whereas offline use shows percentage of questions downloaded. There have been no questions used online or downloaded offline for the class types "Reaction Engineering" and "Mass Transfer."

Question %). For example, 27% of all the total online questions asked are identified as having conceptual content relating to "Material Balances," while 14% are "Energy Balances," 12% "Thermodynamics," etc. The proportion of answers submitted in material balances and energy balances is even greater (40% and 28% respectively). This result is reflective of the larger class size in the introductory course relative to those delivered later in the curriculum.

These data reflect a user community early in its development and still evolving. While over half the questions that have been downloaded for offline use correspond to material balances, few energy balance questions have been downloaded. Almost all faculty who teach energy balances using the tool use it in the online mode. There also have been no questions used online or downloaded offline for the class types "Reaction Engineering" and "Mass Transfer." For the former class type there are 241 questions available, so the limited use is probably due to faculty awareness. On the other hand, for mass transfer only 10 questions exist, so the limitation is in question availability.

To convey the progression of use, the number of faculty user accounts is plotted vs. time in Figure 6. The number of accounts of "active users" is shown for comparison. An active user is defined

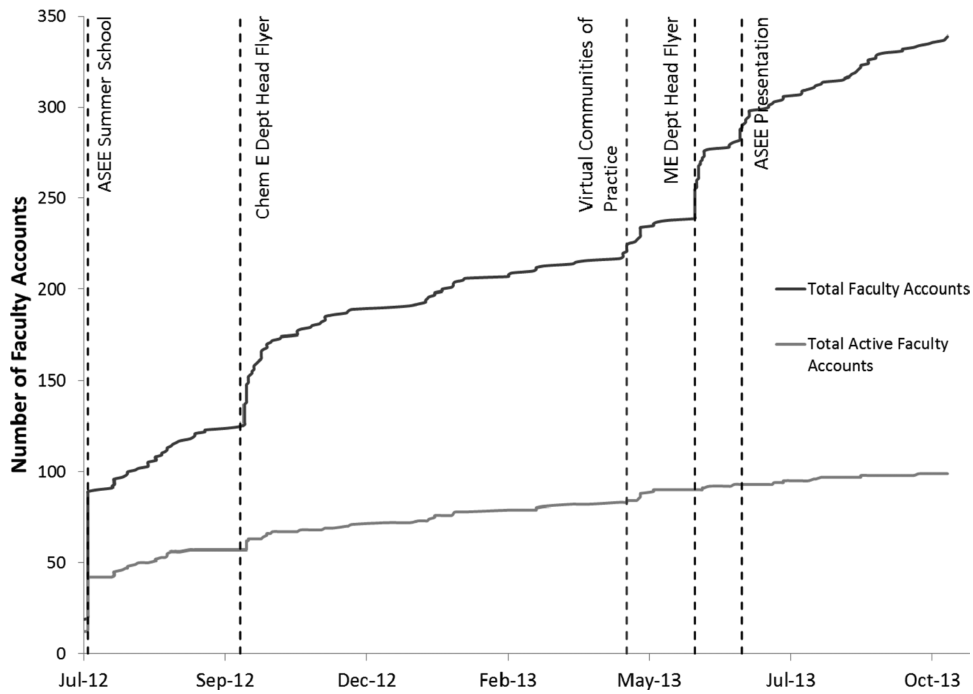

Figure 6. Plot of total and active accounts created since the release at 2012 ASEE Summer School

as someone who has logged in four or more times since the tool was made publically available in July 2012. Also included in the figure are lines marking major communication events that showed a large increase in faculty accounts. The greatest increase in accounts came as a result of the ASEE Summer School Workshop. Other large rises in the number of accounts resulted after the following communication activities: an email sent to chemical engineering (Chem E) and mechanical engineering (ME) department heads that contained a promotional flyer to reach new adopters, two Virtual Communities of Practice (Thermodynamics and Mass and Energy Balances) meetings in which the *AIChE Concept Warehouse* was discussed and demonstrated, and following a presentation and demonstration of the *AIChE Concept Warehouse* at the 2013 ASEE Annual Conference.

User Perceptions

Faculty

All ten faculty users who were interviewed noted positive design features of the AIChE Concept Warehouse website that afforded flexibility in implementation and use. Some participants suggested ways in which the user interface could be improved to be more familiar to other web-based interfaces they use and more user-friendly. Participants also noted the quality of questions as an important factor in their decision to use the tool. Some cited it as better than other resources they had previously used, while a couple noted hesitation and need to avoid "tricky" questions. In addition, participants appreciated the large number of questions for most classes.

