Title

A Specifications-Graded, Sports Drink-Themed General Chemistry Laboratory Course Using an Argument-Driven Inquiry Approach

Authors
Howitz, William J
Frey, Taylor
Saluga, Shannon J
et al.

Publication Date
2023

DOI
10.1021/acs.jchemed.2c00860J.Chem

Peer reviewed

A Specifications-Graded, Sports Drink-Themed General Chemistry Laboratory Course Using an Argument-Driven Inquiry Approach

William J. Howitz,[1,‡] Taylor Frey,[1,‡] Shannon J. Saluga,[1] Melanie Nguyen,[1] Kameryn Denaro[2] & Kimberly D. Edwards.[1,*]

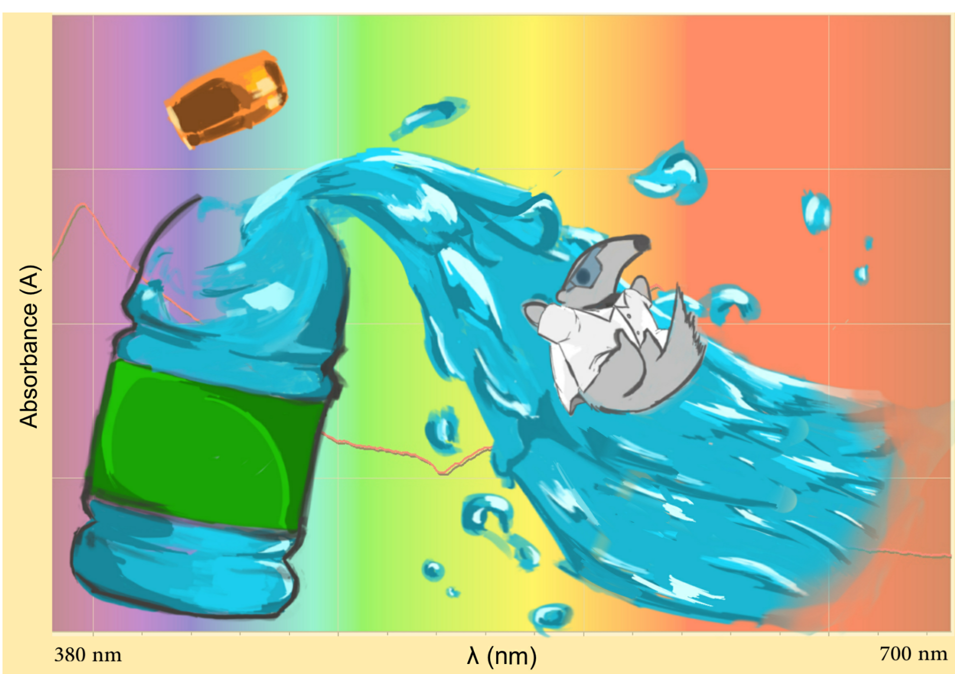
[1]Department of Chemistry, University of California—Irvine, Irvine, CA 92697, United States
[2]Division of Teaching Excellence and Innovation, University of California—Irvine, Irvine, CA 92697, United States

kdmullen@uci.edu*

Abstract:

This paper describes the creation of a theme-based first quarter, of a two quarter sequence, of general chemistry laboratory courses following an argument driven inquiry format and employing specifications grading. The course contains four, two-week projects investigating the chemistry of a popular sports drink. The sugar content, dye concentration, buffering capacity, and the kinetics of dye decomposition are investigated for various flavors of Gatorade. Specifications grading is used to foster teamwork and to provide an opportunity for revision and resubmission of student work. A modified LCAS survey measured student perception of course content.

Graphical Abstract



Keywords
Undergraduate / General, Laboratory Instruction, Curriculum, Problem Solving / Decision Making, Collaborative/Cooperative Learning, Inquiry-Based/Discovery Learning

Introduction

A traditional approach to instructing general chemistry laboratory courses requires students to verify known scientific principles through experiments that provide a diverse, but often disconnected, review of lecture topics. While this approach exposes students to laboratory techniques and hones their data analysis skills, it is ineffective at developing science process skills or improving student attitudes toward the subject matter.[1,2] A guided inquiry approach to laboratory instruction is an improvement over a traditional one because students have the opportunity to investigate a problem by developing and testing out their own solutions.[3] Adding argumentation — a chance for students to share and constructively critique claims, evidence, and justifications with each other — improves the guided inquiry model with sense-making. Sense-making is the process by which people use communication and contextualization to rationalize their world. Laboratory experiments incorporating argumentation allow students to develop sense-making by proposing and defending scientific ideas with peers. Furthermore, the social creation of a scientific argument provides a way for students to determine the argument's veracity by evaluating differing ideas from other individuals or groups.[4-6] This approach, called argument-driven inquiry (ADI), has seven steps:[7]

1. Teams of students are introduced to a task and given a research question.
2. Each team designs a procedure to address the research question and collects data following that procedure.
3. Each team analyzes data to find evidence to propose and justify a claim (which answers the research question).
4. Each team then presents their findings to other teams in an argumentation session.
5. Each student writes a report based on the findings.
6. Each student participates in an anonymous peer review of other students' reports.
7. Each student then revises their report to reflect the comments of their peers and submits it to the instructor for final evaluation.

