The Year-Long First Course in Organic Chemistry

A Review

A. William Johnson
The University of North Dakota, Grand Forks, ND 58202

During the 1988–1989 academic year the author was privileged to receive a sabbatical leave to prepare for teaching the year-long first undergraduate course in organic chemistry in the fall of 1989. As part of this preparation a project was designed to study how the organic chemistry course currently was being taught at a number of well-known institutions in separate parts of the country. Rather than relying on the usual mail survey, this project relied on personal visits by the author with the faculty member(s) responsible for teaching the course, and doing so in their offices and laboratories. This article reports the results of this study with the hope that it presents a useful snapshot of the state of organic chemistry teaching at the college-level in 1988–1989 and may be of use to others in thinking about the present and future nature of such a course.

On-site visits were made at 33 colleges and universities. The institutions did not represent a statistical sampling, neither were they chosen at random. Instead, they were chosen mainly on the basis of being in three geographic clusters to which the author would have personal access during the year. Institutions were included only if they had an ACS-approved undergraduate chemistry program, as published annually in *Chemical and Engineering News*, and had a recent record of having at least eight certified and/or noncertified graduates per year. Five institutions were visited in the Interstate-25 area of northern Colorado and Wyoming, seven were visited in southern Minnesota, 17 were visited in New England, and four other separated institutions were visited. Of the 33 institutions visited, 21 were private and 12 were public institutions. The 12 public institutions all were universities that offered undergraduate and graduate education in chemistry. Of the 21 private institutions, 12 were four-year liberal arts colleges offering only undergraduate programs while nine offered graduate and undergraduate work in chemistry. A list of all of the institutions visited is in Table 1.

The courses of particular interest were those first undergraduate courses in organic chemistry that enrolled sophomore and junior students and in which the major populations usually were premedical students, other preprofessional majors, biology majors, chemical engineering majors, and chemistry majors. Information was obtained with respect to 35 different courses, one at each institution visited except for two courses at each of two public universities. At 28 of the institutions there was a single year-long organic chemistry course offered with chemistry majors and nonmajors both enrolling. At five of the institutions separate courses were offered for chemistry majors and nonmajors. At two of those institutions information was obtained regarding both courses. At two others, information was obtained regarding only the nonmajors course. At the fifth institution information was obtained regarding only the majors course.

Table 1. Institutions Visited

Amherst College	
Boston College	St. Olaf College
Bowdoin College	SUNY–Albany
Brandeis University	Tufts University
Carleton College	University of Colorado
Colorado School of Mines	University of Connecticut
Colorado State University	University of Massachusetts
Dartmouth College	University of Minnesota
Denver University	University of New Hampshire
Duke University	University of North Carolina
Gustavus Adolphus College	University of North Dakota
Macalaster College	University of Wyoming
Mankato State University	Wabash College
Mt. Holyoke College	Wellesley College
Rensselaer Polytechnic Institute	Wesleyan University
Smith College	Williams College
St. John's University	Yale University

A letter first was written by the author to the chemistry department chairperson at the institution soliciting the department's willingness to receive the author for the specified purpose, and the faculty member(s) responsible for the course(s) was provided a single-page form for completion and return to the author if he/she was willing to be interviewed. This form requested logistical information relating to planning a visitation schedule involving several institutions per trip, some basic information about the course, such as hours of instruction, weekly schedule, texts, student population, etc., and solicited permission for the author to sit in on a class session if the travel schedule permitted. Most institutions contacted responded, and every faculty respondent agreed to the latter request. Each institution was visited by the author personally, usually for one-half day. This usually offered time to meet privately with one or two faculty members each for about 1 h, to sit in on the class or a portion of it, to visit the organic chemistry laboratories, to see the chemistry library, and usually to get to the bookstore. A single-page standardized form, one for the lecture course containing eight questions/topics for discussion, and a separate one for the laboratory course containing nine questions/topics for discussion, each with space for notations, was designed and used by the author during the interviews with faculty members to record information, observations, etc. In addition, the author collected syllabi, old examinations, problem sets, laboratory outlines and instructions, and other related materials from many of the faculty members visited. Because this course is offered on a Monday-Wednesday-Friday schedule at the vast majority of institutions it was not possible on a week-long trip to sit in on a class every day. Out of the 35 courses discussed with faculty members, the author personally sat in on 19 class sessions. This article will report the findings of this study, some of which are of a quantifiable nature, but most of which are judgements or impressions gained by the author based on the interviews. Aspects of the lecture portion of the course will be presented first, followed by discussion of the results regarding the laboratory portion of the course.