One online adopter used the "display results" feature and described her/his implementation as follows:

> "I would go to class and then, what I'd try to do is lecture past that point, where I felt like I had explained something and my hope is that, okay now everyone is going to get it right, and then ask a question, a conceptual question, that maybe is phrased a little bit differently or might…even be perceived as being a little bit tricky, but if you understood the concept, it should be something you could get…and then challenge the students to answer it, and after a couple of minutes stopping it, showing the results, which were sometimes surprising for me as it was for the students…just that there was a question I thought everyone would get right and it would be 50/50, half the class would get it right, half the class would get it wrong… so then, we would use that as kind of a discussion point."

This example portrays how using a feature only available online gives instructors the immediate opportunity to refocus her/his lectures. This instructor also used the Concept Warehouse to administer surveys and get immediate feedback from students, a use not foreseen by the developers.

The placement and number of ConcepTests administered differed between adopters. One adopter used them at the very beginning of class as a quiz on the previous reading assignment in an effort to motivate students to complete the assignment. Another adopter used ConcepTests throughout the class period and had a bank of questions available for use at the end of class, time permitting. Others had entire recitations dedicated to ConcepTests. Two adopters stated they used the Concept Warehouse more heavily towards the beginning of the term/semester and less as the term/semester went on due to time and/or difficulty of material. The number of ConcepTests used per day ranged from one to eight. Many of the adopters wrote their own questions and expressed interest in sharing them with other faculty. This interest aligns with the Community Contribution Principle.

A more detailed analysis of faculty perception of the tool is available elsewhere (Gilbuena, Smith, Brooks, Finklestein, & Koretsky, 2013).

Students

Likert Survey Responses

Responses to the Likert statements with a scale from 1 (strongly disagree) to 5 (strongly agree) are shown in Table 4. The first two items relate to perceived engagement, the third to self-efficacy, the fourth to seventh to perceived learning and metacognition, and the eighth to the usefulness of written reflection. In addition to showing values for the average response for each item, Table 4 reports aggregated percent responses of “strongly disagree” and “disagree” as “negative response” and “agree” and “strongly agree” as “positive response.”

Overall students responded positively with averages for engagement and learning items comparing favorably to similar items reported for clickers (Han & Finkelstein, 2013). Students generally connected the use of the AIChE Concept Warehouse to learning with 155 of 179 students responding positively to the statement that its use helped them to understand the concepts behind the problems and 145 of 181 students also agreeing that their conceptual understanding would increase in other classes if the tool were used in those classes. Statement 6 asks students to assess their awareness of misunderstandings while Statement 7 specifically connects such awareness to the tool. A chi-squared test shows that Statement 6 averages (4.08 and 4.00) are significantly greater ($p < 10^{-5}$) than Statement 7 averages (3.59 and 3.74). Interestingly, while students generally responded very favorably both to the statement that they had to think more when they used the tool in class and the statement that the tool helped them understand the concepts behind the problems, they were less ready to attribute their awareness of misunderstandings specifically to the tool rather than the course. Such a result is consistent with the view that learning is promoted by the pedagogy and content the tool enables rather than the tool itself, as discussed by Beatty and Gerace (2009).

Statement	Negative response		Neutral response		Positive response		Average	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1. I am more actively involved in class when the AIChE Concept Warehouse is used	5%	8%	20%	15%	78%	76%	4.01	4.16
2. I have to think more in class sessions that use the AIChE Concept Warehouse than those that do not.	8%	8%	11%	14%	80%	82%	4.16	4.18
3. Seeing the class responses to a concept question (bar graph) helps increase my confidence.	6%	10%	22%	26%	72%	66%	3.91	3.87
4. Using the AIChE Concept Warehouse helps me to understand the concepts behind the problems.	2%	7%	14%	4%	84%	89%	4.14	4.28
5. If the AIChE Concept Warehouse was used in other classes, my conceptual understanding in those classes would be better.	3%	4%	17%	15%	79%	83%	4.03	4.02
6. In this course, I am more aware of my misunderstandings than in courses taught by traditional methods.	9%	7%	10%	14%	80%	79%	4.08	4.00
7. The change in awareness of my misunderstandings is due to the AIChE Concept Warehouse.	13%	8%	28%	24%	60%	68%	3.59	3.74
8. The short answer follow-ups to multiple choice questions helped me to think more about the question and the answer that I chose.	9%	9%	21%	19%	70%	72%	3.81	3.85

Table 4. Student responses to a subset of questions on the end of term survey. For Year 1, n=85 and Year 2, n=94. The responses of "strongly disagree" and "disagree" are aggregated into "negative response" and "agree" and "strongly agree" are aggregated into "positive response."

