TEACHING A PRE-HEALTH PROFESSIONS-ORIENTED COURSE FROM LOUDON/PARISE 6E

Introduction

The HHMI (Howard Hughes Medical Institute) and the AAMC (American Association of Medical Colleges) have advocated, since 2009, that the organic chemistry course taught to future health professionals be changed from a synthesis-oriented course to a course that stresses topics more relevant to human medicine. The AAMC conducted a survey of medical students and practicing physicians that had as its goal a discovery of the topics believed to be most important to their practice. We have relied heavily on this survey for topic inclusion, although this information did not solely determine what material made it into our course. We have been teaching such a course at Purdue since 2011, and the purpose of this document is to share our ideas about how such a course might be organized while still using Loudon & Parise 6E (subsequently referred to as LP6). The text contains material that is suitable for a "traditional" course, but it also contains new and unique material not found in any other textbook that can be used for the biologically oriented course. The ideas here are not meant to be a rigid blueprint, but rather one of many possible solutions to the design of such a course. We hope that users might benefit by using these ideas as a point of departure for their own courses. The topic is organized by period, with a 43-period course, three 50-minute classes per period, in each of two semesters as the basis. (At Purdue, the two "missing periods" required to round out 15 weeks are national holidays [Labor Day in Fall, ML King Day in Spring] and one period off each semester to make up for an evening examination. Two cancelled laboratory periods make up for the other two evening examinations.) Our course is accompanied by a 3-hour lab, once per week, that is either a wet-lab or dry-lab, depending on the topic. We can provide a schedule of laboratory exercises on request.

When we subscribed to the idea of a non-synthetically-oriented course, this did not imply a belief that synthetic design is not an important and valuable problem-solving aspect of organic chemistry. Rather, it has been clear from the medical-education literature, and from our own experience, that students venturing into pre-medical education are not very motivated to learn the significant vocabulary of synthetic reactions needed to solve synthetic problems. We have chosen to substitute a more bio-organic/medicinal/mech–anism focus into our organic course. On course evaluations, our course scores typically 4.5/5.0 in the Likert question, "I understand the relevance of organic chemistry to my profession." We repeatedly hear students say after class, "We just studied that topic in biology; now I see how it works chemically." Our earlier, synthetically oriented, course scored about 3.9/5.0. We explicitly set out to develop a rigorous course that contains plenty of problem solving, not a "watered-down" course.

The student who completes this course satisfactorily and wants to get involved in research in organic synthesis is well prepared to read and understand the sections of the text that deal largely with synthetically important reactions.

It will probably come as no surprise that the biggest changes occur in Semester 2, where we deal with the functional groups that are more common in biology. In Semester 1, we lay the same types of foundations in structure, acid–base chemistry, stereochemistry, and reactivity that are used in a traditional course. Laboratory examples are important in establishing these foundations. But there are important differences. For example, a major section on noncovalent intermolecular interactions is provided that ultimately allows us to describe protein structures in some detail midway through Semester 1. Enzyme catalysis is introduced, first, as an abstract concept; but, as protein structure is developed, the concepts of an enzyme and an enzyme active site take shape. The idea of intramolecularity as a major aspect of enzyme catalysis is introduced in Semester 1. As the course proceeds, an increasing number of biological concepts and examples appear. By the end of Semester 2, we are dealing with carbohydrates, proteins, phosphate esters/anhydrides, and coenzymes. One goal of our course is to induce students to confront large molecules—drugs, proteins, carbohydrates, and coenzymes—early on, and to deal with them fearlessly in terms of small-molecule models.

Our course is not a biochemistry course. Rather, it is a course that stresses the chemistry likely to be encountered in a biochemistry course.

Accompanying this document is a Power-Point presentation with the essence of this document in a less detailed format.

