# Adapting a Student-Centered Chemistry Curriculum to a Large-Enrollment Context: Successes and Challenges

**By Emily J. Borda, Andrew Boudreaux, Ben Fackler-Adams, Paul Frazey, Sara Julin, Gregory Pennington, and Jared Ogle**

*Passive, lecture-based forms of instruction are often ineffective in helping students develop deep conceptual understanding of scientific concepts. Student-centered forms of instruction based in a constructivist framework, where students are guided toward actively constructing their understanding, have been met with greater success. However, implementation of constructivist-based curricula and complementary teaching practices in large introductory college courses is often met with unique challenges. Here we describe and evaluate the scaling of a constructivist-based, student-centered chemistry curriculum from its original implementation in a 24-seat small-enrollment course to a 96-seat large-enrollment course. Postinstruction test scores for the scaled up, student-centered course were intermediate between the large-enrollment traditional course and the small-enrollment student-centered course, suggesting limited success of the scaling. We discuss barriers to scaling and future steps to improve the large-enrollment course. Our goal is to inform similar transformations to student-centered curricula and practices in other large-enrollment courses.*

As research on the effectiveness of active "student-centered" learning over traditional lecture in higher education accumulates (Freeman et al., 2014), faculty face the challenge of adapting student-centered materials and methods to their college classrooms. When the target for adaptation is a large-enrollment course, a logical approach may be to try the new pedagogy first in smaller contexts, such as discussion or laboratory sections, followed by scaling to the larger enrollment context, which comes with a new set of challenges. Here we describe adaptation of a student-centered chemistry curriculum from a small-enrollment chemistry course for preservice teachers to a large-enrollment introductory chemistry course. In sharing our lessons learned, we aim to inform other efforts to scale student-centered curricula and pedagogy in a variety of science disciplines.

## A constructivist-based curriculum

Our goal for adapting student-centered materials to a large-enrollment context was to improve student understanding of core chemistry concepts through instruction that actively engages students in the learning process. Constructivism, which frames learning as a process of creating and transforming knowledge rather than passively assimilating it (Marin, Benarroch, & Gomez, 2000), guided the original development and subsequent adaptation of the curriculum. Although constructivism does not prescribe specific pedagogies, four "essential criteria" have been suggested as common to constructivist-based approaches: (a) elicitation of prior knowledge, (b) creation of cognitive dissonance, (c) application of knowledge with feedback, and (d) reflection on learning (Baviskar, Hartle, & Whitney, 2009).

Chemistry for the Informed Citizen (ChemCit), modeled closely from *Physics and Everyday Thinking* (Goldberg, Robinson, & Otero, 2005) and internally published as of the writing of this article, is structured to engage students with all four components of constructivist-based learning. Each activity begins with a set of questions probing students' initial ideas about the targeted learning goal. The curriculum then guides students through the collection and interpretation of evidence to build a consensus set of ideas. Finally, students reflect on their learning by comparing their current thinking to their initial ideas. "Scientists' Ideas" readings add to this reflective component by reviewing the main concepts in the activity and having students summarize evidence that supports them. Topics include the particulate nature of matter, kinetic molecular theory, physical and chemical changes, and thermodynamics (Borda, Anzalone, Lockett, & Wuotila, 2014).

## Scaling up the curriculum

ChemCit was originally designed for a small-enrollment chemistry course primarily serving preservice elementary teachers. This course has 24 seats and meets for 6 hours per week in a classroom with modular furniture where students, working in groups of 3–4, move fluidly between investigations and discussions. Portable whiteboards are used to facilitate whole-class discussions about initial ideas at the beginning of an activity and to build consensus at the end. The instructor is a facilitator, asking questions to help students construct evidence-based claims. In the courses reported here, homework was graded by the instructor, with opportunities for students to revise their responses.