Free Response Questions

In the sections below results and analysis from coding of students' written responses to each free response question is presented.

Technical Problems

Figure 7 shows the number of responses to the categories for student responses to question 1: Describe any problems specifically based with **technology** that you encountered when the AIChE Concept Warehouse was used in class. The category "blank" indicates that the student left this item blank in responding to the survey. The most common response (n=63) was that there were no technical problems, e.g., "None, my phone worked great." The other frequently coded category was internet connectivity

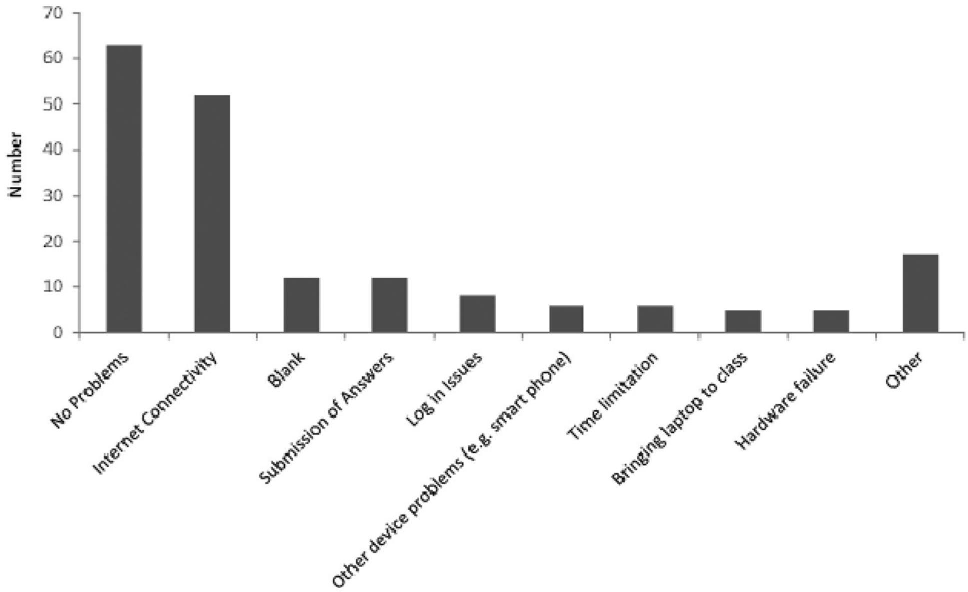

Figure 7. Frequency of coded responses for each category of technology problems question.

(n=52). The majority of these responses indicated an anomalous event ("Only once was wireless down in the classroom, otherwise everything was good.") while some responses alluded to more reoccurring problems ("Sometimes the internet wifi is slow."). One such response in the latter group, indicated a perceived causal relationship between the technology problems and the student's readiness to learn, "some times the internet was working really slow and i was stressing much about trying to get on the website and not spending time learning the content." The remaining responses were approximately equally divided between technology problems with the specific devices the students were using (n=16), e.g., bringing laptop to class, hardware failure, other device problems, and with problems with navigating the website software itself (n=20), e.g., submission of answers, log-in issues.

Benefits

We next discuss coding to question 2: Describe any benefits of using the AIChE Concept Warehouse in class. To interpret the responses, we use the model developed by Blasco-Arcas, Buil, HernáNdez-Ortega, & Sese (2013) to describe the benefits of the use of personal response systems in enhancing student learning performance. They find that "interactivity, active collaborative learning and engagement are three key underlying forces that explain the positive effects." When students reflected on their learning experiences, common themes emerged that are consistent with this model, and illustrated by the following comments.

Regarding interactivity:

- Opportunity to see what you don't understand and what you do understand. Chance to have mistaken notions corrected.
- It's good to practice a lot of conceptual scenarios that we might not otherwise get to see, and then have a discussion about it.
- The concept warehouse promotes problem solving and applying concepts in class instead of just listening to a professor lecture, which stimulates the understanding of the material.

