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Creating Meaningful Learning Opportunities through Incorporating Local Research into Chemistry Classroom Activities

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Abstract: Incorporating real-life context through connections to research early in the curriculum can create meaningful learning opportunities that encourage students to engage deeply with classroom content to construct chemistry knowledge. Course-based undergraduate research experiences have been successful at integrating real-life context, but are often only incorporated into upper-level courses. To provide an additional pathway to foster interaction with research, four activities from an introductory chemistry discussion class were created to incorporate authentic research connections. Care was taken to incorporate metacognitive questions designed to help students make connections between their preexisting knowledge and course content. Marzano's taxonomy was used to analyze the cognitive complexity of tasks, which increased in the revised activities, allowing for more opportunities for knowledge construction. Audio and written work of student groups as they worked through activities was collected. Qualitative analysis of student engagement revealed that control over the content of activities to incorporate opportunities for knowledge construction is not enough to facilitate students consciously engaging in meaningful learning. If instructors wish to promote students integrating chemistry knowledge into their existing framework, course instructors, including graduate teaching assistants, need to be trained on how to properly facilitate classroom experiences to increase the likelihood of success.

Keywords: inquiry-based classroom activities; meaningful learning; undergraduate chemistry

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1. Introduction

1.1. Meaningful Learning to Promote Knowledge Integration

Chemistry instruction should aim to enable students to integrate the knowledge they are learning into existing knowledge frameworks. Incorporating tenets of meaningful learning can be used as a guide for activity design to motivate students to build connections. However, multiple conditions must be met for a student to engage in meaningful learning: (1) students must have some prior knowledge about the topic into which new information may be integrated, (2) the material must contain important concepts related to existing knowledge, and (3) a student must consciously choose to incorporate the material into their existing knowledge [1,2]. Only the content of the material can be controlled by the course instructor; the other two factors depend on the student's prior knowledge and conscious engagement with the course materials. Thus, if an instructor wants to incorporate meaningful learning opportunities into their course, it should be a goal to incorporate information that is relevant to the student population's lives. This will present opportunities for students to choose to engage with the material and incorporate new knowledge into existing knowledge frameworks [1].

Although instructors cannot control whether students will consciously choose to incorporate new material into their existing knowledge, they can promote knowledge integration through the questions asked. Marzano's taxonomy describes the cognitive engagement that tasks may promote from asking retrieval questions to pull information from their memory, comprehension questions that require applying knowledge to situations, analysis questions that use students' knowledge to create new insights, and knowledge utilization that require students to piece together their previous knowledge components to problem solve and accomplish a goal [3]. A study completed by Reid et al. investigated students' knowledge dynamics across five different discussion and lecture settings across four universities in the United States [4]. Their work found that increasing the cognitive complexity of tasks that students complete increased the likelihood of students engaging in knowledge construction where they incorporate previous knowledge into their current knowledge structures. Thus, if instructors want to increase the likelihood that meaningful learning occurs through students' conscious integration of new material, higher cognitive complexity tasks, such as analysis or knowledge utilization, should be used.

1.2. Incorporating Research into the Curriculum Benefits Students

In the aim to make classroom activities relevant and connected to current research, the authors decided to incorporate data and context from a research group at the university. The current research was chosen because there has been a push to integrate research experiences into the undergraduate curriculum [5–8]. Experience with research has been shown to improve retention, increase interest in pursuing a graduate degree, and provide students with experiences for their future careers [6,9–11]. At many institutions there are barriers for students gaining access to research experiences because the quantity of research positions open is far fewer than the number of undergraduate students [12,13]. This problem is further exacerbated at larger institutions with large numbers of undergraduate students. Course-based undergraduate research experiences (CUREs) have been studied in recent years and have been shown to be successful at integrating research into the undergraduate curriculum [10,14,15]. Institutions may be more inclined to offer CURE projects in upper undergraduate courses as they typically have smaller enrollments, so resource constraints are not as high [16–18]. As the goal of a CURE is to introduce students to research to promote retention and engagement in the curriculum, upper-level classes are too late to hit that point. Opportunities must be made available to students in introductory courses to allow all students to engage with research in some form [15]. However, there is a large barrier for large institutions to implement lab-based CURE projects in introductory courses due to their need for resources and rigorous guidelines for implementation, such as needing to use multiple scientific practices, allowing for student discovery, having the project be widely relevant, using collaboration, having the time for iteration, and the need for more personalized grading procedures [15]. Additionally, not all introductory chemistry classes have a laboratory component and so there is a need to investigate other avenues for research integration into curricula outside of the laboratory; thus, discussion sections were chosen to incorporate research data analysis into the curriculum

The authors are not proposing that incorporating research data into discussion activities is a substitute for CUREs or authentic research opportunities in faculty labs, but we are proposing it as another avenue to introduce students to aspects of data analysis and interpretation with authentic research. The classroom discussion activities are designed to incorporate real research contexts and data, allowing students to explore data analysis and become acquainted with research happening on campus. The activities and their implementation incorporate some aspects of CUREs by involving scientific practices; the activities are based upon broadly relevant research, and the activities promote collaboration [15,19]. The incorporation of these components through the real research data presented highlights that the problems, content, and skills students are working to develop in the classroom are relevant to practicing scientists and the impact that their findings have on society.

1.3. Atmospheric Chemistry Is a Timely Real-Life Context

In efforts to make the activities broadly relevant, research from the chosen research group is timely, multidisciplinary, and diverse in topics to allow for a variety of meaningful learning opportunities [20]. The focus of the research involves the characterization of atmospheric pollen under extreme weather conditions, source apportionment of particulate matter, measuring the molecular constituents of sea spray aerosol and its variation with biological processes in the ocean and post-emission chemical perturbations, and development of instrumental methods for the separation and quantification of organosulfates [21–26]. These concepts are broadly related to air pollution and represent a real-life phenomenon that is familiar to most students, who may have related personal experiences. Understanding these concepts and the relationships to health and climate effects is timely as human exposure to particulate matter is among the leading causes of premature death [27]. Particulate matter, also called particulate pollution, can be harmful to health as large particles can irritate the eyes, nose, and throat, but smaller particles can penetrate deep into the lungs or bloodstream [27–29]. The variety of environmental research within the chosen research group allowed for a larger range of concepts in the introductory chemistry course to be related to this common theme as well as being relevant to a variety of career paths, including medicine and environmental science.