ChemCit was adapted to a large-enrollment introductory chemistry course with 96 seats. This course meets for three 1-hour "lecture" sessions and one 2- to 3-hour laboratory session per week. The latter is taught either by the instructor or a graduate teaching assistant (TA). Undergraduate TAs provide further instructional assistance in lab and grade all lab homework, using resources developed by the author team. Preterm workshops and weekly meetings provide professional development to TAs in constructivist-based instruction.

Scaling student-centered practices to large-enrollment introductory science courses is difficult on many levels, from philosophical to logistical (Henderson & Dancy, 2007). Here we focus on the logistical constraints of class size and structure. One constraint of a large course is the difficulty of capturing evidence of individual student thinking quickly enough to be of instructional value. Further, encouraging students to share their ideas without judgment and to "own" their learning is hindered by the difficulty of creating a cohesive culture in a large group. Also, student-driven construction of ideas works best when students can progress at their own pace, a situation that can be incompatible with the lecture/lab format, in which predetermined labs can either rush or delay the development of ideas during class. Finally, constructivist-based activities depend on the collection of physical evidence, and an auditorium classroom constrains the degree to which students can investigate chemical systems. Although these are real barriers, they are not insurmountable, and we describe next how we approached them.

### *Changes to the curriculum*

First, curriculum activities were adapted to formats usable in the large-enrollment context. Materials-intensive activities were transformed into labs, and others were transformed into inquiry-based classroom activities (ICAs) to

**TABLE 1**

**Sample adaptations of open-ended questions into multiple-choice format for use with clickers and online homework.**

| Open-ended question | Multiple-choice adaptation |
|---|---|
| Draw a representation of $Na^+$ and $Cl^-$ ions surrounded by 2–4 water molecules. Pay attention to the direction the water molecules are pointing, and draw dashed lines to represent intermolecular bonds. | $Na^+$ is attracted to a water molecule because:<br>a. It wants to give or take electrons to/from the water molecule.<br>b. Na and O are on opposite sides of the periodic table.<br>c. Parts of the water molecule have partial charges that can attract the charge on $Na^+$.<br>d. Na and O want to share electrons with each other. |
| Use the Bohr model of the atom to explain why the color yellow cannot be created with a hydrogen atom. | How would the spectrum of an atom appear if its electrons were NOT restricted to particular energy levels?<br>a. It would appear the same as it does with the energy level restrictions.<br>b. There would be no frequencies within the visible portion of the spectrum.<br>c. A broad spectrum of all colors would be observed.<br>d. The frequency of the spectral lines would change with temperature. |
| When two phases are present, how does a heat transfer affect the energy of the collection of small particles of a substance? | While water is boiling at a constant temperature of 100°C, the water molecules are increasing in what kind(s) of energy?<br>a. Kinetic energy<br>b. Potential energy<br>c. Both kinetic and potential<br>d. The water particles are not increasing in any kind of energy. |