Steps two, three, and four differ substantially from traditional expository lab settings as they require the students to apply higher order cognitive skills such as designing a procedure, analyzing and evaluating results, and proposing an answer to a research question. Students who take laboratory courses taught using ADI show a more positive attitude toward science and demonstrate increased conceptual understanding, critical thinking, and scientific processing skills than those who took a more traditional expository course.[2,8] Furthermore, because students work in teams and share resources, they build important interpersonal skills needed to constructively engage in discussions of scientific issues.[9] When compared to a traditional expository lab courses, students in ADI courses made significant gains in science content knowledge, the ability to plan and conduct experiments and scientific writing.[10,11] A growing number of laboratory courses using the ADI approach have been developed including high school chemistry, general chemistry, organic chemistry, and physical chemistry.[2,7,8,12-16]

Herein, we describe the adaptation of a thematically connected, ADI approach to laboratory instruction for a large-scale general chemistry laboratory course at the University of California at Irvine (UCI). UCI operates on the quarter system with three, 10-week terms. Non-chemistry majors (predominantly biological sciences, public health, pharmaceutical sciences, and engineering majors) take the chemistry laboratory courses in quarters offset from the lecture courses (Table 1). Laboratory sections meet weekly for 3 hours and 50 minutes and each section serves 24 students supervised by one graduate student teaching assistant (GTA). During the on-sequence course offerings, more than 50 laboratory sections serve 1300+ students each week. The off-sequence course offerings typically serve approximately 150 students with 6 laboratory sections. Typically, students who do not pass the on-sequence General Chemistry Lecture 1 during the fall quarter must follow the off-sequence track.

Table 1: Structure of On-Sequence and Off-sequence General Chemistry Courses

Year	Fall Quarter	Winter Quarter	Spring Quarter
First Year On-Sequence	General Chemistry Lecture I *& No Laboratory Course*	General Chemistry Lecture II *& No Laboratory Course*	General Chemistry Lecture III & **General Chemistry Laboratory I (GCL-I)**
First Year Off-Sequence		General Chemistry Lecture I *& No Laboratory Course*	General Chemistry Lecture II *& No Laboratory Course*
Second Year On-Sequence	Organic Chemistry Lecture I & **General Chemistry Laboratory II (GCL-II)**		
Second Year Off-Sequence	General Chemistry Lecture III & **General Chemistry Laboratory I (GCL-I)**	No Lecture Course & **General Chemistry Laboratory II (GCL-II)**	Organic Chemistry Lecture I *& No Laboratory Course*

Before the adoption of the new course content, the General Chemistry Laboratory I (GCL-I) course contained eight traditional expository-type experiments which addressed a diverse list of topics derived from the corequisite lecture course (e.g., equilibrium, computational chemistry, thermodynamics, buffers, kinetics, and electrochemistry). During the laboratory, students worked in pairs to complete the procedures outlined in the laboratory manual. After completing experimentation, each student worked independently to answer a series of post-laboratory questions requiring students to perform calculations with their collected data.

Instead of the traditional, broad expository coverage of topics, the new course is structured around four Gatorade-themed projects: determining the concentration of sugar in Gatorade, using visible spectroscopy to determine the concentration of dye(s) in Gatorade, measuring the buffer capacity of Gatorade with titration, and determining the kinetics of the degradation of dyes commonly found in Gatorade.[17-21] We chose theme-based instruction because it provides a conceptual framework that increases student perception of their own understanding and their actual assessed comprehensive understanding.[22-26] In addition, it incorporates connections between experiments to make the content more relevant to the students, increasing their engagement and motivation.[23,24,27] Multiple examples of general chemistry laboratory courses with themes can be found in the literature.[28-33]

In conjunction with theme-based instruction, we converted GCL-I's four projects into ADI experiments in the hope of improving students' conceptual understanding of course content and ability to use evidence to justify conclusions.[8] Similar to the processes reported by other ADI practitioners, each of our projects takes place over two laboratory sessions (two weeks). During the first session, a team of three to four students is given a foundational activity requiring the students to practice new laboratory methods or techniques. Before the end of this first session, the team uses knowledge obtained during the foundational activity to plan an experiment aimed at answering a provided research question. During the second session, the team collects and analyzes data to find evidence which answers the research question. At the end of this session, each team presents their claim (their answer to the research question), evidence, and justification in an academic poster session, referred to as an argumentation session. In this student-led argumentation session, members from different teams discuss the validity of evidence and the accuracy of claims with each other. Working in teams allows students to practice the argumentation process which shapes and communicates scientific understanding. Research indicates students learn more when they engage with the ideas and challenges from other students.[4-6] Students complete a laboratory report based on their findings before the start of the next project.

While the approach of Walker, et al, incorporates a peer review process for the laboratory reports, we did not include this process in our course because we adopted a specifications grading system.[7] Specifications grading is an alternative grading system, first popularized by Linda Nilson in her 2014 book, "Specifications Grading: Restoring Rigor, Motivating Students, and Saving Faculty Time".[34] Under this grading system, students earn their letter grade by completing instructor-specified bundles of assignments. These assignments are commonly assessed as satisfactory or unsatisfactory using rubrics in which students must meet set criteria which define a passing threshold. Consequently, there is no partial credit. However, students are eligible to revise and resubmit assignments assessed as unsatisfactory, often in exchange for tokens. Because the number of tokens available to students is limited, this limits the number of assignments students may revise and resubmit. The token-driven feedback from GTAs in our course provides an alternative to the peer feedback process used by Walker et al.[7]

ADI Implementation and Laboratory Course Objectives

Our primary motivation for redeveloping the curriculum for the general chemistry laboratory series was to increase student engagement and interpersonal interactions, especially in the wake of the COVID-19 pandemic. The ADI approach was especially appealing because it actively promotes student communication and collaboration as well as peer-to-peer learning from student-led argumentation. We also felt the ADI format aligned well with the course learning outcomes (Table 2).

Table 2. GCL-I Learning Outcomes (LOs)
Students will be able to:
LO1: Engage in experimental design, scientific argumentation and writing and revision.
LO2: Interpret experimental data and calculated results to develop scientifically sound conclusions.
LO3: Proficiently use an electronic laboratory notebook to record qualitative observations in detail and quantitative data with the correct significant figures.
LO4: Utilize a variety of laboratory glassware (beakers, flasks, pipets, and burets) and correctly use a digital balance to mass samples.
LO5: Operate a simple visible spectrometer to acquire absorbance measurements.
LO6: Demonstrate basic understanding of safety symbols, safety data sheets, corrosives, handling chemical waste, fire and chemical spill response.