Through the integration of local research into discussion activities, the project was aiming to answer the question: In what ways do discussion activities that incorporate research context and data analysis support students in meaningful engagement with course material?

2. Materials and Methods

2.1. Classroom Setting

The study took place at a large Midwestern research-intensive university. Activities were designed for a chemical thinking curriculum general chemistry course. The chemical thinking curriculum focuses on presenting chemistry as a way of thinking and not just a body of knowledge to absorb [30,31]. Chemical thinking emphasizes the scientific practice of data analysis and interpretation as a key aspect of understanding chemistry. This curriculum focuses on students constructing and applying chemical thinking to analyze and discuss explanations and solutions to chemistry problems. Unlike a traditional chemistry curriculum, chemical thinking accomplishes this goal with a primary focus on conceptual understanding over algorithmic problem-solving [15]. The large enrollment course structure included lecture, laboratory, and discussion components. The focus of this project is on the discussion component, which had approximately twenty-eight students in each section and was taught by graduate teaching assistants (GTAs). Discussion sections were fifty minutes and attended once a week by students. Students spent the discussion class time in groups of three to four completing a short quiz and completing activity worksheets. This study was IRB-approved and participants gave informed consent.

2.2. Theoretical Framework

It must be acknowledged that relevance is a continuum and instructors can only aim to make their materials personally relevant to a student population. To this end, we used the relevance continuum, as described by Priniski, Hecht, and Harackiewicz, to influence the study design through activity development, data analysis, and interpretation [32]. This framework places relevance on a continuum and recognizes that types of relevance are not mutually exclusive. The continuum begins with indirect *personal association* where the activity is connected to a memory or object from the student's life. The next type of relevance is *personal usefulness* when engaging in the activity is meaningful because it will help complete a personal goal. This is often seen in students who are taking the class as a prerequisite, who view the usefulness of the activities to help them pass the class to reach their career goal. The highest level of relevance is *identification*, when students view the activity as meaningful because the content is linked to one of their identities. An instructor cannot just tell students that the material is useful to their lives as that may impose additional pressures and make learning intimidating for students [32]. However, instructional materials can be designed to aid students in making relevant connections. To make materials meaningful, instructors must acknowledge that their students have a wide variety of backgrounds and goals to incorporate different avenues for relevance across a semester. Activities discussed in this paper aim to create these meaningful learning opportunities for students while they engage in their classroom discussions by connecting classroom activities to ideas that may be relevant to a diverse set of students.

2.3. Activity Development

2.3.1. Activity Selection

The authors first needed to determine which activities would be most appropriate to replace given the learning objectives and focus of the research projects to be applied to the activities. The scope of the groups' research to be integrated into discussion activities includes understanding the chemical composition and sources of atmospheric particulate matter [20,22–26]. The research group accomplishes these goals through fieldwork using various analytical instrumentation and procedures to study airborne particles. Activities to replace were selected by compiling all the learning objectives for the course, going through them sequentially, and noting where connections to the environmental atmospheric research could be implemented. It was determined that four activities throughout the semester aligned best with these goals. These activities took place on weeks four, five, six, and thirteen. Table 1 describes the content of each week's activities and alignment with the research area.

Table 1. Chemistry concepts discussed for the chosen weeks.

Week	Topics Discussed	Research Alignment
Week 4	Identifying elements/compounds, writing molecular formulas	Identifying compounds in particulate matter and quantifying their concentrations
Week 5	Writing chemical formulas, mass spectrum data, stoichiometry, empirical formulas to molecular formula	Determining concentrations of compounds in particulate matter and using mass spectrometry data to confirm the identity of compounds in particulate matter
Week 6	Calculating frequency and energy, emission, absorption, calculating photons	Using fluorescence spectrometry to identify particle types in pollen
Week 13	Particulate representations of reactions, writing and balancing chemical reactions	Understanding chemical reactions that take place in seawater

2.3.2. Activity Design

All discussion activities for this course were structured to provide meaningful learning opportunities by having students listen to or watch a pre-class video/podcast that related to a topic outside course content. The general structure of all worksheets was to first ask questions related to the pre-class content. The rest of the activity asked questions related to the chemistry concepts discussed in class. Questions are broken into two sections, with a group process skill self-reflection placed after the main activity questions. These two sections will be referred to as the main body and 'continuing on' sections hereafter. An example original activity for Week 5 can be found in the Supplemental Information.

The revised activities were designed to promote meaningful learning opportunities by explicitly making connections to research. For three of the four revised activities, pre-made public access videos that related to the research topic were selected. For the Week 5 activity, the first author and a member of the focus research group created a video describing mass spectrometry and its use in research. Questions were then developed that integrated real research data and conceptual ideas into the chemistry topics discussed in class. The initial questions about the videos were designed to aid students in making connections between the content and their lives and situate the activity in a meaningful way in accordance with the relevance continuum. The worksheet then maintained the relevant connections and focused on connecting the topics to questions that relate to the chemistry concepts discussed in class that week. This was achieved by providing context to the data presented. The position of the process skill reflection between the main body and 'continuing on' questions was maintained. A sample revised activity for week five can be found in the

Supplemental Information. Table 2 describes the differences between the content of the original and revised activities.

Table 2. Structure and content of original and revised activities in the discussion classroom.