The Lecture Course

Lecture class sizes varied from 17 to 170 students, with an average of about 70 and a median of about 65. Five of the institutions operated on quarters, while the rest were on semesters. Because of the differing terms, numbers of class periods, and class lengths encountered, lecture class contact time was calculated and compared on a yearly basis. The average class time was exactly 4200 min per year (i.e., equivalent to two semesters, 42 periods per semester, 50-min class periods). Eighteen courses provided 4200–4500 min, seven provided 3900–4200 min, and five provided less than 3900 min. Three courses provided about 4700 min, and two provided more than 5200 min per year. One institution provided as little as 2800 min for the course for the year, while at the other extreme one provided 5460 minutes of class time. Actual class sessions ranged from 45 min to 180 min. Twenty-three institutions used the 50-min class period, but nine used 60–75-min periods.

Information was obtained on the textbooks currently being used in the courses. A total of 10 different texts were in use, and the frequency of each is shown in Table 2. Interestingly, the current text was in its first or second year of use in 14 of the courses, and an additional six courses intended to change textbooks for the next year. Clearly, there is considerable mobility in the organic textbook market. Most faculty seemed to feel that the current textbooks were far too large, and expensive, for the year-long course, and many reported being frustrated at having to spend time indicating to students those sections for which they were *not* being held accountable! Most faculty indicated that they follow the textbook sequence of chapters, with the frequent exception of the spectroscopy topics.

When asked how and when they dealt with spectroscopy in the lecture course, most faculty reported deviating from the textbook sequence. A few faculty leave all discussion of and practice with spectroscopy to the laboratory course, while a few others provide no laboratory discussion of spectroscopy. Very little lecture attention seems to be given to UV spectroscopy and to mass spectroscopy, with the latter most often mentioned only briefly with respect to molecular weight determination. The most common schedule for discussing the other two spectroscopies, IR and NMR, seemed to be about the end of the first semester or the beginning of the second semester. Two major patterns emerged, with the first being dealing with both IR and NMR in that sequence after having discussed aromatics, and the other pattern being following discussion of alkenes, alcohols, and alkyl halides, but before aromatics. In most instances, IR spectroscopy was being discussed well before a consideration of carbonyl chemistry, even though the latter provides perhaps the most instructionally useful examples of its use. With regard to NMR, initial application was being made to alkane, alkene, alcohol, and aromatic structures that already were familiar to the students. A few faculty introduced the topic of NMR using C-13 spectroscopy before dealing with proton spectroscopy, the latter apparently appearing more complex to students. Most faculty expected their students to be able to use IR and NMR spectroscopy to solve structural problems on examinations, and most faculty made reference to such spectroscopies as subsequent functional groups were encountered.

Table 2. Frequency of Lecture Textbook Usage [by Author(s)]

McMurry	9 institutions
Morrison and Boyd	5
Wade	5
Streitweiser and Heathcock	4
Solomons	3
Loudon	3
Fessenden and Fessenden	2
Pine	2
Vollhardt	2
Carey	1
total	36

Virtually all faculty are discussing mechanisms to a considerable extent and using them to explain and correlate the behavior of functional groups. Using mechanisms as a "conceptual framework" or a "unifying thread" was a frequent response. Only a few faculty were not using the functional group organization for their course. The majority are using the free radical halogenation of alkanes for the first detailed examination of a mechanism, as do most textbooks, and to be taking the time to provide detailed evidence for the current mechanistic theory for that reaction. Some faculty appear to not spend as much time on evidence for the ionic mechanisms, carbocation- and carbanion-based, which are most prevalent throughout the rest of the course. Most subsequent mechanistic presentations seem to involve presenting the mechanism as a *fait accompli* without detailed substantiation.