During the redeveloped GCL-I course, a team of three to four students work together on four ADI projects. The GTA randomly assigns students to teams during the first project and the teams stay together throughout the course. Each project spans two laboratory sessions, which are referred to as the fundamental skills session and the original investigation session. The activities or tasks of both laboratory sessions are initiated with separate guiding questions (Table 3). Answering the guiding question of the fundamental skills session is required to engage in the original investigation session. Not only does the fundamental skills session serve as training experience, it also provides foundational knowledge, as well as data and results for the original investigation session the next week. The understanding and evidence compiled during the two sessions are combined to form the team's poster and each individual's summative laboratory report for each project. Active student participation in lab and the completion of course assignments fulfills the first learning outcome (LO1). This learning outcome is intentionally broadly inclusive and overlaps with the remaining more specific learning outcomes (which are discussed individually below). As the students proceed through the quarter, each project increases in complexity and it is expected that students are applying concepts and skills learned earlier in the quarter to later projects. For example, the solution preparation skills and visible spectroscopy concepts learned during the first two projects are expected knowledge for the last two projects.

Table 3. Guiding Questions for GCL-I

Project	Fundamental Skills	Original Investigation
1	What glassware provides the most precise data for the calibration curve? Students create aqueous sucrose solutions of known concentration to create a density calibration curve with four different pieces of glassware.	Is the mass of sugar in Gatorade comparable to what is listed on the nutrition label provided by the manufacturer? In other words, which glassware gave the most accurate result (the smallest percent error)? Students use their calibration curve to answer the guiding question.
2	What is your dilution plan for creating standard dye solutions and how are these standard solutions used to create a Beer's Law Plot? Students dilute aqueous dye solutions to known concentrations to create a Beer's Law plot.	What dye or combination of dyes is present in your Gatorade sample and what is/are the concentration(s)? Students use their Beer's Law plot to answer the guiding question.
3	How well does the Henderson - Hasselbach equation predict the pH of acetic acid / acetate and ammonia / ammonium buffer solutions? What is the buffer capacity of these solutions? Students create and titrate buffer solutions.	Which titrant and what concentration is appropriate for a sufficient data set? What is the buffer capacity and HA/A^- or B^-/HB ratio of your Gatorade sample? Students use titration to determine the buffering capacity of Gatorade.

4	What are the optimal conditions to observe the kinetics of the crystal violet hydroxylation? What is the reaction order of crystal violet? Students use absorbance spectroscopy to determine optimal concentrations and reaction order.	What are the optimal conditions to observe the kinetics of the bleaching of your chosen dye? What is the reaction order of that dye? Students use dilution and visible spectroscopy to determine the reaction order of a dye in Gatorade.

Before the fundamental skills session each student individually completes a pre-laboratory quiz through the course learning management system (LMS). These quizzes include safety, conceptual, procedural, and calculation questions. The questions are based on short instructor videos, expository laboratory manual instructions, and information about laboratory techniques which are hyperlinked into the laboratory manual. The student is then required to provide an objective, chemical and safety tables, and a draft of expected procedures in their electronic laboratory notebook (ELN) before entering the laboratory (LO3).

At the beginning of the fundamental skills session, the GTA leads the students in their laboratory section in an interactive safety moment activity connected to the pre-laboratory safety reading and quiz (LO6).[35] The GTA then provides a brief demonstration of instrumentation or glassware set up which is central to the session's procedures. Students work with their team during this session to learn techniques, concepts, and calculations that will help them with their original investigation (LO4, LO5). Though working in a team, each student has a set task to accomplish that answers one part of the guiding question and can use the laboratory manual, their peers, and the GTA for additional assistance if necessary. At the end of the fundamental skills session, students share their individual findings with their teammates and, collectively, the team then analyzes the data and answers the fundamental skills guiding question (LO2). Students enter or attach their work to a scaffolded ELN page. The team then reviews the original investigation guiding question and creates an outline of an experimental procedure for the next laboratory session, the original investigation session.

Before the original investigation session, each student individually completes a second pre-laboratory quiz which includes questions related to the assigned safety reading and requires them to summarize information from the fundamental skills session, evaluate sample claims, evidence, and justification, and use a computational chemistry program to better understand chemical behavior. Each student must independently provide an objective and a draft of expected procedures (which was outlined by the team at the end of the last laboratory session) in their ELN before entering the laboratory. During the laboratory session, the team revises their procedure as they perform experimentation, make observations, perform calculations and/or create relevant graphs, and analyze data to propose an answer to the original investigation guiding question. All work is recorded in the ELN.

The original investigation session finishes with a student-led argumentation session. The expectation for the argumentation session is that each team of students will create a poster with three main components: claim, evidence, and justification (Figure 1). The claim is typically the team's answer to the guiding questions for the original investigation session. For example, if the original investigation guiding question is to determine the identity and concentration of the dye in Gatorade, then the team would make a claim stating "The dye in the orange Gatorade is Yellow-6. The concentration of the dye is 79.7 µM." Next, the team would provide any evidence that supports their claim, which could include calibration curves, spectra, calculations, error analysis, etc. Lastly, the team would craft a justification section, linking the evidence to their claim. This section allows the students to explain how their evidence supports their claim by using scientific concepts and theory (LO1, LO2). While "correct" answers (or claims) to the original investigation guiding question exist, the team or student does not need to arrive at one of these answers. Furthermore, a variety of procedural approaches and potential answers to an original investigation guiding question encourages more discussion during the argumentation session. As the quarter proceeds, the complexity of each project increases, leading to even more varied approaches during the original investigation session.