	Initial Questions	Main Body Questions	Reflection	'Continuing On' Questions
Original Activities	Prompt review/ summary of pre-class material	Guide students to achieve learning outcomes—data for analysis comes from a variety of sources/contexts	Guides students to reflect on proficiency in professional skills	Provides additional opportunities to master material, data for analysis comes from a variety of sources/contexts
Revised Activities	Promote connections between pre-class material, content, and relevance to research/daily life	Guide students to achieve learning outcomes—data for analysis comes from research context	Guides students to reflect on proficiency in professional skills	Provides additional opportunities to master material, data for analysis situated in local research data and continues theme

2.4. Data Collection

Data used in this report come from a larger project that investigates a variety of student and instructor interactions in large introductory courses. Groups for this analysis were selected randomly from those who had consented to participate in the study. Two groups were selected for analysis where their audio and written work were collected using a note-taking app and screen recording on an iPad. General classroom recordings were also collected to document classroom activities and instructor facilitation. Pseudonyms were used to maintain the confidentiality of the participants. Pseudonym genders are random and have no relation to the participants.

2.5. Analysis

2.5.1. Activity Design Coding

The questions for both the original and revised activities were qualitatively coded according to the cognitive level as discussed in Marzano's taxonomy [3]. Marzano's taxonomy allowed us to classify tasks based on hierarchical cognitive processes required for students to answer questions, providing more information about how the activities were scaffolded to help students reach higher levels. This is in contrast to other taxonomies, such as Bloom's [33], which focus on the actions that would be completed or question complexity and have a looser hierarchical structure [34–36]. This coding was completed to determine the level of cognitive complexity the students needed to engage in to answer the given questions. Questions were coded based on their labeling in the discussion activity. Questions that were labeled with multiple parts (a, b, c, etc.) were coded as separate questions because it was seen that divided questions were asking students to complete different tasks at varying levels.

2.5.2. Student Work Coding

Collected audio and written work were qualitatively analyzed using the coding software MAXQDA [37]. All redesigned activity weeks were selected for analysis along with one week prior and one week after the redesigned activities to fully characterize differences across the semester. This resulted in eight weeks of analyzed activities during weeks three through seven and twelve through fourteen. An open coding method to form themes, as described in Merriam and Tisdell, was used to code all student audio and written work [38]. To triangulate themes, coding was completed on student worksheet answers and the audio of group conversations. All coding was completed considering the relevance continuum when creating open codes related to relevant connections students made. Related open codes were narrowed to axial codes to create the themes discussed in the results section.

3. Results and Discussion

The goals of this project were to redesign discussion activities to provide opportunities for meaningful learning and evaluate the effectiveness of the redesigned activities in promoting meaningful learning. This was accomplished by situating the learning objectives within the context of research happening within the department. The analysis yielded mixed results for the extent to which the activities achieved the intended outcomes. Some aspects of the implementation showed that students made outside connections, but others revealed that students were dismissive of connections. The Results and Discussion will address these themes across the activity questions students completed.

3.1. Revised Activities Promoted Knowledge Integration

The revised activities took care to incorporate opportunities for scientific practices to promote knowledge integration [19]. Questions across all activities provided opportunities for students to *analyze and interpret data, use mathematics and computational thinking, construct explanations, and engage in argument from evidence*. These practices were incorporated to promote interaction with the authentic work of practicing scientists and provide relevancy to the tasks. After analysis of activities using Marzano's taxonomy, the original and revised versions of activities were compared for their diversity in the question level to see how questions may promote conscious knowledge integration. Because the activities are broken into two sections and students are only anticipated to get through the main body questions during the classroom period, comparison begins with this section. Table 3 summarizes the number of each Marzano cognitive level for questions in the main body of the activity. The original versions reached only the analysis level of questions, while in the revised set, there are two instances of knowledge utilization. Additionally, because the goal of activity editing was to create meaningful learning opportunities, at least one metacognition question was added at the beginning of each activity to help students relate the activity content to their preexisting knowledge. Overall, there were more higher cognitive complexity questions for the main body questions in the revised activities.

Table 3. Summary data of the frequency and percentage of each question level in the main body questions.

Activity	Original Week 4	Revised Week 4	Original Week 5	Revised Week 5	Original Week 6	Revised Week 6	Original Week 13	Revised Week 13
Retrieval	3 (33%)	2 (18%)	0 (0%)	0 (0%)	4 (50%)	6 (50%)	2 (13%)	1 (5%)
Comprehension	3 (33%)	4 (36%)	5 (100%)	3 (30%)	3 (38%)	1 (8%)	11 (73%)	9 (47%)
Analysis	3 (33%)	2 (18%)	0 (0%)	5 (50%)	1 (13%)	4 (33)	2 (13%)	6 (32%)
Knowledge Utilization	0 (0%)	1 (9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (5%)
Metacognition	0 (0%)	2 (18%)	0 (0%)	2 (20%)	0 (0%)	1 (8%)	0 (0%)	2 (11%)
Total Questions	9	11	5	10	8	12	15	19

Next, we look at the question level for all questions in the activity. The 'continuing on' questions are extra questions after the process skill reflection that are completed in class if the group finishes the main body questions before the end of class or are used as additional practice problems for students on their own [39,40]. This design allows students to continue to integrate previous knowledge into their existing knowledge framework to meaningfully connect material. Additionally, the original activities did not consistently discuss the same topics in the main body and 'continuing on' questions. The revised activities keep the same research topic context in both sets of questions. This was designed to allow students to relate materials discussed in their discussion sessions to the 'continuing on' questions. Table 4 summarizes the number of questions at each question level for all questions included in each weekly activity. The same trend can be seen with the main body questions where the question level increases across all edited activities. When students completed the 'continuing on' questions, they had additional access to analysis and knowledge utilization questions that allow for opportunities to expand their knowledge construction of chemistry concepts.

Table 4. Summary data of the frequency and percentage of each question level in the main body and 'continuing on' questions.