Semester 1 (*Abbreviations:* S1 = Semester 1, S2 = Semester 2)

Periods	Topic(s)	LP6 Reference	Comments/Rationale
1–3	Structure and bonding	Chapter 1	This section follows the text closely. If students have had a good general chemistry (or AP) training in chemistry, this material can be assigned and diagnostically tested in the first week without explicitly covering it. This strategy would leave more time for other topics. The exception is MO theory, which generally requires specific coverage.
4–6	Alkanes and functional groups	Chapter 2, Chapter 27 (Introduction) and Table 27.1, pp. 1376–1377	This section follows the text closely. Modifications of this section can include introduction of amino acids and focusing on the side-chain functional groups. The text provides support for treating metabolism as a form of combustion (Sec. 2.7B). Physical properties can be skipped and covered in Periods 24–27.
7–10	Acids and bases	Chapter 3; Chapter 27, Sec. 27.3	This section follows the text closely. Our course has a very strong acid–base and mechanistic emphasis. Therefore, we devote lots of time to this chapter, including drawing resonance structures, the use of pK_a, and the use of free-energy diagrams to rationalize the effect of structure on pK_a. The pK_a values of drug molecules, carboxylic acids, and amino acids provide both laboratory and biological examples for all of these topics.
11–16	Alkenes, dienes, and alkynes; reaction rates; carbocations	Chapter 4; Chapter 14, Sec. 14.1, 14.2, 14.4, 14.5A, 14.6A; Chapter 15, Sec. 15.1; Chapter 5, Sec. 5.2–5.3, 5.6–5.7, Supplement on Biopolymers	Except for enzyme catalysis, these topics are not strongly biological, but are chosen to provide adequate foundation for mechanisms and other topics to come later. Chapter 4 is followed closely; only selected parts of Chapters 14 and 15 are used. Some comments on this section 1. Alkenes and alkynes are covered together. 2. The structures and stabilities of conjugated dienes are introduced with π MOs, which are needed for a discussion of UV and fluorescence. 3. The polar effects of double and triple bonds are visited, as well as the effects of hybridization on pK_a, with the pK_a values of pyridine and piperidine rings in drugs as examples. Hydrocarbon acidity is part of this discussion. 4. HBr addition is used because it is a convenient way to introduce carbocations, including rearrangements, and we can also use it to illustrate radical addition (in the presence of peroxides) as well as addition to conjugated alkenes. As given in Chapter 4, HBr addition is used to develop the concepts of reaction rates. 5. Hydration is used to contrast addition to double and triple bonds, and to introduce enols. Fumarase is introduced as an enzyme catalyst for hydration, and we return to it in stereochemistry (Periods 21–23) and again in conjugate additions (S2, Periods 24–28). 6. Catalytic hydrogenation is used to introduce catalysis, because it can be used in later sections, and because it is an easy addition for students to see. Hydrogenation is also covered for alkynes to illustrate stereochemistry.