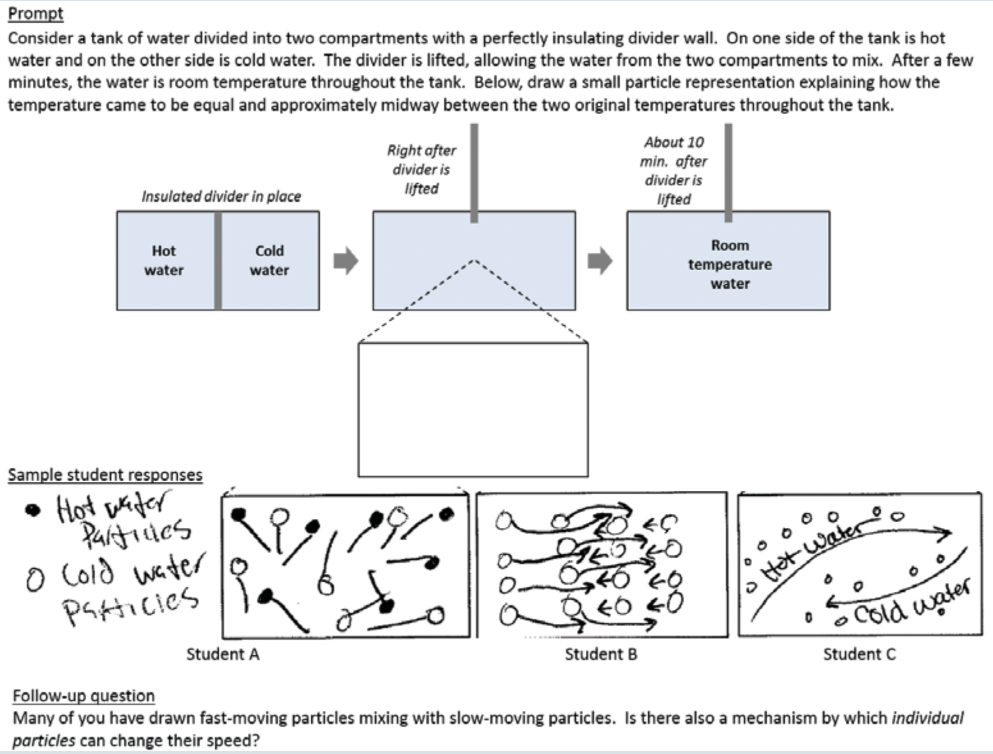
be used in the classroom. To facilitate evidence collection in the classroom, we replaced laboratory procedures with videos, live demonstrations, and/or work with simulations in ICAs. Lab sessions were sometimes used for the completion of ICAs in cases where classroom pacing was slower than expected. Labs and ICAs retained the same question structure as the original activities, guiding students to construct and reflect on their ideas.

### *Changes to pedagogy*

In the large-enrollment courses, the majority of students' time was spent working through the constructivist-based activities in small groups, arranged by combining two lab pairs. In the classroom these groups worked together on ICAs, and during labs they discussed results of investigations. Small-group work was interspersed with whole-class discussions to share initial ideas, clarify difficult points, and construct evidence-based claims. Instead of using the portable whiteboards to facilitate discussions, however, several questions were transformed into multiple-choice format to be used with clickers. This adaptation, exemplified in Table 1, works best when common student difficulties are known and can be articulated as distractors. In cases where student thinking was less accessible by multiple-choice questions, samples of student work were collected by the instructor and shared anonymously on the document camera. Figure 1 shows a question from the curriculum, samples of student work for display, and a follow-up question devised by the instructor based on these samples. In lab, prescribed check-ins (McDermott, Shaffer, & Rosenquist, 1996) replaced whiteboard discussions. During check-ins, instructors and TAs led discussions with lab groups through questions prepared during TA meetings. In both classroom and lab, the questions had two purposes: To gauge student understanding (e.g., “If all the air molecules inside a sealed syringe suddenly stopped moving, what would happen?”) and to help students construct the major concepts in the curriculum (e.g., “What creates pressure on a small particle level?”).

**FIGURE 1**

**Sample open-ended question from ChemCit, student work shown on document camera, and follow-up question based on student responses.**



Prompt

Consider a tank of water divided into two compartments with a perfectly insulating divider wall. On one side of the tank is hot water and on the other side is cold water. The divider is lifted, allowing the water from the two compartments to mix. After a few minutes, the water is room temperature throughout the tank. Below, draw a small particle representation explaining how the temperature came to be equal and approximately midway between the two original temperatures throughout the tank.