Activity	Original Week 4	Revised Week 4	Original Week 5	Revised Week 5	Original Week 6	Revised Week 6	Original Week 13	Revised Week 13
Retrieval	7 (54%)	3 (16%)	0 (0%)	1 (6%)	5 (42%)	6 (35%)	3 (14%)	2 (8%)
Comprehension	3 (23%)	9 (47%)	5 (63%)	4 (24%)	4 (33%)	4 (24%)	15 (71%)	11 (42)
Analysis	3 (23%)	4 (21%)	3 (38%)	9 (53%)	3 (25%)	6 (35%)	3 (14%)	10 (38%)
Knowledge Utilization	0 (0%)	1 (5%)	0 (0%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	1 (4%)
Metacognition	0 (0%)	2 (11%)	0 (0%)	2 (12%)	0 (0%)	1 (6%)	0 (0%)	2 (8%)
Total Questions	13	19	8	17	12	17	21	26

Simply looking at the summary data of the question level does not tell the whole story of how students may engage with questions. Because of the increase in the number of questions across worksheets, the authors wanted to investigate the structure of the worksheets to see if the ordering/arrangement of questions may have factored into any changes in student engagement. This goal was accomplished by analyzing the order in which students interact with problems on both the original and revised version of each activity. Figure 1 shows the Marzano coding for the original and revised versions of the Week 4 activity. Marzano's cognitive levels of retrieval, comprehension, analysis, and knowledge utilization were plotted across questions. Metacognition questions are indicated with a capital M on the plots. The black line indicates where the process skill reflection was placed in the activity and all questions to the right of that line are in the 'continuing on' section.

The plot shows that two additional questions were asked in the main body questions in the revised activity. The questions added were metacognition questions that directly asked students to relate previous knowledge to the content of the pre-class activity. These questions were added to increase the likelihood that students would make meaningful connections to the activity. These plots also show that in the revised activity, as questions increased in the cognitive level, they have often been grouped with a, b, and c parts to help scaffold the students' understanding. All revised activities were compared, and associated plots can be found in the Supplemental Information (Figures S1–S3). The same trends of questions being added to integrate metacognition or better scaffold chemistry ideas can be seen across all four activities.

3.2. Students Make Connections When Prompted

Throughout the semester, students were always asked to complete questions at the beginning of the activity about the pre-class content they were viewing. Across the analyzed activities, one to three of these questions were asked for a total of fourteen questions across the eight selected activities. Questions about the pre-class content varied, asking students to summarize the video, think about previous knowledge, or use what they learned to give advice on an environmental issue.

When students were asked metacognitive questions such as "How might what you have learned so far in the lecture be relevant to the video?" or "What were your group's ideas about pollen suppression before watching the video?" they were able to make connections with previous knowledge. Example written responses can be seen in Figure 2.

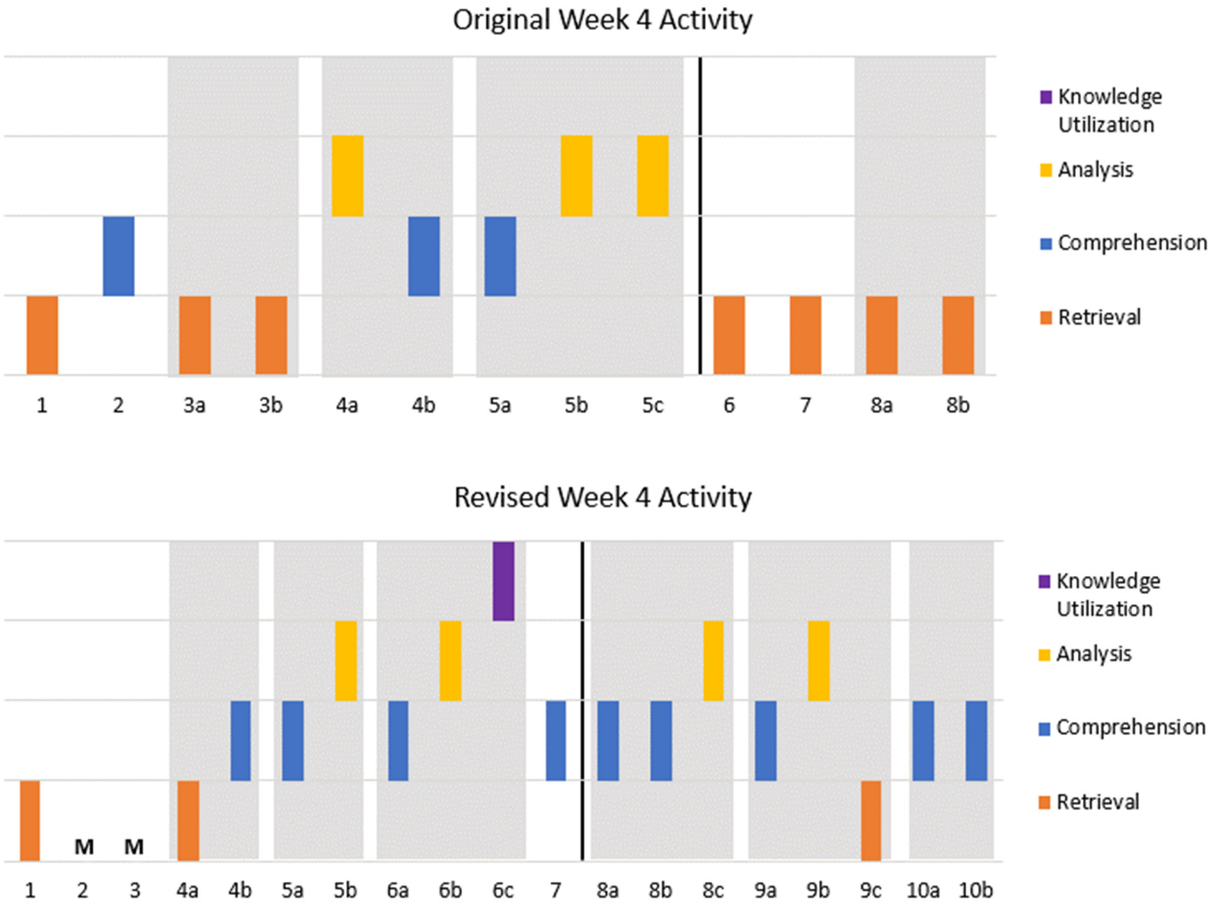
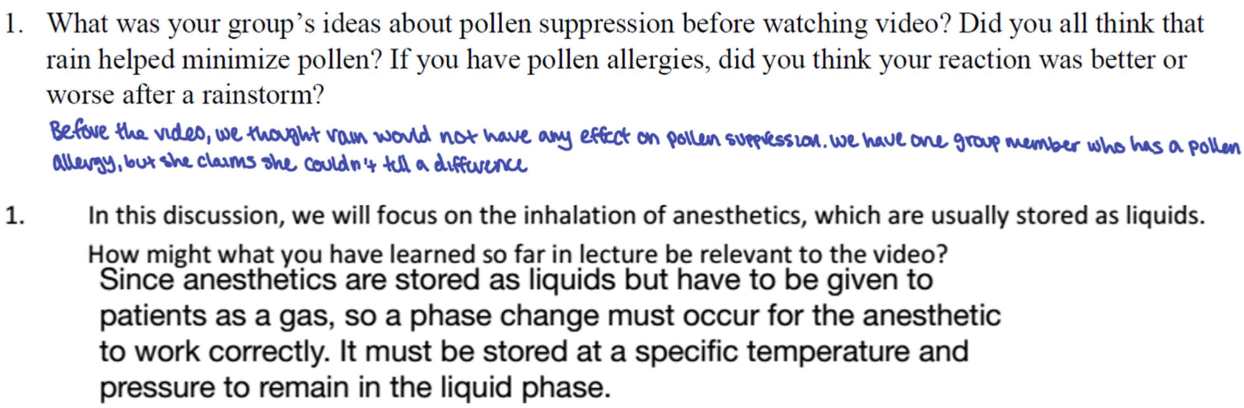