			7. Bromine addition is used to (a) show mechanistic variation in addition; (b) to contrast with electrophilic substitution of bromine in semester 2; and (c) to provide an example that illustrates reaction stereochemistry (later). 9. Free-radical addition of HBr and free-radical polymerization introduce both free radicals and polymers. 10. A short supplement on biopolymers (Supplement 5.1, provided at the end of this outline) is provided to introduce proteins and DNA as polymers. Alternatively, students can be asked to read Sec. 21.12B. 11. Hydroboration, oxymercuration, ozonolysis, and the Na/NH_3 reduction of alkynes are not covered. 12. Hydroboration of triple bonds and the use of acetylenic anions in synthesis are not covered.
17–23	Stereochemistry	Chapters 6 and 7; Chapter 27, Sec. 27.2	We follow the chapter closely. Aspects of this chapter worth emphasis include the following: 1. The stereochemistry of reactions is illustrated with fumarase-catalyzed hydration, bromine addition, and catalytic hydrogenation of alkenes and alkynes. These all tie in with reactions studied earlier. 2. Fumarase is used as an example of a chiral, and therefore enantioselective, catalyst. 3. The stereochemistry of amino acids is used to introduce the D,L system and to explain why enzymes are chiral.
24–27	Nomenclature; noncovalent intermolecular interactions	Chapter 8, Chapter 27, Sec. 27.8A, Sec. 27.9, Sec. 26.5.	Emphasis on noncovalent interactions is a major change from the traditional course. We follow the text closely. 1. This section starts with comprehensive nomenclature rules. This is the last time that nomenclature is covered explicitly in class, although each functional group in the text contains its unique nomenclature. 2. The study of noncovalent interactions is built progressively from physical properties of pure compounds, to solutions and solubility, to the structures of biomolecules. 3. Other topics related to medicine or biology include: the importance of melting point to solid (and therefore drug) solubility; the importance of water solubility to phase II metabolism; and ion channels and ionophore antibiotics as examples of ionic solvation. 4. The climax of this section is to demonstrate how noncovalent interactions determine the higher-order structures of proteins and DNA. We incorporate parts of later chapters here. In class, we use examples of proteins that are mostly β-barrel (e.g., fluorescent green protein) and others that are largely α-helix (e.g., transmembrane receptors), demonstrating their structures using PyMol or Jmol with coordinates from the PDB. We have found that students are learning about macromolecules at a more superficial level in their biology courses, so that this

			section provides chemical underpinning for what they are learning in biology. A PowerPoint presentation of Noncovalent Interactions is available on request from Marc Loudon at *loudonm@purdue.edu*.
28–33	IR, NMR, and UV spectroscopy	Chapter 12 through Sec. 12.5; Chapter 13 through Sec. 13.7; Chapter 10, Sec. 10.9A; Chapter 13, Sec. 13.12. Chapter 15, Sec. 15.2	Why do we include spectroscopy in a "bio-related" course? The HHMI/AAMC explicitly supported the retention of spectroscopy in the first course on the grounds that it fosters skills in problem solving that involve interpretation of data. Of course, it also serves to show how structures are determined. 1. The outlines of Chapters 12 and 13 are followed closely with the exceptions noted below. 2. Concurrent labs with unknowns accompany this section; lab modules extend class material to the spectroscopy of carbonyl compounds, which is not covered explicitly in S2. 3. Mass spectrometry is skipped, but it can be visited in the context of peptide sequencing in Semester 2 if desired. 4. Although ^{13}C-NMR is not covered, this is supported by the text and could be added/substituted for other topics. 5. Coverage of group relationships within molecules (from Chapter 10) further extends the section on stereochemistry and explains diastereotopicity in NMR spectra. 6. We have added a section on NMR imaging is provided so that students have been introduced to an important medical use of NMR. This shows how imaging is different from "structural" NMR. 7. UV spectroscopy provides an opportunity to touch on both the chemistry of vision and the use of sunscreens, both of which have discussions in the text. 8. A section on fluorescence (15.2D) provides another (optional) bio-related application of spectroscopy.
34–39	Substitutions and eliminations	Chapter 9, Sec. 9.1–9.7; Chapter 10, Sec. 10.1, Sec. 10.4A,B,E; Chapter 11, Sec. 11.1, 11.3B, 11.5A,B, 11.7, 11.8	Alkyl halides scored very low on the AAMC topic survey. However, we stay with alkyl halides because so much of the fundamental data on substitutions and eliminations has been obtained on these compounds. The objective is not to learn all about alkyl halides, but rather to learn the principles involved in substitution and elimination reactions. 1. S_N2, S_N1, and E2, and E1 reactions of alkyl halides are covered, and we discuss but de-stress the competition between E2 and S_N2. S_N1 is important because of its appearance in glycosylation reactions, and because it provides an opportunity to introduce carbocations in a different context. 2. The following topics are skipped: free-radical substitution of alkanes; carbenes; and organometallics. 3. The acidity, basicity, and dehydration of alcohols are covered. Dehydration is