Regarding active collaborative learning:

- Lets you actually apply some of the concepts that you learned in class, also it is nice when we talk to our classmates an(d) get a different view on the problem or a reinforcement of yours
- (The) AIChE Concept Warehouse is a catalyst for conversation about challenging conceptual ideas. A lot of the concepts in thermodynamics are abstract and hard to understand because they conflict with our prior perceptions of the way the world works. By talking about them as a class and confronting them head on, we can better understand the concepts and correctly solve real life problems.

Regarding Engagement:

- It is more engaged than lecture. I get to see what other people said and their reasoning behind their answers which helps me to better understand why the answer is what it is. Rather than just knowing the answer.
- (It) really helps to engage difficult concepts and have the professor explain them after we get a chance to chew on them
- It engages me in class to start problem solving right away on the material we just covered. It let's (sic) me work with others giving me different perspectives on how to solve the problem.

In addition to interactivity, active collaborative learning and engagement, an additional common theme emerged from the coding process - general enjoyment during class when the tool was used. The following comments illustrate this theme:

- I really enjoy coming to class when we use concept warehouse. It's fun to test how well I understand thermo throughout the course of the class.
- it's fun, like a game show that involves my learning about the subject
- General enjoyment through the stronger feeling of participation.

Technology Mediated Conceptual Learning

The data above suggest that interactive use of the AIChE Concept Warehouse is perceived to enhance student engagement and learning of troublesome concepts. Coupled with findings reported from the literature, we infer that concept-based instruction is enabled by these types of tools.

Moreover, the rapid uptake of the AIChE Concept Warehouse by the chemical engineering community indicates that the community is receptive of this type of resource and it can enable faculty to implement concept-based instruction more easily.

However, as illustrated by the distribution of responses to the first free response question, implementing active learning pedagogies utilizing computers and other mobile devices in class presents challenges to students and instructors. It is not realistic to assume that the technology will be entirely transparent to students at all times. Inevitably, technology problems can arise for both instructors and students. When they occur, they consume the cognitive load needed to engage and learn troublesome concepts. For this reason, technology problems can seem to magnify in perception.

In terms of delivery in class, it is useful for instructors to be mentally ready to be adaptive with the day's lesson plan. Even if technology problems are infrequent, students will take cues from how an instructor responds to them. Additionally, an important role in instruction becomes how the instructor frames the use of technology. Such framing should attempt to minimize students' anxiety about the technical problems allowing them to focus on the conceptual mastery. Finally, as with any technological based resource, instructors should be aware of the learning curve for both themselves and their students. We encourage instructors not to abandon the use of technology too quickly during the initial "start-up" period of its use.

CONCLUSION

A web-based tool, the *AIChE Concept Warehouse*, has been developed to provide instructors a resource to help implement concept-based instruction. It has been well received by the community with hundreds of faculty joining in the first year of public release. Instructor and student perceptions are positive, viewing the tool as useful in increasing engagement and conceptual learning. While this tool specifically focuses on chemical engineering and related disciplines, the architecture of this tool is generic and not discipline specific. The following critical principles have been identified for design of such web-based tools: question quality, question quantity, emergent use, familiarity, support, community contribution, and data collection.

This paper has focused on the development, initial community use, and faculty and student perceptions of the tool itself. However, we conclude with two broader questions that have emerged which warrant further investigation. What are the ways this type of tool can enable growth of a discipline-specific community of learning focused on concept-based instruction? In what ways does this type of tool provide empirical evidence of student learning that can enable education researchers to help improve instruction and student learning?

ACKNOWLEDGMENTS

The authors acknowledge support from the National Science Foundation's Course, Curriculum and Laboratory Improvement Program, under the grants NSF 1023099, 1022957, 1022875, 1022785. The authors are grateful to Ron Miller for useful discussions and to Richard Felder for helpful comments. We would also like to thank our beta testers. Finally, we appreciate the other individuals that have contributed concept questions and constructive feedback.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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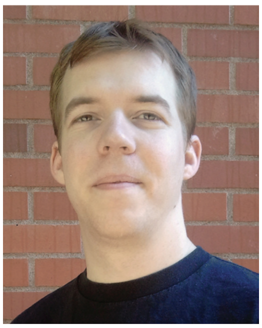

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