Figure 1. Marzano question level coding for the original and revised Week 4 activities. The black line indicated where the reflection is placed and the questions to the right are in the continuing on section. M indicates a metacognition question. Gray boxes are used to highlight when questions are scaffolding for students to answer with parts a, b, c, etc.



1. What was your group's ideas about pollen suppression before watching video? Did you all think that rain helped minimize pollen? If you have pollen allergies, did you think your reaction was better or worse after a rainstorm?

Before the video, we thought rain would not have any effect on pollen suppression. We have one group member who has a pollen allergy, but she claims she couldn't tell a difference

1. In this discussion, we will focus on the inhalation of anesthetics, which are usually stored as liquids. How might what you have learned so far in lecture be relevant to the video?

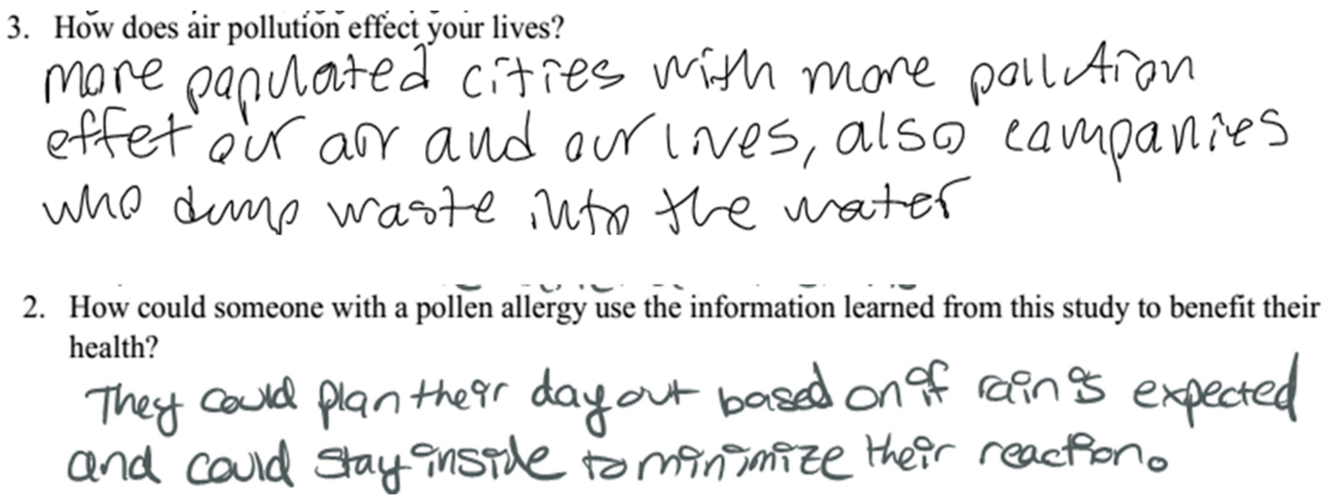
Since anesthetics are stored as liquids but have to be given to patients as a gas, so a phase change must occur for the anesthetic to work correctly. It must be stored at a specific temperature and pressure to remain in the liquid phase.

Figure 2. Example student responses from pre-class content metacognition questions on in-class activities.

Both the written and audio data of student discussions showed that students would interact with the content of the questions when directly asked in this manner. When discussing the pollen suppression questions, Jasnah shared a personal connection that they had a pollen allergy but had not thought about how the rain had affected their symptoms. This question prompted them to think about their personal experiences and they shared that: "Now that I think about it, it makes sense [that allergies would get worse] because after rain the smell of the grass bothers me more".

Audio interactions consistently indicated that students would incorporate previous knowledge when explicitly prompted to do so. Another example is from when students were discussing an activity related to phase changes, Shallan stated that: "We have been learning about phase changes in lecture and when administering anesthesia needs to be put in a gas form which is a phase change", relating their experience with the classroom content to how anesthesia is delivered.

Additionally, some questions asked students to consider environmental issues and sometimes offer advice such as: "How does air pollution affect your lives?" and "How could someone with a pollen allergy use the information learned from this study to benefit their health?". When questions of this type were asked, students were able to bring in outside, previous knowledge, and offer a variety of observations and advice. Examples of student group written responses can be seen in Figure 3.