			stressed as another example of the E1 reaction. 4. Alcohol-derived leaving groups (e.g., sulfonate esters) are covered to set the stage for an exploration of phosphates and pyrophosphates as leaving groups. This is covered here briefly and more extensively in Semester 2. 5. Ethers are not discussed, except to discuss basicity and to note that the —OR group is a poor leaving group. 6. The reactivity of epoxides is discussed, because it ties in with cyclic ions (bromonium ion), with anchimeric assistance (below), and because epoxide reactivity provides a nice example of a biological S_N2 reaction (reaction of glutathione with epoxides) that further illustrates phase II metabolism. 7. Oxonium and sulfonium salts are introduced with the goal of discussing *S*-adenosylmethionine ("SAM") as a methylating agent in the context of S_N2 reactions. We show that, while the large structure of SAM is important for binding to enzymes, the methylation reaction involves a very small part of the molecule. 8. The development of the nitrogen mustards as chemotherapeutic agents are used to introduce intramolecularity as a source of rate acceleration in the context of anticancer drug development. 9. Enzymes are discussed as an important example of intramolecularity.
40–43	Oxidation in Organic Chemistry	Chapter 10, Sec. 10.6, 10.7, 10.8, 10.9B, 10.10; Chapter 27, Sec. 27.8A; Chapter 11, Sec. 11.9B; Chapter 17, Sec. 17.5B.	1. Oxidation and reduction are defined and illustrates with Cr(VI) oxidations of alcohols. 2. NAD^+ is introduced as an example of biological oxidation. As with SAM, we show that the chemical reaction involves a small part of this complex molecule. 3. The stereochemistry of ethanol oxidation by NAD^+ is also discussed; this discussion reinforces the ideas of group relationships introduced in NMR. 4. Octet expansion is introduced with emphasis on oxidation of thiols and sulfides. 5. Disulfides are noted as an important oxidation product of thiols in the context of protein disulfide bonds. 6. Cytochrome P450 oxidation and the "radical rebound" mechanism is introduced as an important process in phase I metabolism. (CyP450 inhibition can be a source of drug toxicity.)

Semester 2 (*Abbreviations:* S1 = Semester 1, S2 = Semester 2)

Periods	Topic(s)	LP6 Reference	Comments/Rationale
1–4	Addition to dienes; resonance; aromaticity; noncovalent interactions involving aromatic rings	Chapter 15, Sec. 15.4, 15.6–15.8; Chapter 26, Sec. 26.2	1. Diene structure and stability was introduced in Chapter 4; we can review here if necessary. 2. HBr addition to conjugated dienes introduces the effect of resonance on reactions; kinetic and thermodynamic control; HBr addition to alkenes serves as a familiar point of departure. 3. We cover the full summary of resonance structures; how to draw them and how to use them. 4. The Diels–Alder reaction is skipped. 5. Aromaticity is treated fully. Here we can point out the difference between the indole ring of tryptophan and the imidazole ring of histidine as bases in the context of aromaticity. 6. We explore noncovalent interactions between aromatic rings, and pi–cation interactions.
5–7	Electrophilic aromatic substitution	Chapter 16, Sec. 16.4A–B, 16.5A–C, 16.6, 16.7	1. Aromatic substitution is restricted to one or two reactions—halogenation and nitration. Use of halogenation allows contrast with halogen addition to alkenes (Periods 11–16, S1) and dienes (Periods 1–4). We stress general mechanistic concepts. 2. The treatment of activating and directing effects is very brief. The—OH group is used as a major example of an activating group, and the biosynthesis of thyroid hormones is discussed in this context. The —NO_2 group serves as the example of a deactivating group; this provides a useful contrast to nucleophilic aromatic substitution in the next section, in which the —NO_2 group is an important activating group. 3. Catalytic hydrogenation of benzene is used to illustrate further the resistance to addition and to discuss empirical resonance energy. 4. The carcinogenicity of benzo[*a*]pyrene reinforces the reactions of epoxides and the concepts of phase I metabolism. This can alternatively be covered in Periods 38–40.
8–10	Allylic and benzylic systems	Chapter 17, Sections 17.1, 17.3B, 17.4, 17.5B (review), 17.6	1. Allylic and benzylic reactivity is discussed; this topic ties in with resonance from Periods 1–4. 2. Cytochrome P450 oxidation can be reviewed here if desired with a re-focus on allylic radicals. 3. We treat the biosynthesis of terpenes and steroids in some detail to show the biochemical relevance of allylic reactivity.