Information was obtained from faculty regarding the extent to which they incorporated special topics, or "real-world chemistry," into their lectures and the manner in which they did so. Three basic patterns were observed: (1) waiting until the end of the course to present a few lectures on appealing topics such as proteins, carbohydrates, lipids, etc., such as is often included in the late chapters of most textbooks; (2) incorporating a full lecture periodically into the course on a topic of interest and relevance to the chemistry being discussed, such as terpene biosynthesis or polymer chemistry; (3) pausing during a lecture to include a brief dissertation on a special topic. A count indicates that about one-half of the faculty followed the first pattern, with many admitting that the topics received little attention because time was running out at the end of the course. About one-eighth of the faculty followed the second pattern and selected up to one-half dozen topics to cover during the semester. About three-eighths of the faculty followed the third pattern. Topics included in the various patterns ranged very widely, but a few examples are pheromone chemistry, polymer chemistry, chemical contraception, CFC's, industrial routes to bulk chemicals, mental drugs, methyl *t*-butyl ether (MTBE), chemical warfare, terpenes, DNA, and pesticides. The general impression obtained was that most faculty do not give a lot of attention to such topics, because the time would come at the expense of some of the standard organic chemistry that needed to be covered.

The means used by faculty to test students were determined and it was found that there was a great deal of uniformity. Only a couple of faculty gave a "practice" exam before a class exam. Only seven out of 35 faculty gave in-class short quizzes with any regularity. All gave regular in-class examinations, with the number ranging from one to five in the term. Three was the most common number, and frequently those who gave more exams dropped the student's lowest score in calculating the course grade. All gave a final examination in the course, with all of such exams being partially over the entire term's content, with the remainder of the final examination covering the last portion of the course on which the students had not been previously examined. Twenty-two of the faculty never use the ACS standardized examination in chemistry, and many of these faculty seem to ignore it as a matter of principle because it is a multiple-choice examination. The other 13 faculty use it occasionally or regularly in the final term of the year-long sequence. Twenty-two faculty regularly assign problem sets to their classes, most drawing directly upon the text they use, but most faculty (28 out of 35) did not grade problem sets. Some discussed parts of them in class, and others had teaching assistants review them in discussion sessions, but most did not follow up on the assignment.

Faculty were asked about the future directions they saw being needed for this course. Answers ranged widely, but they virtually all came around to the same problem—the amount of time available for this course. Most agreed it was unlikely to receive more time in most curricula, so, in order to include more subjects, something would have to go. At the same time, most faculty agreed that their incoming students are not coming to the course with a significantly better background in chemistry. When asked what they would cut from the present course, many had no ready answer, but a few suggested less time for that introductory material which is a review of freshman chemistry. Others suggested cutting the attention given to many name reactions that are less used nowadays, and others would take time from nomenclature. Many complained that there was no leadership on this problem coming from the textbook writers and publishers, and that the texts were just getting continually larger, compounding the problem. Authors were viewed as simply adding new material to already over-full texts and seldom eliminating any content, leaving that tough choice to individual faculty members.

Topics suggested for inclusion in courses in the future included bioorganic chemistry, including the use of enzyme catalysts in organic synthesis, molecular design, computer modelling, computer-based synthesis, organometallic chemistry, surface chemistry and catalysis, more carbanion chemistry (and less carbocation chemistry), and more emphasis on the real-world examples of organic chemistry. A number of institutions either have or are contemplating the introduction of a third semester of organic chemistry for chemistry majors that would, in part, deal with some of these topics as well as with topics such as spectroscopy, molecular mechanics, molecular orbital theory, complex syntheses, etc.

The Laboratory Course

Most of the courses reviewed included a laboratory as a required part of the course. However, a few institutions offer the laboratory as a separate course, most often with a different instructor, and students thereby have the option of not taking the laboratory. However, for most curricula the laboratory seemed to be required. In such instances, however, many students would only take the first term (quarter or semester) of laboratory, depending on the requirements of their major field of study.

Laboratory time in courses averaged 97.6 h for the year, with the smallest number being 63 h and the largest being 168 h. Seven courses had less than 80 h per year, five had 81–89 h, 11 had 90–100 h, four had 101–110 h, three had 111–120 h, and five had more than 121 h of laboratory for the course. Most courses operated for the full academic year (two semesters or three quarters), but four institutions only offered two quarters of lab and five institutions operated the lab for the second semester only, but usually with double the usual hours per week. There are two obvious advantages to the latter schedule—the students can learn the initial laboratory techniques in conjunction with an experiment on a chemical reaction they previously have studied in lecture, and the usually numerous dropouts from the first semester do not take up scarce laboratory space. Twelve institutions offered lab for three hours per week, 13 had four hours, five had five hours, and six institutions had six or more hours per week of laboratory. Some institutions offered a pre-lab lecture within the lab time, but many had an additional hour per week available.