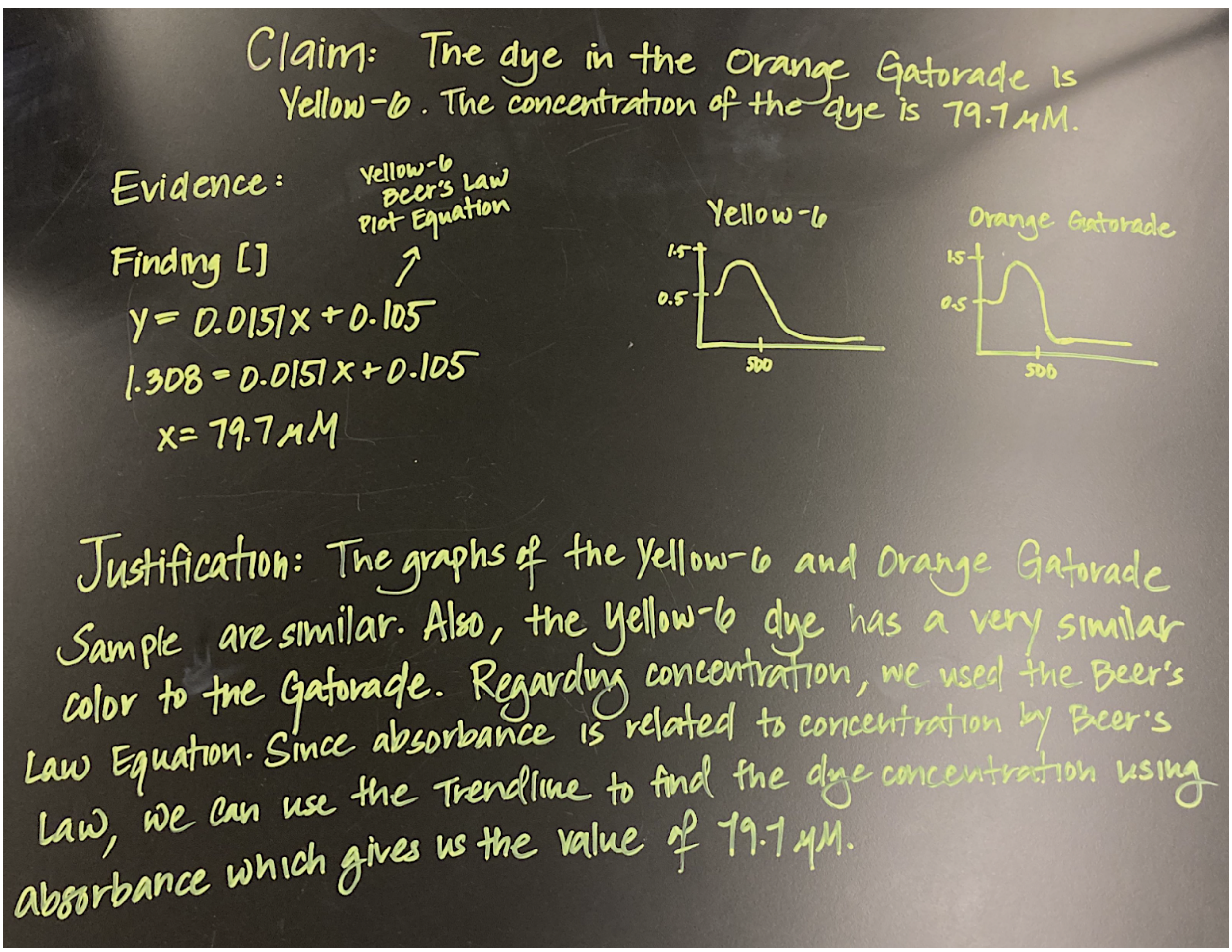


Figure 1. Benchtop Poster from Project 2. Students create their poster on the laboratory benchtop with chalkboard markers and then present their poster which engages the students in scientific argumentation. *Other poster examples provided in SI.*

At the beginning of the argumentation session, the team splits up. One student, the team leader, stays next to the poster to answer questions from other teams. The remaining students, the travelers, visit other teams' posters as a group and ask questions. Students are encouraged to ask their own questions to each team, but if conversation is lacking, a set of questions is available to stimulate discussion (see SI for examples). After this session, the team reconvenes to critique their own poster in light of any new understandings discovered from the posters of, and discussions with, the other teams. The team is able to then determine if a new claim is justified or, if time permitting, more data needs to be collected.

After the entire project is completed, students individually write a formal laboratory report describing their conceptual, experimental, and analytical understanding of the original investigation process (which may include pertinent fundamental skills information) and the content of their team's poster (their claim, evidence, and justification). Students who change their claim after the argumentation session are encouraged to include further justification and an error analysis if warranted. A summary of the responsibilities of the student versus the team at each stage of the process are included in Table 4.

Table 4: Summary of Individual versus Team Responsibilities throughout the ADI Process

Section of the ADI Process	Individual Duties	Team Duties
Before Fundamental Skills Laboratory Session	Completes a pre-laboratory quiz. Drafts an objective, chemical and safety tables, and procedures in their ELN.	None.
During Fundamental Skills Laboratory Session	Participates in the safety moment activity. Completes a designated task while the other members of the team complete their own designated tasks. Submits laboratory notebook pages at the end of the session.	Analyzes the data from each member of the team and answers the fundamental skills guiding question. Drafts an outline of an experimental procedure in preparation for the original investigation laboratory session.
Before Original Investigation Laboratory Session	Completes a pre-laboratory quiz. Drafts an objective and detailed procedure based on the outline drafted with their team at the end of the fundamental skills laboratory session.	None.

During Original Investigation Laboratory Session	Submits laboratory notebook pages at the end of the session.	Performs experimentation, makes observations, performs calculations and/or creates relevant graphs, and analyzes data to propose an answer to the original investigation guiding question. Revises the procedure as needed. Creates a poster. Participates in an argumentation session.
After Original Investigation Laboratory Session	Writes a formal laboratory report.	None.