11–12	Reactivity of vinylic and aryl halides; phenols and quinones	Chapter 18, Sections 18.1–18.4, 18.8	1. We show why vinylic and aryl halides are not reactive in S_N2 and S_N1 reactions. 2. We cover nucleophilic aromatic substitution. 3. Transition-metal catalysis, a very important topic in a synthetically-oriented course, is skipped. One could cover transition metals to the level of electron counting using vitamin B_{12} as an example. 4. We cover phenols as radical scavengers (vitamin E and ascorbic acid as examples). We cover quinone–phenol equilibria in electron transport.
13–16	Aldehydes and ketones	Chapter 19, Sec. 19.1, 19.2, 19.5–19.8, 19.10A, 19.11A,B, 19.14	1. The nomenclature and properties of aldehydes and ketones are covered briefly. (Nomenclature is assigned but not covered explicitly in class.) Properties (boiling points, dipole moments) are briefly noted in the context of the interactions studied in Chapter 8. 2. Spectroscopy is covered in S1 spectroscopy lab, and can be skipped here. 3. The basicity of aldehydes and ketones is covered. (α-Hydrogen acidity is covered in next section.) Carbonyl basicity can be extended by discussing (or giving as problems) reactions in which a protonated carbonyl group acts as a carbocation electrophile in aromatic substitution—for example, Problems 19.60 and 19.61, pp. 1000–1001. 4. Nucleophilic carbonyl addition is introduced with cyanohydrin formation, and acid-catalyzed addition is introduced with hydration. 5. The discussion of addition equilibria and rates follows the text. 5. Simple carbonyl addition is illustrated with hydride reduction, especially $NaBH_4$ reduction, which is activated by hydrogen bonding. 6. Laboratory hydride reduction is followed logically with biological hydride reduction involving NADH; this ties in with NAD^+ from S1. Once again, attention is focused on the reactive part of the molecule. 7. Grignard additions are skipped. (This is a major change from a synthetically-oriented course.) 8. Acetals (especially cyclic acetals, with sugars as an example), imines, and enamines are covered; acetals as protecting groups is skipped. 9. The Wolff–Kishner and Wittig reactions are skipped 10. Oxidation of aldehydes to carboxylic acids is covered briefly.
17–19	Carboxylic acids	Chapter 20, Sections 20.1, 20.2, 20.4, 20.5, 20.7, 20.8, 20.11	1. Carboxylic acids and their nomenclature, especially common nomenclature, are covered. (Spectroscopy is covered in spectroscopy labs, S1.) 2. Acidity and basicity of carboxylic acids is covered briefly; because carboxylic acids have been used as the major examples in Periods 7–10 (S1), a brief review suffices here. 3. Soaps and detergents, particularly micelles, provide another good example of noncovalent interactions; micelles are contrasted with phospholipid vesicles.