Information was obtained on the laboratory texts used in the various courses. A total of 10 different texts were in use, in addition to 11 institutions not using a text, instead choosing to prepare their own laboratory manual. Two institutions used two texts, leading to a total of 37 items in the list for 35 courses. As is traditional, faculty were very selective in the experiments they choose to use from the texts. Faculty seemed to particularly appreciate those texts which contained essay-type content on the background of the experimental techniques being studied. The frequency of text use is in Table 3.

Table 3. Frequency of Laboratory Textbook Usage [by First Author]

Pavia	7 institutions
Williamson	6
Fieser	3
Fessenden	2
Landgrebe	2
Mayo	2
Ault	1
Lehman	1
Mohrig	1
Moore	1
total	26

All faculty stressed the need for students to be well prepared for each laboratory in order to learn and appreciate the significance of the experiments and to get way from the "cookbook" approach. Faculty have devised a number of means to ensure that students are well prepared for laboratory work. These include requiring students to hand in a "pre-lab write-up" before gaining entry into the laboratory, giving a short quiz on the experiment before it is conducted, and even going so far as to prohibit students from taking their lab text into the laboratory.

There is very little use being made of movie film, film strip, or video instruction in the laboratory. A very few are using film strips, generally quite old, and a couple of institutions have made their own videos for instruction in particular experiments. Use of video for experimental technique demonstration, instrument usage instruction, or for instructing on the theory of various spectroscopies would seem to be obvious, but it has made almost no inroads in organic chemistry courses.

As expected all faculty seemed to appreciate the importance of safety procedures, potential hazards, and waste disposal. However, the extent to which this was emphasized seemed to vary considerably. Some relied on the preamble to the lab text and to each experiment to alert students, some gave a formal safety lecture, and others prepared extensive handouts and/or sign-off sheets for students. A few institutions required students to take a safety examination after such instruction and before being permitted to commence work in the laboratory. A couple of institutions relied partially on a videocassette presentation on safety. Some required students to look up toxicity data regarding their reagents for each experiment. Many institutions have cut the quantities of reactants to minimize the waste disposal problem, and some experiments simply are no longer conducted because of safety considerations.

A long-standing problem in organic chemistry instruction has been the basic philosophy behind the laboratory. Is its purpose to support and exemplify the material covered in lecture, or is it to be free-standing? If the purpose is the former, and most faculty seemed to agree with that approach, then it should be coordinated in with the lecture content and schedule. However, in most lecture courses it is some time before organic chemical reactions are discussed, so the laboratories usually "stall" by initially teaching techniques on materials provided to students and later conducting actual reactions when the lectures catch up. Ideally, it would save time to be able to teach techniques using the products from various experiments that also exemplify some reaction chemistry. Some faculty paid close attention to coordinating the timing of preparative experiments with lecture coverage, but many did not. No general solutions to this problem were observed other than not to have lab the first term and to have more lab hours in the second term.

Computers were almost totally absent from the organic laboratory course, the only exceptions being a couple of institutions that were using them for simulating NMR spectroscopy, one that used them for "drill-type" supplemental learning and one that used them for retrosynthetic analysis. Many faculty spoke of future possibilities, including simulations, molecular modelling, and computer-based synthesis, but these applications seemed not to be imminent in most instances.

Inquiries were made regarding the instrumentation available to students in the laboratory. Most laboratories did not use or show UV or mass spectroscopy in the laboratory. Only a few showed and allowed students to use polarimetry. The majority of labs had a GC experiment conducted by the students, and 21 of these allowed or required students to present GC spectra for all of their subsequently prepared liquid products. Infrared spectroscopy was in widespread use, with 24 institutions providing hands-on use and 17 of these permitting or requiring students to characterize subsequent preparations by IR spectra. Six institutions provided a "dry lab" experience with IR spectra, usually showing the instrument in operation to students but not letting them operate it. Three institutions did not have an IR experiment or experience for students in the lab, although they did cover the topic in lecture and expected students to be able to analyze spectra.

The picture was more diverse regarding NMR spectroscopy. The 33 institutions handled NMR in the laboratory as follows: nine provided a hands-on experience, with only a couple allowing students regular access thereafter; six showed the instrument to students with a laboratory assistant operating it, and at a few institutions that assistant would be available to run spectra for students throughout the term, usually on an overnight basis; eight institutions provided a "dry lab" experience only; two institutions provided a computer-simulation experience used by all students to obtain NMR spectra, usually in conjunction with an experiment on unknowns; eight institutions provided no laboratory experience regarding NMR spectroscopy, although they did cover it in lecture and expected students to be able to analyze spectra. When dealing with organic qualitative analysis experiments, most institutions provided the spectra to students, only a few allowing students to obtain the various spectra themselves.