Final Exam

A final exam is given during the last full week of instruction (either ninth or tenth week of the quarter). The two hour exam covers safety, technique, and argumentation topics. The safety portion consists of selected questions from the pre-laboratory quizzes and is delivered through the course LMS with a lockdown browser. This portion of the exam is given during the first 30 minutes of the practical session. Students spend the remaining exam time working on a packet containing two technique questions and two argumentation questions. All four of the ADI projects are represented between the two question types. Students must answer one technique question and one argumentation question. The ability to choose which question to answer is intentionally introduced to reduce student anxiety.[36,37] Technique questions require students to assemble a set of glassware or equipment in the laboratory and collect and analyze a small set of data to display their technique knowledge. Argumentation questions provide a set of data which must be analyzed to identify evidence that will be used to create and justify a claim. An assessment of student performance on argumentation is ongoing and will be evaluated in subsequent laboratory courses.

The Role of Instructional Staff in the Laboratory

Each laboratory section is run by one GTA and at least one undergraduate learning assistant (ULA). Most GTAs are first year graduate students who have received a week-long general GTA training before their first quarter of graduate school. Former GCL-I students who did well in the course are invited to apply to be ULAs in subsequent quarters. Once selected by the instructor, incoming ULAs take a learning assistance certification course. ULAs are primarily used to support the GTAs, but do not grade any student work.

Because few, if any, of our GTAs and ULAs have prior teaching experience in laboratory courses using an ADI approach, we developed a three hour ADI-specific training session that they take at the start of the quarter to prepare them for their roles in GCL-I. This training starts with a brief lecture introducing the basic ideas of ADI instruction. Then sample data from one of the course's projects is provided for teams of GTAs and ULAs to analyze from which they develop a poster displaying their claim, evidence, and justification. The GTAs and ULAs subsequently engage in an argumentation session as previously described so they know what to expect during the original investigation sessions.

The role of the GTA and the ULA differs in each laboratory session. During the fundamental skills session, GTAs and ULAs demonstrate techniques and answer most student questions directly. The only prohibition given to them is that they cannot answer the fundamental skills guiding question for the students. During the original investigation session, they are instructed to act as facilitators. They ask leading and redirecting questions prompting peer-to-peer interaction. They are also instructed not to interfere unless directly addressed. We intentionally trained our GTAs and ULAs in this fashion as the intention of ADI is for students to develop their own process, ask their peers questions, and engage in lively conversations about the experiments. Thus, GTAs and ULAs take a backseat role while most of the argumentation is student-led.

Specifications Grading

Students must pass a set number of assignments in each category (bundle) to earn a specific grade (Table 5). All assignments in GCL-I were evaluated using the specifications grading system. These assignments included laboratory notebook assignments associated with the fundamental skills and original investigation sessions, and laboratory reports for each project. Each assignment was assessed as satisfactory or unsatisfactory depending on the number of rubric criteria a student met relative to the instructor-defined passing threshold. Most of the course rubrics have between 10 and 15 criteria. The passing threshold for the laboratory notebook assignments is set near 80% of the rubric items, as recommended by Nilson.[31] The laboratory reports were assessed as satisfactory with either a high-passing or low-passing threshold, specified by 80% or 60% of the rubric items respectively. We implemented this high-pass and low-pass system in order to differentiate students' grades. Students under this system must pass the majority of assignments to earn grades above a C. We have so few assignments during the quarter that we needed to make students accountable for the majority of assignments. Rubrics are designed so that assignments of the same type often use very similar or identical language and rubric criteria (such as those for observations, data analysis and justification). Each assignment rubric and associated passing threshold are posted on the LMS for students to view. Letter grade requirements are also posted in the syllabus on the course LMS (Table 5).

Table 5. Letter Grade Requirements For GCL-I Course Using Specifications Grading.

Assessment	Minimum to Earn D[a]	Minimum to Earn C	Minimum to Earn B	Minimum to Earn A[b,c]
Fundamental Skills Laboratory Notebook Assignments	Pass 2	Pass 3	Pass 3	Pass 4
Original Investigation Laboratory Notebook Assignments	Pass 2	Pass 2	Pass 3	Pass 4
Post Laboratory Reports	High Pass 1 & Low Pass 1 OR Low Pass 3	High Pass 1 & Low Pass 2 OR Low Pass 4	High Pass 2 & Low Pass 1 OR High Pass 1 & Low Pass 3	High Pass 3 OR High Pass 2 & Low Pass 2
Final Exam Components: Safety Knowledge, Technique, Argumentation	Pass 1	Pass 2	Pass 2	Pass 3

[a]Students who do not meet the minimum criteria for D grade earn an F in the course.
[b]Our institution does use plus and minus grades, and our course has set criteria for students to achieve these grades. To earn a plus grade, students must meet the criteria for the letter grade above and also earn at least 80% on prelaboratory quizzes. To earn a minus grade, students must meet the criteria for the letter grade above and also earn less than 65% on prelaboratory quizzes.
[c]To earn an A+ requires earning a High Pass on all four postlaboratory reports and earning at least 95% on prelaboratory quizzes.

Students have the ability to earn up to six tokens throughout the quarter. One token can be used to revise and resubmit an assignment that was assessed as unsatisfactory or three tokens can be used to attend a makeup laboratory section in the case of an unexcused absence. The first three tokens are earned by completing introductory course assignments. These include quizzes assessing foundational chemistry knowledge, specifications grading and ADI information, and academic integrity and laboratory safety understanding. Additional tokens are earned for completing surveys for education studies and mid-quarter GTA evaluations.

Peer cooperation is essential to the ADI process, therefore, competitive grading processes may work against full student participation. Specifications grading emphasizes attaining competency in specific areas, encouraging students to work collaboratively together and learn from each other. The students' ability to use tokens for review and resubmission is a substitute for the ADI peer review step. Students are able to leverage token use for the revision of up to half of the assignments in the course with the benefit of TA grading and feedback. Because of the short time scale of the quarter system in conjunction with insufficient LMS peer grading tools for a large enrollment multi-section laboratory course, peer review was not possible for GCL-1.