			4. The general pattern of carboxylic acid reactions is outlined; Esterification (both Fischer esterification and alkylation) are covered; the latter will be relevant to alkylation by pyrophosphates. 5. Anhydride and acid chloride syntheses are skipped; these classes of compounds will be introduced in the next section. 6. Carboxylic acid reduction is skipped. 7. Carbonic acid derivatives and decarboxylations are covered with a focus on the "electron sink" requirement for decarboxylation. Thiamine pyrophosphate-promoted decarboxylation provides a biological example.
20–24	Carboxylic acid derivatives	Chapter 21, Sections 21.1–21.3, 21.5–21.8, 21.9A–C,E, 21.12	1. All carboxylic acid derivatives, their structure and nomenclature, are introduced; the structures of amides are stressed. (Thioesters are covered in Periods 35–37.) 2. We tie in physical properties of carboxylic acids with Period 24–27 (S1) material. (Spectroscopy is covered in spectroscopy labs, S1.) 3. The basicity of esters and amides is covered briefly. 4. Reactions are introduced conceptually, and then hydrolysis is discussed as a generic reaction, with emphasis on esters and amides. We consider relative reactivity in the context of hydrolysis. Lactone formation provides a reinforcing example of the proximity effect. 5. Reactions with nucleophiles are discussed, stressing utility and reactivity of acid chlorides and anhydrides. (These will be used as laboratory examples of "high-energy" compounds in Periods 35–37.) Penicillin provides an example of the reaction of amides with nucleophiles. 6. The reduction of esters and amides is covered, stressing "hydride" as the nucleophile. This will tie in with thioester reduction in Periods 35–37. 7. The reactions of carboxylic acid derivatives with Grignard and organolithium reagents is skipped. 8. Describe waxes, fats, phospholipids (review) and proteins (review) in context of carboxylic acid derivatives.
25–29	Enols, enolates, and α,β-unsaturated carbonyl compounds	Chapter 22, Sections 22.1–22.2, 22.4–22.6A–D, 22.7, 22.8D, 22.9A,B,D	1. α-Hydrogen acidity of carbonyl compounds, enolates, and enols are the major themes of this section. 2. α-Halogenation is skipped. 3. Careful coverage of aldol additions and condensations follows. The directed aldol can be skipped unless one wishes to cover alkylation of ester enolates with the lithium amide bases. In that case, the use of these bases can be introduced here. Acid-catalyzed aldol reactions are covered, stressing the role of the enol as a nucleophile. Intramolecular aldol reactions provide another example the proximity effect. The synthetic analysis of aldol products in terms of starting materials is covered with a view toward stressing connections in biosynthesis.

			4. We cover one or more examples of the aldol reaction in biology, including aldol reactions of enamines. 5. The Claisen, Dieckmann, and crossed Claisen condensations are covered, and we synthetically analyze the Claisen condensation with a view toward using this in biosynthesis. 6. Knowledge of the Claisen condensation is applied to the biosynthesis of fatty acids. 7. Aldol reactions of ester enolates utilize the biological example of HMG-CoA biosynthesis. (Covering any of the laboratory models requires earlier introduction of lithium enolates and/or organometallics.) 8. Conjugate addition is introduced; biological examples are provided in the vignettes on p. 1158–1159 and (in Chapter 18) on pp. 923–924. 9. The contrast of conjugate addition with carbonyl addition provides another example of kinetic vs. thermodynamic control. 10. The conjugate addition of enolates (Michael reaction) can be skipped, but the fumarase reaction is covered as an example of a biological conjugate addition. This ties in with earlier use of fumarase as a hydration catalyst (S1, Periods 11–16) and a stereoselective catalyst (S1, Periods 21–23). 11. Reduction, reaction with organometallics, and other synthetic applications of α,β-unsaturated compounds are skipped.
30–31	Amines	Chapter 23, Sections 23.1–23.3, 23.4, 23.6, 23.7, 23.10A, 23.12B	1. The nomenclature, structure, and physical properties of amines are assigned but not covered explicitly except to stress amine inversion and amine classification (primary, secondary, tertiary). 2. We jump to Section 23.12B to stress biological importance of amines as hormones, neurotransmitters, hallucinogens, etc. 3. The basicity of amines provides an opportunity to reinforce acid–base principles introduced in S1, Periods 7–10, including polar effects and resonance effects. We stress the manufacture of amine-containing drugs as salts and the reasons (solubility and prevention of oxidation.) 4. The spectroscopy of amines is skipped. 5. Quaternary salts are covered, and we emphasize amphipathic salts as disinfectants. 6. The roles of amines as nucleophiles are reviewed: alkylation, reductive amination, acylation. (These topics were introduced in other sections.) 7. The Hofmann elimination, aromatic substitution, the Curtius and Hofmann rearrangements, and other synthetically-related reactions are skipped. 8. Cover diazotization, particularly the alkylation reactivity of aliphatic diazonium salts; can skip Sandmeyer and related reactions. 9. Skip synthesis of amines.