Follow-up question

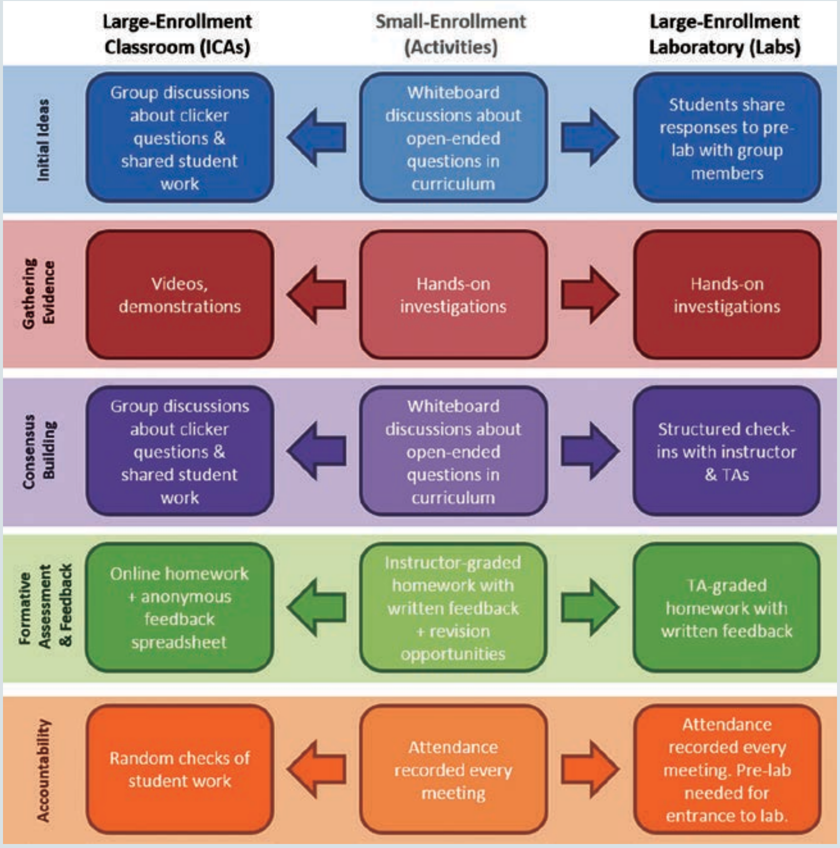
Many of you have drawn fast-moving particles mixing with slow-moving particles. Is there also a mechanism by which *individual particles* can change their speed?

To help students assess their progress and enforce completion of outside-of-class work, weekly online homework was assigned in the large-enrollment course. Because lab homework was graded by TAs, online homework was dedicated to ICAs. An anonymous spreadsheet containing responses and instructor feedback to multiple-choice and open-ended questions was posted online every week. Through unique codes, students could identify their own responses, feedback, and scores. Further, the instructor highlighted especially well-articulated responses to serve as models. An example of a highlighted response to a question asking students to use a small particle model to explain the differences between phases of matter is: “In order to take on the shape of any container, small particles of a liquid must be able to rearrange their positions with respect to each other. . . . In order to do so, they must be able to travel past each other. However, they must always be a fixed distance from one another, because the volume of a set number of water particles cannot change." This response was highlighted because it showed clear and logical connections between the behavior of small particles and macroscopic observations.

Finally, because class time was used to facilitate student construction of ideas, attendance was essential. Both the small-enrollment course and large-enrollment lab sections had strict attendance policies. In large-enrollment classroom meetings, random checks of completed work were carried out. Figure 2 summarizes the major adaptations discussed previously. We believe this process can be applied to many contexts and disciplines. For example, although our target was a 96-seat course, the same process of adapting materials to lab sections, modifying questions, sharing feedback digitally, and so forth can be applied to even larger courses (e.g. 500+). Peer leaders or learning assistants would be necessary in such cases to support group discussions. Likewise, although all the sample questions in this article focus on chemistry, open-ended questions can be converted to clicker questions in biology, physics, or geology as well. Further, it is important to emphasize that scaling can (and perhaps should) take place incrementally. Each arrow in Figure 2 represents a process that can be undertaken in isolation. For example, we began by modifying activities for the lab portion of the large-enrollment course.