The extent to which microscale experiments were being introduced to the laboratory was an obvious topic of discussion in view of the considerable publicity surrounding the topic in recent years. The status of the 35 courses with respect to using microscale laboratory equipment and experiments was as follows: five were using it at present for the entire course; five had used it and had now reverted to a "regular" scale; 18 had considered its use but had decided to not introduce it, usually for practical or philosophical, and not financial reasons; five were using it in part of the course; two used it for one term only, using a "regular" scale for the other term(s). In addition, two institutions had introduced the use of microscale into their advanced organic chemistry laboratory instead. The advantages most often cited for the use of microscale included the compactness of the equipment, and therefore the smaller locker/drawer space required for each student, the safety factors resulting from lower amounts of chemicals being present, a diminished waste disposal problem, an economic advantage due to smaller amounts of chemicals used during the year, and a few cited the forcing of students to learn better lab techniques more quickly. The reasons most often cited for not using microscale equipment in this course included the observation that most students obtained very little, if any, product from the liquid-producing experiments, resulting in an unsatisfactory lab experience (the same complaint was not heard for experiments producing solid products), the difficulty most students had learning small-scale technique without having first mastered larger scale techniques, the absence of separatory funnel experience, the lack of experience with exothermic experiments done on a larger scale, and the absence of what is a necessary part of organic chemistry, particularly as experienced in industrial laboratories—the preparation of larger quantities of starting materials for research. Most teaching laboratories are now using ground glass equipment, with most of that equipment being of smaller scale than in pre-ground-glass days, and many faculty reported doing a number of very small scale experiments with such ground glass equipment. A number of faculty seem to feel that what is needed is neither large-scale nor microscale laboratories, but a mixture of scales being presented in each laboratory, starting out with larger size experiments for the development of initial experience. Most faculty also report that they have cut the scale of many experiments from that presented in the laboratory texts to achieve some of the advantages cited for the microscale labs. Many speak of a "miniscale" as being most appropriate. Most institutions are not financially prepared to invest continuously in both microscale and regular-scale equipment, and some of the ground glass kits seem to be adaptable to all three scales—micro, mini, and preparative.

Finally, with respect to the laboratory portion of the course faculty were asked about future directions, which in many cases came from perceptions of present problems needing solutions. A number of faculty are concerned about the continuing lack of integration between the lecture topics and the laboratory experiments, and some are considering the solution of reserving laboratory for the second term of the course, as is now the case at several institutions. This would also help in controlling the costs of the course, especially the number of student places required and the amounts of materials to be purchased and discarded as waste. Most faculty want to see the lab become more realistic as to how organic chemistry is done today, and that means the incorporation of more, and more sophisticated, instrumentation into the experiments, and the provision of more hands-on opportunities for students. A number of faculty instead see a major potential for the use of computer simulations of instrumental techniques, and even of experiments themselves. A resolution of the micro–mini–macro issue in the scale of experiments seems to be evolving.

There were many suggestions regarding kinds of experiments that should be incorporated into the laboratory experience. Mentioned were more experiments that emphasize more multistep syntheses, experiments that generate data that resolve questions of mechanism (e.g., kinetic data via NMR), experiments that emphasize analysis, such as relating to pollution/contamination questions of the modern world, experiments at the bioorganic frontier, such as enzymatic catalysis, experiments involving organometallic chemistry, and more experiments with polymers, not just their preparation but studies of their properties. Some faculty still maintain that the laboratories are "too cut and dried", "too dull", and that more opportunity for ingenuity must be provided if we are to attract bright science-oriented students into chemistry as a field of study. No longer requiring every student to work with the same compound in an experiment is seen as essential by some and is already practiced by one institution.

Conclusions

Suffice it to report that faculty are thinking seriously about their courses and seeking their improvement for students. They are constrained, but not totally inhibited, by three major factors: (1) the time allowed in the curriculum for the subject of organic chemistry seems unlikely to increase, even though the knowledge and understandings to be communicated to students continues to increase at a fantastic rate; (2) there are serious limits to the funding available for upgrading the equipment in laboratories; and (3) the national concern with safety and waste disposal limits significantly the experiments that can be used as teaching tools.