Laboratory Course Assessment Survey

A modified version of the **Laboratory Course Assessment Survey** (LCAS) was given to GCL-I students near the end of the quarter while students were engaged in the fourth and final project.[38] LCAS is a 17-item survey designed to measure the effectiveness of course-based undergraduate research experiences (CUREs). It contains three sections by assessing student perception of collaboration with peers, generation of new knowledge, and work revision and repetition. We chose to use the LCAS tool because, in addition to the above mentioned activities, it also measures student perception of the course activities central to the ADI process: experimental design, data collection and analysis and engaging in argumentation.

The GCL-I course was first piloted during the off-sequence GCL-I offered during the fall quarter of 2021 with an enrollment of 99 students and then offered on-sequence during the spring quarter of 2022 with an enrollment of 1225 students (see Table 1). The breakdown of the most affected student demographics is provided in Table 6.

Table 6. GCL-I Student Demographics

Quarter	**Fall 2021**	**Spring 2022**
Enrollment	99	1225
Number of G-TAs	3	28
Biological Sciences Majors	16%	54%
Undeclared/Unaffiliated Students	26%	12%
First Generation College Students	52%	32%
Low income Students	39%	30%
International Students	10%	7%

The averages and standard deviations for each LCAS prompt are provided in Table 7. For the large enrollment spring quarter course, there are a few notable results. The team structure of the ADI approach resulted in more than 75% of the respondents choosing that every survey item happened weekly in the collaboration section (C1-C6). For two of the discovery and relevance statements approximately 80% of respondents somewhat agree or strongly agree that they are expected to formulate a hypothesis & develop new data-based arguments during the course (D3 & D4). This result is indicative that the students connected with the central aspects of the ADI process in the GCL-I curriculum: answering of the guiding question and the justification of how the data collected is evidence for their claim (i.e, the formation of a scientific argument). The result from the discovery and relevance section which the students disagreed with more than any other is the statement: “In this course, I was expected to generate novel results that are unknown to the instructor that could be of interest to the broader scientific community or others outside of class” (D1). This result is reasonable for the first college chemistry course taken by nonmajors and is most likely connected to the thematic nature of the course. The students are familiar with the overarching theme of the course (the chemistry of Gatorade) and, therefore, would not be as likely to perceive the science as novel. A clear indication of the team-based inquiry nature of the GCL-I course is evident in the response to the third statement in the iteration section. The majority of students (86%) either somewhat agreed or strongly agreed with the statement that they were expected to “share and compare data with other students” (I3). The statements in the iteration section which students disagreed with the most are that they were expected to “revise/repeat work to fix errors” and “change the methods of investigation” (I1,I2). These results are most likely due to the more expository structure of the fundamental skills sessions and the limited knowledge that first quarter general chemistry laboratory students have of laboratory methods and techniques. Our hope is that as students learn more laboratory methods and techniques in the second quarter general chemistry laboratory course (GCL-II), they will employ more than one strategy to achieve their experimental goals. We will track changes in this outcome using the same LCAS survey used in GCL-I.

Table 7. Modified LCAS Results for GCL-I

Quarter (Enrollment)	F21 (99)		S22 (1224)	
	Avg	*SD*	Avg	*SD*
Collaboration	22.8	*0.6*	22.1	*0.6*
C1. Discuss elements of my investigation with classmates and instructors	3.9	*0.5*	3.8	*0.8*
C2. Reflect on what I was learning	3.8	*0.7*	3.6	*0.8*
C3. Contribute my ideas and suggestions during class discussions	3.9	*0.5*	3.6	*0.7*
C4. Help other students collect or analyze data	3.9	*0.5*	3.7	*0.7*
C5. Provide constructive criticism and challenge each other’s interpretations	3.7	*0.6*	3.7	*0.6*
C6. Share the problems and seek input on how to address them	3.8	*0.5*	3.7	*0.7*
Discovery / Relevance	19.7	*1.0*	18.4	*0.9*
D1. Generate novel results that could be of interest the community	3.2	*1.2*	3.0	*1.2*
D2. Conduct an investigation to find something previously unknown	3.9	*1.1*	3.6	*1.1*
D3. Formulate my own research question or hypothesis to guide an investigation	4.1	*0.9*	4.0	*1.0*
D4. Develop new arguments based on data	4.4	*0.8*	4.1	*1.0*

D5. Explain how my work has resulted in new scientific knowledge	4.2	*1.0*	3.8	*0.9*
Iteration	24.0	*1.1*	20.9	*1.0*
I1. Revise and repeat work to account for errors or fix problems	3.9	*1.1*	3.2	*1.3*
I2. Change methods of investigation if it was not unfolding as predicted	3.7	*1.2*	3.1	*0.9*
I3. Share and compare data with other students	4.5	*0.9*	4.0	*1.0*
I4. Collect and analyze additional data to address new questions	3.9	*1.2*	4.1	*1.0*
I5. Revise and repeat analyses based on feedback	4.0	*1.2*	4.1	*1.0*
I6. Revise drafts of papers or presentations based on feedback	4.0	*1.2*	3.5	*1.0*

Collaboration was measured on a four point scale: weekly (4), monthly (3), 1 or 2 times (2) and never (1). Discovery / Relevance and Iteration were modified from a six point to a five point scale: (5) strongly agree, (4) somewhat agree, (3) neither, (2) somewhat disagree and (1) strongly disagree.

Substantial differences were found in survey responses when comparing the smaller enrollment fall offering of GCL-I to larger enrollment spring offering of GCL-I. The values for the collaboration & discovery sections both were slightly lower for the spring GCL-I, with the largest deficit occurring with the statement, "In this course I was expected to explain how work has resulted in new scientific knowledge" (D5). Students also disagreed more with the statements in the iteration section during the large enrollment spring GCL-I course. The only two statements to receive comparable agreement levels during both the fall and spring courses were the expectations to "collect and analyze additional data to address new questions" (I4) and "revise and repeat analyses based on feedback" (I5). The notable differences between the two courses are:

- the lower percentage of first generation students in the the spring (32%) versus fall (52%)
- the higher percentage of biology majors in the the spring (54%) versus fall (16%)
- the lower percentage of unaffiliated / undeclared majors in the spring (12%) versus the fall (26%)
- the larger enrollment & number of GTAs in the spring (1225 students, 28 GTAs) versus the fall (99 students, 3 GTAs)

The potential roles played by student demographics and GTA numbers (and training) warrant further investigation.