**FIGURE 2**

**Summary of scaling process.**



|  | Large-Enrollment Classroom (ICAs) | Small-Enrollment (Activities) | Large-Enrollment Laboratory (Labs) |
|---|---|---|---|
| Initial Ideas | Group discussions about clicker questions & shared student work | Whiteboard discussions about open-ended questions in curriculum | Students share responses to pre-lab with group members |
| Gathering Evidence | Videos, demonstrations | Hands-on investigations | Hands-on investigations |
| Consensus Building | Group discussions about clicker questions & shared student work | Whiteboard discussions about open-ended questions in curriculum | Structured check-ins with instructor & TAs |
| Formative Assessment & Feedback | Online homework + anonymous feedback spreadsheet | Instructor-graded homework with written feedback + revision opportunities | TA-graded homework with written feedback |
| Accountability | Random checks of student work | Attendance recorded every meeting | Attendance recorded every meeting. Pre-lab needed for entrance to lab. |

## Evaluating the adaptation

To evaluate the effectiveness of our adaptation, we compared learning outcomes from several large-enrollment ChemCit (LE-ChemCit) courses with courses using the original, small-enrollment ChemCit (SE-ChemCit) curriculum. To serve as a baseline, we also included data from large-enrollment courses using a traditional lecture approach (LE-TL) prior to adaptation. For the most recent offering of LE-ChemCit in this study, the textbook (Suchocki, 2007) was made optional because of substantial additions of Scientists' Ideas readings. Results from this course, called LE-ChemCit OT ("Optional Text"), were analyzed separately. These four sets of courses (Table 2) were all taught by a single instructor (first author) and had similar content (Borda et al., 2014). We administered the Chemical Concepts Questionnaire (CCQ), a combination of previously validated instruments (Mulford & Robinson, 2002; Yezierski & Birk, 2006), at the beginning and end of each course to assess students' conceptual understanding of chemistry content. Cronbach's alpha was determined to be .78 for the instrument, suggesting good internal consistency.

### *Outcomes*

To account for course-level differences in incoming student knowledge and therefore more accurately reflect student learning in the curricula reported here, posttest scores were adjusted for pretest covariance. This was done using the following equation: $\text{post}_{\text{adj}} = \text{post}_{\text{raw}} - b(\text{pre} - \text{pre}_{\text{mean}})$, where b is the *y*-intercept of the best fit line on a posttest (*y*-axis)/pretest (*x*-axis) scatterplot. Both raw and adjusted posttest means were greater for ChemCit students than for students in traditional lecture courses (Table 2). Students in SE-ChemCit achieved the largest posttest scores, whereas those in LE-ChemCit OT had the small-

**TABLE 2**

**Mean Chemical Concepts Questionnaire scores and results from pairwise comparisons.**

| Curriculum | # courses | n (total/ sample)[a] | Pre Mean % (Std. dev.) | Raw Post Mean % (Std. dev.) | | Adjusted Post Mean % (Std. dev.) | | |
|---|---|---|---|---|---|---|---|---|
| LE-TL | 2 | 127/112 | 49 (20) | 54 (21) | | 52 (20) | $p < .001$, $d = .62$ | |
| LE-ChemCit | 3 | 238/146 | 42 (20) | 64 (20) | | 65 (20) | | |
| LE-ChemCit OT | 1 | 83/64 | 41 (16) | 59 (23) | $p = .044$, $d = .61$ | 60 (20) | | $p < .001$, $d = 1.00$ |
| SE-ChemCit | 2 | 35/29 | 45 (18) | 72 (17) | | 72 (19) | | |

[a]Total number of students in courses (no class reached the maximum enrollment of 96-LE or 24-SE)/study sample consisting of consenting students who completed all assessments. All learning outcomes are reported only for the latter students.

est scores of all ChemCit courses. Analysis of variance (ANOVA) revealed significant differences between adjusted posttest scores for the different curricula, $F(3, 344) = 13.4$, $p < .001$. Follow-up pairwise comparisons further revealed significant differences between the traditional lecture curriculum (TL-TC) and two of the three ChemCit curricula, as well as between LE-ChemCit OT and SE-ChemCit (Table 2). The reported effect sizes (Cohen's *d*) are in the moderate to large ranges (Cohen, 1988).