3. How does air pollution effect your lives?

more populated cities with more pollution effet our air and our lives, also companies who dump waste into the water

2. How could someone with a pollen allergy use the information learned from this study to benefit their health?

They could plan their day out based on if rain is expected and could stay inside to minimize their reaction.

Figure 3. Example of student responses from pre-class content environmental questions on in-class activities.

The written response and audio interactions showed consistent results that students were able to discuss and tie in information when asked environmental questions. When students were discussing how air pollution affects their lives, Rysn stated that: "Air pollution deteriorates the ozone, allowing more heat to reach the earth". Shallan added: "Air pollution can worsen health conditions you already have".

Students also made connections to broader societal impacts, as seen in their written responses (see Figure 3) and in their classroom discussions, where Navani stated: "Air pollution hurts more populated cities because they have more industry". Evi pulled in more ideas when they said: "Air pollution can change the clouds and weather" and "Locations with more air pollution affects our economy". These interactions show that students are readily able to tie in connections to both society and their personal lives when they are prompted for it by questions.

However, some questions did not ask students to think about previous knowledge and only asked them to summarize the video directly, such as: "What key ideas did you learn from the video?" and "Summarize the benefits and costs of nitrogen in our modern world". When these types of questions were asked, students responded only as asked and did not incorporate information from outside of the video. Example written responses can be seen in Figure 4.

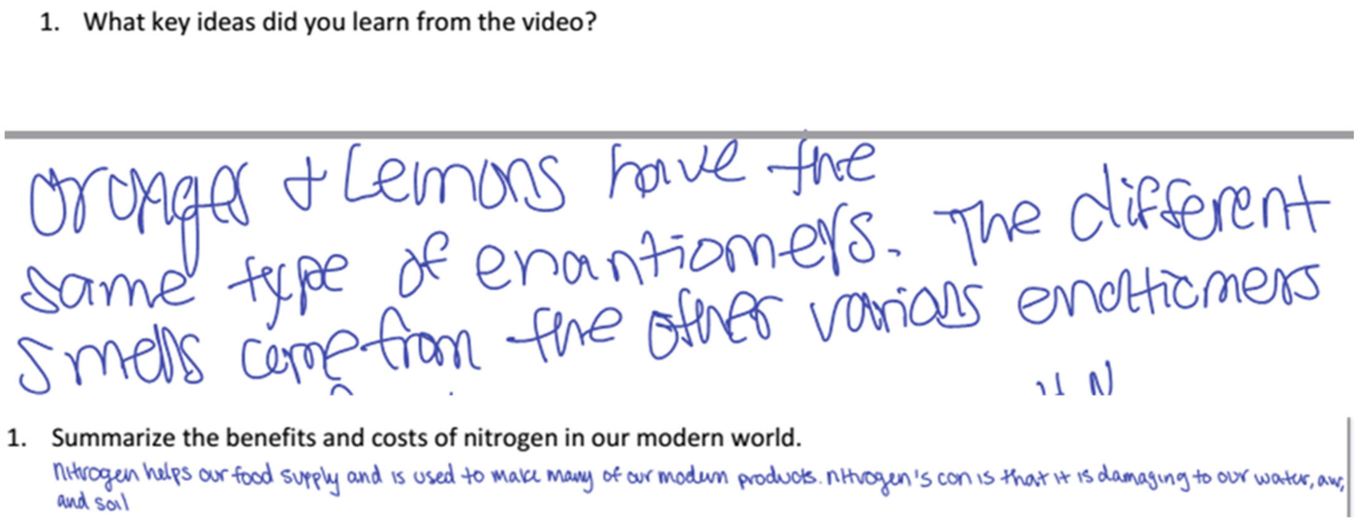


Figure 4. Example student responses from pre-class content summary questions on in-class activities.

The written response and audio data of student discussions when answering these summary questions showed that there was little interaction with the video content as students would only say verbatim what was in their worksheet responses or not talk about them at all, and the recorder would answer the question by themselves rather than engaging the group in responding. These results highlight that worksheets designed to promote knowledge integration should take care to design questions that will elicit previous knowledge and help students make connections to experiences outside the classroom.

3.3. Students Were Generally Dismissive of Contextual Information

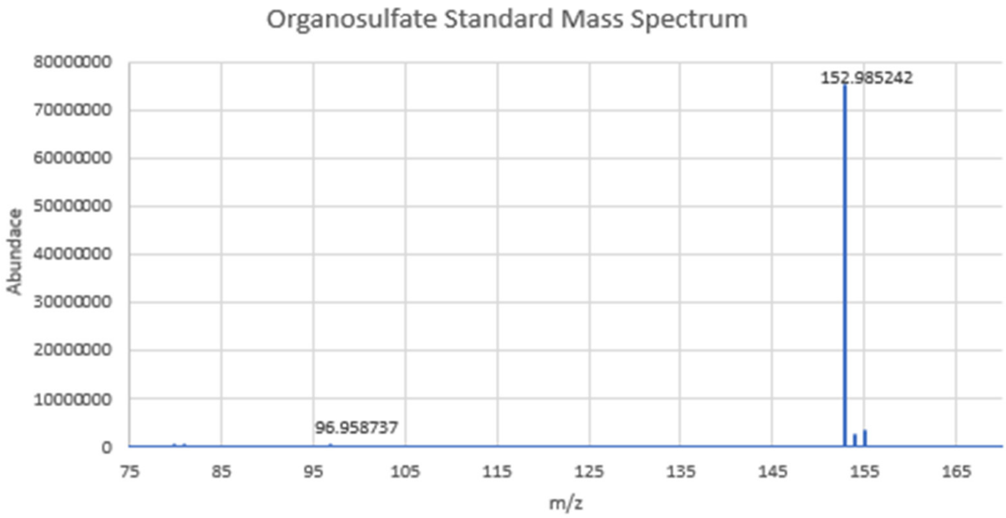
Contextual information was provided for all problems, describing where data came from and the importance of the studies to situate students before solving problems. Although students were able to make connections when prompted, their interactions revealed that overall, students were dismissive of the pre-class activity and the contextual information. This was seen whether or not the activities incorporated research data. As an example, across weeks five and seven, students were asked to propose structures for compounds from data. In Week 5, a revised activity was used that focused on identifying compounds in particulate matter. One question asked on the activity can be seen in Figure 5. This question gave the students mass spectrometry and elemental analysis data and asked students to identify the formula and explain how they reached their answer. The additional context was given about why the researchers would want to identify the substance in particulate matter and the method they would use to complete the analysis.

