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In the Classroom

Case Studies as a Basis for Discussion Method Teaching in Introductory Chemistry Courses

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…students are more motivated and internalize material more effectively when they participate actively as learners in the classroom.

Three case studies that have been used as a framework for discussion classes in Introductory Chemistry are presented. When used as a supplement to lectures, they serve to deepen student knowledge of a wide range of material from the traditional curriculum including empirical and molecular formulae, Lewis Structures, molecular shapes, reaction enthalpies, gas laws, solubility products, and colligative properties. The case studies also help to foster student appreciation of the interdependence of these topics and allow students to apply their knowledge to realistic situations. Classroom techniques incorporating the cases are described. Some student reaction to the approach also is included.

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Introduction

The case study/discussion method of teaching has been employed for many years and with considerable success in the humanities, business, educational, legal, and medical fields [1]. Practitioners of the art point to numerous studies [2] that indicate students are more motivated, and internalize material more effectively when they participate actively as learners in the classroom. While the more student-passive, lecture style of teaching may be of greater efficiency in transmitting large amounts of information or in elaborating complex and detailed arguments, the cost of this teacher-centered approach is often an uncomfortably high percentage of students who are left unmotivated, unable to reason for themselves, and for whom the material covered by the teacher remains obscure and undigested. It usually is only through homework assignments or examinations that teachers discover that they are the only ones for whom the material has been covered.

Despite the drawbacks of totally lecture-based classes, these remain the almost exclusive pedagogical tool in nonlaboratory science courses in universities throughout the world. Interest in student-centered, active-learning approaches in science is, however, on the increase [3]. While case studies sometimes have been used in chemistry courses to examine societal, environmental, and ethical issues, their use in the teaching of the technical curriculum in Introductory Chemistry (or, indeed, in higher level courses) is extremely rare. There is to our knowledge no published source of cases available for such purposes, although some have been disseminated at meetings [4] and likely will become available in book form. In the meantime, we present here three case studies which we have written and found to be of value in Introductory Chemistry. In addition to the cases themselves, we describe some of the techniques we have found to be effective in employing the cases as a framework for class discussion, and we relate some classroom experiences and student feedback surrounding their use.

Case Studies

Case Study 1: Gases

Take a few minutes to read the following case. You may refer to your text book and do any calculations that you think may be important.

A space agency is planning to send a balloon to a height of 20 km where the pressure is 76 mm Hg and the temperature is -50 °C. They are considering five possibilities:

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i. A balloon filled with 12 L of carbon dioxide at atmospheric pressure and 25 °C.

ii. A balloon filled with 12 L of helium at atmospheric pressure and 25 °C.

iii. A balloon filled with a mixture of 6 L of nitrogen and 6 L of helium at atmospheric pressure and 25 °C.

iv. A balloon filled with 20 L of helium at atmospheric pressure and 25 °C.

v. A balloon filled with 12 L of air heated to 50 °C and at atmospheric pressure.

The balloon is made of a very elastic material that can allow it to stretch to a volume of 150 L without bursting. The agency comes to you as the local expert on gas behavior. What advice would you give them concerning the relative merits of the five options?

Case Study 2: Nicotine

For today’s class we are going to divide into groups of about six students per group, in order to examine some aspects of the important molecule, **nicotine.**

As you know, nicotine is present in cigarettes and other tobacco products. There is much debate currently on the addictive nature of nicotine and on how nicotine acts in the brains of smokers and others exposed to cigarette smoke or tobacco products. See the recent article in Chemical & Engineering News [5].

The molecular formula of nicotine is $C_{10}H_{14}N_2$.

Each group may ask for further information from the instructor to help with their assignment, but should not receive information from other groups except for specific information given in the instructions below.

Each group should elect one member to report the group’s findings to the class at the end.

Read through the assignments for <u>all</u> groups before starting on your group’s assignment.