32–34	Carbohydrates	Chapter 24, Sections 24.1–24.6; 24.11	1. The first six sections of Chapter 24 are covered at a minimum. 2. Fischer projections are discussed here. (There is a tendency to eliminate FPs from the organic course, but they make discussion of noncyclic carbohydrate structures relatively easy. Also, they are being retained in biochemistry texts.) 3. Sections 24.7–24.10 can be covered if the Fischer proof is discussed, but this is optional. 4. Disaccharides and polysaccharides are introduced.
35–37	Thioesters, phosphate esters, and phosphate anhydrides	Chapter 25	Chapter 25 is followed closely. The emphasis is on reactions and mechanisms that are important in biology. Hydrolysis is the "model laboratory reaction" on which these discussions are based.
38–39	Heterocycles and DNA	Chapter 26, Sections 26.1–26.2; 26.4E; 26.5	1. The focus is on the nitrogen heterocycles. 2. The dramatic difference in basicity between the indole of tryptophan and the histidine of imidazole is noted and explained with the theory of aromaticity. 3. Pyridoxal phosphate-promoted reactions are covered; the idea of the pyridinium ion as an electron sink is reinforced with NAD^+ oxidations from S1 Periods 40–43. 4. Nucleosides, nucleotides, and DNA are covered. (Note that ATP was a major focus of Chapter 25.) The structure of DNA was introduced in S1 (Periods 24–27) and this is reviewed again. 5. Alkylation of DNA is covered as a source of DNA damage and mutagenesis.
40–43	Amino acids, peptides, and proteins	Chapter 27, Sections 27.1–27.3, 27.6B, 27.7, 27.8A,C,D,E, 27.9, 27.10	1. The fundamentals (structure, acid–base properties, stereochemistry) have been covered in earlier sections. Protein structure has been covered to some degree in earlier sections, particularly S1, Periods 24–27. These can be reviewed as needed. 2. Synthesis and enantiomeric resolution of amino acids are skipped. 3. Peptide synthesis is skipped, but biosynthesis of proteins is covered. 4. Hydrolysis of peptides (both chemical and enzymatic) is covered. 5. Primary structure of proteins is reviewed. Sequencing by the Edman degradation is covered. Sequencing by mass spectrometry and by complementary DNA are optional coverages. 6. Posttranslational modification (phosphorylation, glycosylation) tie in with earlier material in Periods 32–37. Hemoglobin A1c provides medical relevance for nonenzymatic glycosylation. 7. Enzymes and drugs as competitive enzyme inhibitors are discussed. This discussion ties in with the more generic discussion of enzymes in S1, Period 39.

(See next page for some other ideas.)

Other Possibilities.

1. "My favorite drug." Students, working in groups, have been asked to submit a short paper on the chemical aspects of "my favorite [prescription] drug." They are asked to discuss the chemical aspects of the drug—its synthesis, or its mechanism—anything involving chemistry.
2. "Capstone pathways project." Students are asked to analyze a biochemical pathway from the point of view of chemical mechanism, for example, the biosynthesis of an amino acid, glycolysis, or gluconeogenesis. This can also form the subject of classwork in the last week of class, substituting for other topics.