These learning outcomes data suggest: (a) the small-enrollment ChemCit curriculum and associated pedagogy resulted in deeper understanding of key concepts than the traditional lecture approach, but (b) the effectiveness of ChemCit in the large-enrollment context appears to have been dampened compared with the small-enrollment context. The lower post-CCQ scores for ChemCit in the large-enrollment context may be due to failure to completely overcome the barriers for implementing student-centered practices in this context. In large-enrollment courses, evidence of student learning is captured through clickers and shared student work, but it is difficult to capture all students' ideas and engage all students in follow-up discussions. Even when student thinking is represented in a detailed way on online homework, providing tailored written feedback is time-consuming, and students may not engage with that feedback. Anecdotal evidence suggests many students looked at the anonymous spreadsheets only to find their grade and did not look at other students' responses or even feedback to their own responses. This is consistent with evidence that feedback given alongside scores is often ignored (Butler, 1988).

Issues of accountability and student buy-in also arise when a curriculum relies heavily on collaborative work. Classroom norms that include valuing attendance and participation, combined with systems to enforce these, are more easily developed in contexts with fewer students. Furthermore, the scale-up described here represents adapting not only to a larger student enrollment, but also to a different student population. Preservice teachers in the small-enrollment courses might already value the student-centered approach because of their teaching perspectives and/or coursework. Thus, the dampened success of the scaling could be due in part to different knowledge or mindsets about learning.

Finally, the smaller post-CCQ scores for LE-ChemCit OT compared with LE-ChemCit suggest students in a large-enrollment, student-centered course may benefit from a textbook. We have observed it is difficult for students in this context to develop confidence in their learning, and there is a desire to check their claims against an authority source. Although large-group discussions are meant to establish consensus ideas, a textbook can serve as an additional support when true consensus cannot be achieved through classroom discussion.

## Implications and future directions

From this analysis, and from experience in teaching this course, we have constructed a set of suggestions for colleagues interested in embarking on their own scaling projects. First, personal response system software that handles open-ended questions or can facilitate "virtual whiteboarding" can enable richer sense-making discussions than multiple-choice questions alone. An instructor could presumably sift quickly through a classroom set of written or drawn responses, select a few that represent the most common ideas, and use these to guide discussion. Second, learning assistants or peer leaders can make a large class smaller by engaging all students in structured small-group discussions. This suggestion would be especially important in very large (e.g., 500+) courses. Third, feedback on homework should be given separately from scores (Butler, 1988) and be connected to graded assignments to encourage reflection on the feedback. Fourth, a well-designed textbook, used strategically, can give students a much-needed authority source against which to check their understanding.

Finally, we are reminded of the importance of continuous framing of a course. Studies suggest when pedagogy violates students' expectations, students are less likely to be satisfied with the course, even if they made significant learning gains (Gaffney, 2013). In this case, the instructor must work harder to develop a shared culture in which participation is valued and student-constructed knowledge is seen as valid. In our study, students in the large-enrollment course presumably represented a greater variety of learning orientations compared with the preservice teachers in the small-enrollment course, making framing especially urgent in the scaled course. Explicit framing, including discussions about learning, a grading system that rewards effort, and assessments emphasizing reasoning over correctness (Elby, 2001), can motivate high-quality student engagement. ■

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***Emily J. Borda*** (bordae@wwu.edu) *is an associate professor in Department of Chemistry and Science, Math, and Technology Education, and* ***Andrew Boudreaux*** *is an associate professor in the Department of Physics and Science, Math, and Technology Education, both at Western Washington University in Bellingham, Washington.* ***Ben Fackler-Adams*** *is an instructor in the Department of Science, Skagit Valley College, Mt. Vernon, Washington.* ***Paul Frazey*** *is a professor and* ***Sara Julin*** *is a professor, both in the Division of Sciences, Mathematics and Engineering at Whatcom Community College in Bellingham, Washington.* ***Gregory Pennington*** *is teacher at Mount Baker Middle School in Mount Vernon, Washington, and* ***Jared Ogle*** *is a teacher at Cedarhurst Elementary School in Burien, Washington.*