Following are each group’s assignments:

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Group 1:
You will be given a structural formula for the nicotine molecule. Use this to help you figure out the shape of the molecule (i.e. the geometry and angles around each atom).

Group 2:
You will be given a molecular model of the nicotine molecule. Use this to help you figure out the Lewis Electron Dot Structure of the entire molecule.

Group 3:
A substance from tobacco smoke was analyzed and found to contain 74.1% C, 8.6% H and 17.3 % N. Could this substance be nicotine? Report your finding to Group 4.

If you have time left over, help Group 4 with their assignments.

Group 4:
Group 3's substance was studied in a mass spectrometer, and found to have a molecular weight of 81.1. Could this substance be nicotine? If so, report your finding to Group 3. If not, can you come up with a possible structure for Group 3's substance, based on the information both groups have available?

Group 5:
The standard enthalpy of formation of nicotine is +248.7 kJ mol^{-1}. Write the chemical equation that represents this enthalpy of formation of nicotine. Is the formation of nicotine in this equation an exothermic or endothermic process?

A combustion of nicotine in an atmosphere of pure oxygen proceeded by the following equation:

$$C_{10}H_{14}N_2(g) + O_2 \rightarrow CO_2(g) + N_2(g) + H_2O(g)$$

Balance the above equation. Report your findings to Group 6.

If you have time left over, help Group 6 with their assignments.

Group 6:
If nicotine is burned in an atmosphere of pure oxygen, what chemical products would you guess might be formed? Check your answer with Group 5.

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If nicotine is burned in a limited supply of oxygen (such as when smoking a cigarette) what products might then be formed?

Use the structural formula of nicotine to estimate the enthalpy change for the combustion in pure oxygen, based on bond energies.

Calculate the enthalpy change for the above combustion reaction, based on enthalpies of formation.

Why are the estimated and calculated enthalpies not exactly the same?

Case Study 3: Lead Pollution

Our class has been commissioned by a city to help solve a crisis in the quality of its water. The city would like us to identify the pollutant and determine a method for eliminating it from the city's water. Time is short and so we will split up into groups, each of which will be concerned with a specific aspect of the problem.

Your group number is the number at the top of this page. You will be told in which part of the room your group will meet. Some background to the problem is given below, but each group may ask for further information from the instructor to help with their assignment.

Each group should elect one member to report the group's finding to the class at the end. These findings will be combined in order to report to the city.

Read through the assignments for all groups before starting on your group's assignment.

Background:

The water coming into the city's treatment plant is cloudy and contains high levels of lead. The city has a regulation stating that the concentration of lead must be less than 5 ppb for the water to be considered safe. There are several places from which the lead contamination can be coming. The three most likely places are a nearby chemical plant, a paint plant that is close to the city, and water containing lead leached from contaminated soil during recent floods. The pipes carrying the water contain lead and if the water is too acidic it can dissolve high levels of this lead from the pipe. There is a chemical company that may be improperly disposing of sulfuric acid in the lake near the city. There is also a paint company near the town that has used the same reactors for mixing paint for many years. Although their paints no longer contain lead, these reactors

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may be contaminated with lead. Water from washing these reactors with sodium phosphate, if improperly disposed of would produce high concentrations of lead in the water. Also, the river running along the freeway recently flooded several times. The soil in the area is contaminated with lead from the time when gasoline contained tetraethyl lead. The lead in the soil has previously been analyzed and was found to be mostly lead hydroxide.

The city's chemists have performed some tests on the water and information from these tests can be obtained from your teacher on a need-to-know basis. The city has restricted this information so that only those who really need it may have access to it. The following tests have been performed: osmotic pressure determination, percent weight analysis of lead and oxygen in a substance precipitated from the water, and the weight of precipitate when sodium sulfide is added to filtered water. K_{sp} values for some lead salts are given in Table 1.

TABLE 1. K_{sp} Values for Lead Salts.