The initial purpose of this review was to serve the author's own purposes of self-development and application to his future teaching responsibilities, so it would be presumptive to suggest to others how the modern organic chemistry course should be revised. However, the following aspects now are being addressed by the author in his course:

1. A serious attempt is being made to make this course more interesting to the clientele—to create numerous opportunities for relating the subject to their fields and/or to societal issues. The importance of chemistry in their eyes should be enhanced, and a few students might even be converted to chemistry majors—the discipline certainly needs recruits! Why leave much of the exciting chemistry with biological implications to the biochemists in subsequent courses? Special topics are not being left to the end of the lecture class but are being worked in throughout the terms.
2. With the course already "over-full" of content, time for the above needs to be released. The comprehensiveness of the treatment of some subjects is being reduced, retaining those reactions that still are important and used, but foregoing discussion of some that have been around for a long time but really are not used much anymore. Some carbonyl chemistry is a good example of a topic ripe for cleansing in the first organic course.
3. The first detailed mechanistic experience will be with carbocation chemistry, as the base from which many of the first-semester reactions will be discussed, and not with free radical chemistry. *The latter will be covered toward the end of the first semester.*
4. Our laboratories will be improved considerably through enhanced instrumentation, and new experiments will be designed to incorporate such in the regular routine. In addition, the application of simulation processes will be explored.
5. Infrared spectroscopy will not be presented until after carbonyl compounds have been discussed.
6. The laboratory schedule has been reorganized and several steps have been taken to provide more time for the experimental work, so that the lab will be less of a "rat race" and the major accomplishment in the eyes of students will not be just having finished *the experiment!*

Acknowledgment

The author acknowledges the financial support of the *Office of Instructional Development at the University of* North Dakota, which supported the travel undertaken in pursuit of this project. Also acknowledged is the kind hospitality, cooperation, and interest of the many faculty members located at the institutions named and visited in the *course of the project.*

A Simple Model for Visualizing an Organic Extraction

In an extraction experiment, the separate water and organic layers are easy to see, yet students often have difficulty visualizing the process at the molecular level. We have developed a model that provides a concrete and effective way to demonstrate the tendency of molecules of like polarity to associate with each other during the extraction.

Materials and Construction

Materials needed for this model are a shallow uncovered cardboard box roughly 45 cm long, 30 cm wide, and 5 cm deep (readily available at a local grocery store from soup or pet food can cases); some colored paper (red and blue work nicely); *about 14 5-cm diameter Styrofoam balls; some Velcro; and a red magic marker.*

The model is quickly and easily constructed. First divide the bottom of the cardboard box across the short dimension to form two equal sections, each about 22 cm × 30 cm. Use the red and blue colored paper to cover the halves. On the blue half, glue or (if you have adhesive-backed Velcro) stick on 2- × 2-cm squares of Velcro (loops) in three equally spaced rows and three equally spaced columns. Be sure that no row or column is closer than 9 cm to any wall of the box. Also, the rows and columns should not be closer than 6 cm to each other. Finally, color half of the Styrofoam balls with the red magic marker, and glue or stick on 6–8 2- × 1-cm equally spaced pieces of Velcro (hooks) on each of the remaining white Styrofoam balls.

Procedure

Explain and demonstrate an organic extraction in the usual manner. Then use the model to improve students' visualization of the molecular process. The two colored *sections of the box represent the two immiscible layers, aqueous* and organic, in an extraction flask. The red section represents the nonpolar "organic" layer of the extraction, and the blue layer represents the polar "aqueous" layer. To begin, place all 14 balls into the box. The white Styrofoam balls (with Velcro) will represent the nonpolar molecules of a solution to be extracted. Then, by slowly tilting the box back and forth, the mixing action of the extraction flask can be simulated. When the box is tilted, the balls roll around and collide with the walls of the container and each other. As this tilting action continues, the white Styrofoam balls (with Velcro) will stick in the blue section (with Velcro) of the box, and the red Styrofoam balls (with no Velcro) will be left in the red section of the box (with no Velcro). This demonstrates a simple organic extraction in which polar molecules are extracted into an aqueous phase and the nonpolar molecules are extracted into an organic phase.

It is also interesting to note that sometimes the balls with Velcro will stick to each other, just as molecules with OH groups will associate through hydrogen bonds.

This model was demonstrated May 6, 1989, at the Thirty-Second Annual Undergraduate Research Symposium of the Minnesota Section of the American Chemical Society.

John W. Hill
Joseph P. McGurran
University of Wisconsin—River Falls
River Falls, WI 54022