Summary, Lessons Learned and Future Implementation

The ADI-driven GCL-I theme-based format incorporates a structured review of fundamental concepts with a hands-on application of new concepts. The thematic connection offers a conceptual framework connecting projects and increasing the relevance of the content covered. Furthermore, the iterative application of methods and skills from previous projects gives student teams increasing responsibility and freedom to collaboratively develop experimental design skills.

Specifications grading supports ADI because it is not a competitive grading system. This fosters collaboration within and between teams. Assignment revision and focus on specific repeated important rubric criteria encourages students to take an iterative approach to course material. It should also be noted, that while specifications grading has grown in popularity, especially in STEM over the past 5-6 years, most of the published examples to date have been in lecture courses. In fact, the only published example of a laboratory-only course served as the inspiration for the design of the system used in this course.[39]

The modified LCAS results indicate that the GCL-I course results in varying amounts of student engagement in scientific inquiry, practices, and the collaborative and iterative nature of science. The results also reveal a difference in student perception of the course that may be connected with course size and student demographics.

Despite a challenging return to in-person instruction after a pandemic-induced year long remote setting, both the students and instructional team felt the endeavor was a success. The positive student response to our redeveloped ADI laboratory experience will help to inform the creation and implementation of additional general chemistry laboratory courses, specifically the implementation in the second quarter of the general chemistry laboratory series. Future courses, currently in the early stages of implementation and development, will retain the same overall structure, scaffolded approach, and active engagement.

Acknowledgments

We thank the University of California, Irvine Chemistry department for their support and resources during this endeavor. A chapter of doctoral thesis work of Taylor Frey, one of the primary authors, is a significant source for this article.[40] We also thank our GTAs, Yong Li, Jordan Castro and Lauren Anderson-Sanchez, and our ULAs, Christine Wei, Justin Kwon, Andrea Alba, and Ana-Teresa Mendoza, for their contributions to the General Chemistry ADI development team and their students for adapting quickly and professionally to the unfamiliar ADI environment. Without their help, this transition to argument driven laboratories would be impossible. Special thanks to Andy Thach for graphical abstract art.

Associated Content

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this URL in.]

IRB Statement, Project Manual Links, Survey Questions, Posters, Questions to Stimulate Argumentation Discussion, Sample Quiz and Exam Questions, Gradescope Use and Token Accounting with Canvas

[Brief statement in nonsentence format listing the contents of the material supplied as Supporting Information.]

References

1. Domin, D. A Review Of Laboratory Instruction Styles. *J. Chem. Educ.* **1999**, *76* (4), 543.
2. Hakkikadayifci, Ayseyalcin-Celik. Implementation of Argument-Driven Inquiry as An Instructional Model in A General Chemistry Laboratory Course. *Science Education Journal* **2016**, *27* (3), 369-390.
3. Abraham, M. What Can Be Learned From Laboratory Activities? Revisiting 32 Years Of Research. *J. Chem.l Educ.* **2011**, *88* (8), 1020-1025.
4. Sampson, V.; Grooms, J.; Walker, J. Argument-Driven Inquiry As A Way To Help Students Learn How To Participate In Scientific Argumentation And Craft Written Arguments: An Exploratory Study. *Science Education* **2010**, *95* (2), 217-257.
5. Linn, M. C., & Eylon, B.-S. Science Education: Integrating Views of Learning and Instruction. *Handbook of Educational Psychology* **2006**, 511–544.
6. Duschl, R. A.; Schweingruber, H. A.; Shouse, A. W. *Taking science to school: Learning and teaching science in grades K-8*; National Academies Press: Washington, D.C., **2007**.
7. Walker, J.; Sampson, V.; Zimmerman, C. Argument-Driven Inquiry: An Introduction To A New Instructional Model For Use In Undergraduate Chemistry Labs. *J. Chem.l Educ.* **2011**, *88* (8), 1048-1056.
8. Sampson, V.; Enderle, P.; Walker, J. The development and validation of the assessment of scientific argumentation in the classroom (ASAC) observation protocol: A tool for evaluating how students participate in scientific argumentation. *Perspectives on Scientific Argumentation*. **2012**, *2315*, 235-264.
9. Grooms, J. A Comparison Of Argument Quality And Students' Conceptions Of Data And Evidence For Undergraduates Experiencing Two Types Of Laboratory Instruction. *J. Chem. Educ.* **2020**, *97* (8), 2057-2064.
10. Walker, J. P.; Sampson, V.; Southerland, S.; Enderle, P. J. Using the Laboratory to Engage All Students in Science Practices. *Chemistry Education Research and Practice* **2016**, *17* (4), 1098–1113.
11. Grooms, J.; Enderle, P. J., Sampson, V. Coordinating Scientific Argumentation and the Next Generation Science Standards through Argument Driven Inquiry. *Science Educator* **2015**, *24* (1), 45–50.
12. Walker, J.; Sampson, V.; Zimmerman, C.; Grooms, J. A Performance-Based Assessment For Limiting Reactants. *J. Chem. Educ.* **2011**, *88* (9), 1243-1246.
13. Choi, A.; Hand, B.; Greenbowe, T. Students' Written Arguments In General Chemistry Laboratory Investigations. *Research in Science Education* **2012**, *43* (5), 1763-1783.
14. Stanford, C.; Moon, A.; Towns, M.; Cole, R. Analysis Of Instructor Facilitation Strategies And Their Influences On Student Argumentation: A Case Study Of A Process Oriented Guided Inquiry Learning Physical Chemistry Classroom. *J. Chem. Educ.* **2016**, *93* (9), 1501-1513.
15. Petritis, S.; Kelley, C.; Talanquer, V. Exploring The Impact Of The Framing Of A Laboratory Experiment On The Nature Of Student Argumentation. *Chemistry Education Research and Practice* **2021**, *22* (1), 105-121.
16. Çetin, P.; Eymur, G. Developing Students' Scientific Writing And Presentation Skills Through Argument Driven Inquiry: An Exploratory Study. *J. Chem. Educ.* **2017**, *94* (7), 837-843.
17. Henderson, S.; Fenn, C.; Domijan, J. Determination Of Sugar Content In Commercial Beverages By Density: A Novel Experiment For General Chemistry Courses. *J. Chem. Educ.* **1998**, *75* (9), 1122.