Salt	K_{sp}	Salt	K_{sp}
$Pb_3(AsO_4)_2$	4.1×10^{-36}	$Pb(OH)_2$	2.8×10^{-16}
$PbBr_2$	6.3×10^{-6}	PbI_2	8.7×10^{-9}
$PbCO_3$	1.5×10^{-13}	$Pb_3(PO_4)_2$	3.0×10^{-44}
$PbCl_2$	1.7×10^{-5}	$PbSeO_4$	1.5×10^{-7}
$PbCrO_4$	1.8×10^{-14}	$PbSO_4$	1.8×10^{-8}
PbF_2	3.7×10^{-8}	PbS	8.4×10^{-28}

Group 1:
Your job is to determine the possible compounds of lead that are of no concern because their solubility is so low that the lead concentration in water will not exceed the acceptable limits. Use the background information to identify these compounds. Report your findings to groups 2, 3, and 4. Help these groups with their calculations if you have time.

Group 2:
Your job is to determine the counterion associated with lead and the chemical formula of

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the compound by using the osmotic pressure data. Once the counterion is determined, you should be able to determine from where the lead originated from by carefully reading the background material. Check your answer with Groups 3 and 4.

Group 3:
Your job is to determine (using the background material above and the percent weight data) which of the possible counterions is associated with lead and what the formula of the lead compound is. Once the counterion is determined, you should be able to determine from where the lead originated by carefully reading the background material. Check your answer with Groups 2 and 4. Help these groups with their calculations if you have time.

Group 4:
Your job is to determine the K_{sp} of the lead compound assuming that the water is originally saturated with the lead compound. Use the available data on the weight of precipitate formed on addition of sodium sulfide to filtered water. From the table of K_{sp} values (Table 1), determine which lead compound is likely to be the contaminant. Once you have determined this, you should be able to determine from where the lead originated by carefully reading the background material. Check your answer with Groups 2 and 3.

Group 5:
It has been suggested that bubbling carbon dioxide through the water would lower the lead content. Determine, from Henry's law and the K_{sp} value for lead carbonate, if this method will work. If it will, find the pressure of carbon dioxide that is needed to produce enough carbonate to lower the lead content below the acceptable limits. The Henry's law constant for carbon dioxide in water at 25 °C is 4.45×10^{-5} M/mm Hg.

Group 6:
From the list of K_{sp} values (Table 1) determine what is the best common ion to lower the concentration of lead in water. Are there other considerations that need to be taken into account when determining which common ion to use? Decide what you will recommend adding to the water to remove lead ions. Calculate the concentration of this compound needed to lower the lead content below the acceptable limits.

Group 7:
Your job is to devise a test that can be used by the city to determine when the level of

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lead is below the acceptable limits. The city is interested in a quick and inexpensive test. They prefer something that does not require instrumentation and that can be performed by workers without chemical backgrounds. You may find the K_{sp} values in Table 1 front helpful for this work.

Osmotic Pressure Laboratory Report
A solution of the water saturated in the lead contaminant was found to have an osmotic pressure of 0.380 mm Hg. The data was collected at 25°C.

The gas constant is 0.08206 L atm K-1 mol-1

Weight Percent Analysis of Contaminant
The sample was found to contain the following: 85.9% lead

There is at least one other element present, the identity of other elements was not able to be determined.

Weight Analysis of Precipitate Formed by Addition of Sodium Sulfide
Sodium sulfide was added to a 10.0 L sample of contaminated water until its concentration was 0.01M. A black precipitate weighing 0.010g formed.

Discussion of the Case Studies

General techniques for use in scientific case study/discussion classes

Our purpose in incorporating case studies into Introductory Chemistry classes is to provide a format in which students can apply newly acquired knowledge, thereby consolidating and deepening their understanding of it. Additionally, they develop their skills in communicating scientific information, exercise and strengthen their problem-solving abilities, learn to appreciate the connections between apparently isolated chunks of material, and see the utility of what they have learned in realistic situations. The student-to-teacher and student-to-student dialogue that accompanies a good discussion provides valuable feedback to the teacher on the status of student comprehension and is particularly valuable in drawing out and exposing misconceptions, many of which would otherwise remain buried, only to surface in later courses, if at all. While a detailed account of discussion techniques is beyond the scope of this article (several of the references contain excellent descriptions of the philosophy, methodology, and scope of

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case study/discussion teaching), we include some observations pertaining to promoting discussion in science classes in general and with these three cases in particular.