A similar question, asking students to propose a structure when given data, was asked in Week 7, as seen in Figure 6. However, this question was not given any context outside of that the compound is present in vanilla.

In both of these activities, each group analyzed treated the questions similarly by only discussing the process for finding the solution to the question(s) directly asked. Even when students were prompted with the metacognitive questions at the beginning and provided with reasoning for why a scientist would want to find the solution in the Week 5 activity, they did not read the context provided before the data out loud and it never came up in discussion. This observation was present across all questions asked within the main body across both the original and revised activities. This highlights the conclusion that you cannot just write questions with context and expect students to discuss connections and connect with the material on any level from personal association to the identification.

5. Particulate matter composition includes a wide variety of substances, as we saw last week. We know that this project uses tandem mass spectrometry, which was discussed in this week's video to track compounds by the sulfate functional group, which frequently fragments to bisulfate anion (HSO_4^-) and/or sulfate ion radical ($SO_4^{-\bullet}$) under MS/MS.

After analyzing their samples, the researchers wanted to confirm the identity of one organosulfate. Researchers can use a standard to confirm the identity of an organosulfate. These standards are organosulfate salts with a potassium cation. The mass spectrum of this standard showed major MS peaks at *m/z* 152.9852 corresponding to the intact anion and *m/z* 96.9587 corresponding to a fragment ion can be seen below.



Elemental analysis was also completed on the organosulfate and revealed the following composition:

Element	Percent Composition
Potassium	20.34
Carbon	18.74
Hydrogen	2.62
Sulfur	16.68
Oxygen	41.60

a. What is the empirical formula of the substance?

b. What is the molecular formula of this substance?

c. Explain how you arrived at your answer to part b.

Figure 5. Example question from the Week 5 activity that asks students to identify the substance in particulate matter using mass spectrometry data in the same way the researchers do in their work.

As discussed in the previous section, students would only connect with the material when they were specifically asked to connect or draw on previous knowledge. Students did not appear to value engaging with the pre-class content because, across all weeks, students in the group shared that they had not even watched the video. When the video was needed to answer questions, groups were able to complete the questions by having someone watch the video in class, while others began working on problems. Students shared that they did not think the context questions were important because they would not benefit them for the class. Jasnah, when directed toward the problem questions, said: "I think these [class content questions] are going to be more important".

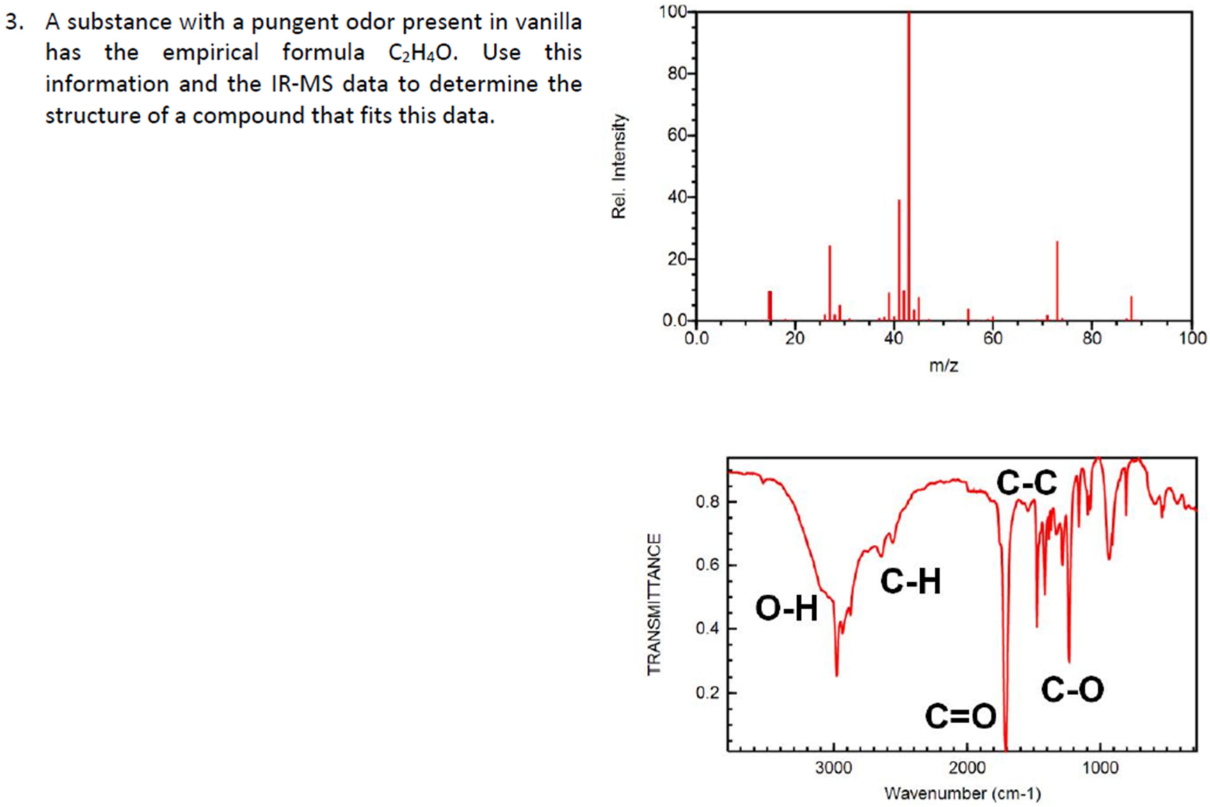


Figure 6. Example question from the Week 7 activity that asks students to identify the substance in vanilla.