18. Sigmann, S.; Wheeler, D. The Quantitative Determination Of Food Dyes In Powdered Drink Mixes. A High School Or General Science Experiment. *J. Chem. Educ.* **2004**, *81* (10), 1475.
19. Mandel, N.; Le, B.; Ward, R.; Hansen, S.; Ulichny, J. Titrating Consumer Acids To Uncover Student Understanding: A Laboratory Investigation Leading To Data-Driven Instructional Interventions. *J. Chem. Educ.* **2022**, *99* (6), 2378-2384.
20. Arce, J.; Betancourt, R.; Rivera, Y.; Pijem, J. The Reaction Of A Food Colorant With Sodium Hypochlorite: A Student-Designed Kinetics Experiment. *J. Chem. Educ.* **1998**, *75* (9), 1142.
21. Madriz, L.; Cabrerizo, F.; Vargas, R. Exploring Chemical Kinetics At Home In Times Of Pandemic: Following The Bleaching Of Food Dye Allura Red Using A Smartphone. *J. Chem. Educ.* **2021**, *98* (6), 2117-2121.
22. Froyd, J. White Paper On Promising Practices In Undergraduate STEM Education. **2008**.
23. Tessier, L.; Tessier, J. Theme-Based Courses Foster Student Learning And Promote Comfort With Learning New Material. *Journal for Learning through the Arts: A Research Journal on Arts Integration in Schools and Communities* **2015**, *11* (1).
24. Wingert, J.; Wasileski, S.; Peterson, K.; Mathews, L.; Lanou, A.; Clarke, D. Enhancing integrative experiences: Evidence of student perceptions of learning gains from cross-course interactions. *Journal of the Scholarship of Teaching and Learning***.** **2011**, *11* (3), 34–57.
25. Leber, P.; Szczerbicki, S. Theme-Based Bidisciplinary Chemistry Laboratory Modules. *J. Chem. Educ.* **1996**, *73* (12), 1130.
26. Handal, B.; Herrington, A. On Being Dependent Or Independent In Computer Based Learning Environments. *e-Journal of Instructional Science and Technology* **2004**, *7* (2).
27. Budner, D.; Simpson, B. Project-Based Integrated Lecture And Laboratory Quantitative Analysis Course. *J. Chem. Educ.* **2018**, *95* (9), 1533-1540.
28. Shultz, M.; Kelly, M.; Paritsky, L.; Wagner, J. A Theme-Based Course: Hydrogen As The Fuel Of The Future. *J. Chem. Educ.* **2009**, *86* (9), 1051.
29. Byrd, H.; Donnell, S. A General Chemistry Laboratory Theme: Spectroscopic Analysis Of Aspirin. *J. Chem. Educ.* **2003**, *80* (2), 174.
30. Bell, P. Design Of A Food Chemistry-Themed Course For Nonscience Majors. *J. Chem. Educ.* **2014**, *91* (10), 1631-1636.
31. Logan, J.; Rumbaugh, C. The Chemistry Of Perfume: A Laboratory Course For Nonscience Majors. *J. Chem. Educ.* **2012**, *89* (5), 613-619.
32. Hopkins, T.; Samide, M. Using A Thematic Laboratory-Centered Curriculum To Teach General Chemistry. *J. Chem. Educ.* **2013**, *90* (9), 1162-1166.
33. Nivens, D.; Padgett, C.; Chase, J.; Verges, K.; Jamieson, D. Art, Meet Chemistry; Chemistry, Meet Art: Case Studies, Current Literature, And Instrumental Methods Combined To Create A Hands-On Experience For Nonmajors And Instrumental Analysis Students. *J. Chem. Educ.* **2010**, *87* (10), 1089-1093.
34. Nilson, L.; Stanny, C. *Specifications Grading: restoring rigor, motivating students, and saving faculty time*, 1st ed.; Stylus Publishing, LLC: Sterling, Virginia, **2014**.
35. Hill, R.; Finster, D. *Laboratory Safety for Chemistry Students,* 2nd ed.; John Wiley & Sons, **2016**.
36. Pretorius, L.; van Mourik, G.; Barratt, C. Student Choice And Higher-Order Thinking: Using A Novel Flexible Assessment Regime Combined With Critical Thinking Activities To Encourage The Development Of Higher Order Thinking. *International Journal of Teaching and Learning in Higher Education* **2017**, *29* (2), 389-401.
37. Irwin, B.; Hepplestone, S. Examining Increased Flexibility In Assessment Formats. *Assessment & Evaluation in Higher Education* **2012**, *37* (7), 773-785.
38. Corwin, L.A.; Runyon, C.; Robinson, A.; *Dolan, E. The Laboratory Course Assessment Survey: A Tool to Measure Three Dimensions of Research-Course Design*. CBE-Life Sci. Educ. **2015**, (14), 1-11.
39. Howitz, W.; McKnelly, K.; Link, R. Developing And Implementing A Specifications Grading System In An Organic Chemistry Laboratory Course. *J. Chem. Educ.* **2020**, *98* (2), 385-394.
40. Frey, T. L.. Investigation of Nanopores Drop-Casted with Polymers of Intrinsic Microporosity as Ion Selective Systems And Curriculum Development for the General Chemistry Laboratory Series. *UC Irvine*. **2022**, ProQuest ID: Frey_uci_0030D_17842. Merritt ID: ark:/13030/m5vr0cbr. Retrieved from https://escholarship.org/uc/item/98q69803