It is important for the success of any discussion class that the instructor's activity shift from telling (lecturing) to questioning, probing, and facilitating student discussion [6]. True discussion is not to be equated with the Socratic method, for in the latter the teacher leads the students to predetermined conclusions along a single path of reasoning, whereas a genuine discussion is inherently unpredictable, and the instructor must be prepared to relinquish some control. Student questions should, as far as possible, be redirected to other students. In technical courses, however, there often are correct and incorrect answers and modes of thinking that must still somehow be conveyed by the instructor [7]. In the event that by the end of the discussion, important points remain unresolved, divergent student opinions are not reconciled, or the relevant has not been clearly distinguished from the irrelevant, the teacher may find it necessary to clarify and settle these issues in a closing summary. Instructors may find that discussions involving technical scientific material need to be more tightly focused and more highly structured than discussions in nontechnical courses. They may discover that very specific and unambiguous questions can guide the discussion to a deeper and more complete analysis than broader, open-ended questions. Open-ended questions should be used with caution, for unless they are carefully crafted in a fashion that encourages students to describe their reasoning process they are apt to elicit shallow responses. For example, in Case Study 1, if the first question asked is "Which is the best of the five balloons?" the response likely will be unproductive (even if correct) because students have not been challenged to think about the many issues involved in the problem. It might be better to ask questions such as "What happens to air pressure as altitude increases?" or "Why will the carbon dioxide balloon not float?" and other such questions that focus attention on the core scientific material. Alternatively, students could be questioned as to how they would determine which balloon is best. This can then lead to consideration about what calculations and chemical principles come into play in analyzing the case.

The blackboard can be a valuable asset in directing and summarizing a technical discussion. As major points emerge, judicious placement of student comments on the board can lead, at the end of the session, to a written and logically organized case analysis that leaves students with a sense of wonder and pride at what they have achieved. Student comments that are correct, but tangential to the discussion, can be acknowledged by placing them on a side board. Some practitioners of discussion

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teaching advocate the preparation of a blackboard outline prior to the class [8]. This may be particularly important where extended numerical calculations are involved.

Case Study 1

This is a deceptively simple case. Depending on the available time and the degree of preparation of the students, it can be explored at a number of levels of detail. We have used this case to support both small-group and full-class discussions. Either way it is important for the teacher to have a well thought out plan of questions to lead the students into the desired areas, otherwise they may very quickly come to an ill-conceived conclusion that misses much of the scientific content.

As illustration of the different levels of detail that can be explored, a question about which balloons will get off the ground can be answered (1) simply by recourse to students knowledge of which gases are more dense or less dense than air, (2) by calculation of gas densities based on formula weights and the ideal gas equation (with the additional complexities of gas mixtures in some of the balloons), or (3) by an even more detailed examination of Archimedes's Principle. We have found that students at this level have little or no feel for the degree of precision to which a calculation need be taken in order to answer a simple yes/no question of this kind; that is, they have not developed an ability to estimate, or an understanding of where an estimate is called for in a scientific context. This is especially the case for students who are accustomed to routine problem solving exercises.

A following question may ask what will happen to the balloons as they rise into an area of lower air pressure. It is by no means obvious to all students that diminishing atmospheric pressure will cause the balloons to expand (in this regard, the demonstration of a balloon in a vacuum desiccator expanding as the air is pumped out is useful) and discussion of this point can lead to considerations of pressure equalization and Boyle's Law. Subsequently the effect of decreasing temperature on each balloon's size can be considered, and discussion of the relative magnitude of changes associated with variations in pressure and temperature should indicate the need for some calculations.