Splitting up work was consistent across all aspects of the worksheet as Shallan revealed that they were able to leave class once the worksheet was done when they said: "I am working ahead on this because if we get the main part done, we can leave". Evi also mentioned that they were "going to work through the iClicker [clicker questions] so we can get done and out", as another student watched the video to answer questions. Once, when Jasnah wanted to discuss the questions further, Shallan responded with: "Nah let's just get going so we can leave". This was met with the whole group expressing that was a good point and they split up the work to finish quickly.

Student comments also indicated that they were not making connections to personal usefulness for their future careers. For example, Eshonai said, "volunteer and research and letter of rec is what I am riding on to get into medical school". Students in both groups talked often about how the class was difficult, with Rysn stating that: "You know I feel like I am emotionally intelligent, not chemistry intelligent" and Navani saying: "What we are learning is not going to be on the exam and if it is it is going to be worded so hard, we won't understand it". This impeded students' ability to engage with the meaningful learning opportunities because they were motivated only to finish the activity so they could get out of class.

3.4. Facilitation Did Not Promote Engagement

The researchers looked at the facilitation of the activities, particularly related to the contextual information and how GTAs discussed them in class to investigate potential influences on the lack of meaningful student engagement. GTAs did not receive special instructions on how to implement the redesigned activities, and facilitation strategies remained consistent across all weeks. Both groups had the same GTA who led class like office hours, circulating the room as students worked at their own pace through the clicker questions and activity.

When analyzing the facilitation, it was often seen that the GTA did not promote interaction with the pre-class content. The GTA did not encourage interaction with the videos across any weeks and sometimes actively discouraged it by stating several times across the weeks: "You do not have to watch the video" or "If you don't watch the video that is fine". This may have been the influence for students not watching the video before class and just having one person view it long enough to answer the questions.

Additionally, as indicated by students mentioning that they could leave early if they finished the worksheet, the GTA announced this across multiple weeks saying: "Once you finish it all you can leave". The first time this was announced, Shallan said, "Oh, let's go speedy" and the group began splitting the worksheet up as mentioned above. This event revealed that the messaging of the GTA led to groups working quickly and ignoring content through the problems so that they could leave before the end of scheduled discussion time. The motivation of the students to leave class early led to a lack of meaningful learning to occur as they ignored the contextual information unless explicitly asked to connect information from class and their lives.

4. Limitations

The findings presented in this paper are limited in their generalizability and transferability by the small number of student groups analyzed at the institution, which may not be representative of all student populations. However, quotes from student interactions and triangulation with their written work were used to create a reliable argument that contextualized the findings and is informed by participant voices rather than extrapolated by the researchers. A description of the classroom setting was provided so that the reader may determine transferability to their populations. The findings from this work are limited to the topics related to atmospheric chemistry and students may interact differently across different topic areas.

5. Implications for Research and Practice

5.1. Practice

Our results indicate that control over the structure of the activity to increase cognitive engagement is not enough to ensure meaningful learning will occur in a discussion classroom. Two direct implications for practice can be seen from this work for educators wanting to increase meaningful learning by incorporating authentic research data and contexts in their classrooms. First is that the questions at the beginning to prompt the recall of previous knowledge are likely not enough to encourage students to integrate that knowledge into subsequent questions throughout an activity. If instructors want to promote meaningful learning, they should more explicitly incorporate questions throughout the whole activity that would have the students make connections to the research context. Any questions intended to promote knowledge integration should be purposefully designed to have students recall their previous knowledge. This can occur through scaffolding questions asking for students to recall information.

The second implication for practice is that facilitators wanting to promote meaningful learning should be better prepared to implement contextualized activities to promote productive interactions with the content and the connections to current research. For teaching teams that include a mix of professors, GTAs, and undergraduate teaching assistants, training on how to implement activities should occur with follow-up opportunities to gain support and ask questions after teaching has occurred. The training could be formal pieces of training available at the institution, or informal through teaching meetings at regular intervals throughout the semester. Teaching guides for activities that promote meaningful engagement could also be created for instructors at any level so that they may refer to them when teaching until they are comfortable.

5.2. Research

There are multiple pathways for additional research opportunities using meaningful learning across STEM settings. Studies more closely investigating the relationship between facilitation and interactions with activities designed to promote connections could reveal more specific instructional practices to promote meaningful engagement. Large-scale studies either with a larger student population or across institutions could expand the generalizability of these results. Research involving student interviews could be done to elicit student motivation or the ability to connect prior knowledge with different types of activities to learn how activities could be designed better to stand alone to promote meaningful engagement. Our work only used CUREs as an inspiration for using research data to promote meaningful learning, but it highlights the need for more work investigating the utility of out-of-lab research experiences. Future work could build upon the work of Sommers et. al, investigating the utility of CURE-style instructional materials that could benefit STEM disciplines if the benefits can be seen without needing the resources that a large-scale CURE implementation would require [18].

6. Conclusions

Four activities from an introductory chemistry class were edited to incorporate authentic research connections early in an introductory chemistry class. Activities incorporated scientific practices to promote interaction with the authentic work of practicing scientists and provide relevancy to the tasks. Special attention was taken to incorporate metacognitive questions designed to help students make connections between their preexisting knowledge and course content. This provided meaningful learning opportunities, where student groups engaged with the material, as they were able to find connections to their existing knowledge frameworks. By incorporating authentic research, cognitive question complexity was increased, allowing for more opportunities for meaningful learning through knowledge integration to occur as students analyzed and interpreted research data.

Analysis of student work revealed that students were able to make connections with previous knowledge when prompted by the metacognition questions in the worksheets. However, students were generally dismissive of the contextual information presented throughout the worksheet and were motivated to finish the worksheets quickly so they could leave class early. These dismissive interactions were encouraged by the facilitation from the GTA and highlighted the need for better dissemination of facilitation strategies that are more likely to promote meaningful engagement within student groups.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci13020192/s1, Sample activities pre-/post-revision; question level coding for additional activities.

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