A question asking if any of the balloons will burst can lead to use of the ideal gas equations to estimate the size of the balloons when they reach the desired height. This will lead to the conclusion that balloon (iv) has a volume of 149.7 L and is on the point of bursting. At this point we have found that many students express the opinion that this

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is the best option, based on a spurious notion of optimization, again probably fostered by numerous routine calculations in previous courses. The idea of uncertainty can now be introduced into the discussion, both in terms of the significant figures in the calculations in relation to the uncertainties in the numerical data for this real-world situation, and, if desired, in terms of nonideal gas behavior. The requirement for a suitable margin-of-error in a real life situation where numbers are uncertain should emerge from the discussion.

We have found that some students raise the issue of chemical reactivity of the gases, citing the inertness of helium as a relevant consideration. The likelihood and possible nature of any chemical reactions can be discussed, and the relative importance of the physical versus the chemical properties of the gases in this situation will, one hopes, emerge.

Case Study 2

In this study the "case" is a molecule. Nicotine was chosen because of current concern and debate relating to the tobacco industry [5], but other interesting molecules (aspirin, AZT, etc.) could be substituted. Focusing on a molecule and its various physical and chemical properties cuts across the traditional chapter organization of most General Chemistry texts, and allows students to integrate their knowledge of chemical formulae, molecular structure and shapes, thermochemistry, etc., in a single application. The classes are organized as small group discussions, each group of four to six students focusing on a different aspect of nicotine's chemistry and sharing information with other groups before finally reporting to the class as a whole. This models, in a rudimentary way, the process in which groups of scientists investigate a problem and share information before reporting their findings to the wider scientific community. We have found this case study to be a useful form of review prior to a test or of value to assess the retention of material from first semester Introductory Chemistry in second semester students.

Case Study 3

The lead pollution case also allows students to integrate knowledge from various parts of their Introductory Chemistry course and is conducted in small groups that need to share information with other groups in order to make the problem simpler. Some groups work on identifying the source of the lead pollution, others on lowering the levels of lead in the water, and still others on a quality control test to determine when the lead level

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has been reduced to an acceptable level. This division of labor models, on a simple level, the division of labor found in scientific laboratories. We have observed that students charged with using their knowledge of solubility product constants to develop a quality control test based on precipitation had a difficult time. This portion of the case requires that students bring several different concepts and calculations together. An expanded format may be helpful in enabling students to apply their knowledge to this problem. For example, students can obtain information from outside of the classroom setting or in an associated laboratory experience. The use of more case study/discussion experiences in Introductory Chemistry should build students' skills in approaching these types of questions.

Conclusion

The cases we have described are amenable to adaptation, modification, and embellishment according to the needs and interests of teacher and students. We offer them not only for their direct utility in the classroom, but also as illustrations of different case styles that we hope will stimulate and assist instructors in writing their own cases.

Student responses to each case study were examined through questionnaires in which students were asked: (1) if the discussion was helpful to their understanding of the material, (2) if the discussion was of value as a classroom activity, and (3) if the discussion was of use in helping them to see how the material they learned can be used in realistic situations. For all three questions the student responses were very positive; almost all students reported that they found the activity to be of value and helpful to their understanding. One trend we have noted is that in sections where more time is allotted to the discussion activity, the responses are more favorable. A full 50-min class period is recommended for case studies 1 and 2, and even more time (75–100 min) for case study 3. If discussion is brought to an end prematurely the students may be left confused and frustrated. A 2–5 minute summary by the instructor can help to focus attention on what has been learned and bring a sense of closure. In any event, a discussion class with its inevitable false starts, dead ends, and back-and-forth flow is less time efficient than a lecture. A successful discussion takes time to explore the nooks and crannies of the subject "territory" rather than marching through in a linear fashion. The dialogue of discussion teaching creates opportunities to focus on process in addition to content. It also provides what lecture cannot—an insight into what the students are really thinking.

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