A Simple Method for Predicting a Molecule’s Biological Properties From Its Polarity

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Abstract

The distinction between very polar and less polar substances is a foundation of biochemistry, cell biology, and physiology; it surfaces in multiple concept inventories and elaborations of biological core concepts. However, in our experience, most biology courses do not explicitly teach students how to assess the polarity of any given molecule, thus limiting students’ ability to predict related biological properties such as the molecule’s solubility in bodily fluids, its rate of diffusion through cell membranes, the location of its receptors (at the cell surface or inside the cell), its rate of filtration by the kidneys, and the extent of its persistence in the blood. Here we present a quantitative yet student-friendly method for determining a molecule’s “C/fun” ratio—the number of carbon atoms per polar functional group—which correlates closely with the logP value, a widely used indicator of polarity. In addition, the lesson incorporates the Test Question Templates (TQT) framework to provide transparent guidance to both instructors and students on formative and summative assessments of understanding. Our lesson stresses the connections between polarity and the above-mentioned biological properties to help students appreciate the biological utility of understanding polarity. Given its central position in biochemistry and cell biology, polarity might be considered a Threshold Concept, i.e., one that is troublesome (hard to understand), transformative (affecting scientific identity), integrative (connecting other concepts), and irreversible (hard to forget once mastered).


Editor: Kristin Fox, Union College

Received: 7/19/2022; Accepted: 2/22/2023; Published: 3/29/2023

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Conflict of Interest and Funding Statement: SDG’s work was supported by a grant from the Everett Community College Foundation. None of the authors have a financial, personal, or professional conflict of interest related to this work.

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Learning Goals

Students will:

◊ understand how a molecule’s chemical bonds dictate its overall polarity and thus its hydrophilic or hydrophobic character.

◊ understand how and why a molecule’s polarity correlates with several biological properties, including its rate of simple diffusion through cell membranes, the location of its receptors (at the cell surface or inside the cell), its rate of filtration by the kidneys, and the extent of its persistence in the blood.

◊ From the Biochemistry and Molecular Biology Learning Framework:

   » What factors determine structure?
   » How are structure and function related?
   » How is structure (and hence function) of macromolecules governed by foundational principles of chemistry and physics?

Learning Objectives

Students will be able to:

◊ determine the number of carbon atoms per polar functional group for a given chemical structure.

◊ classify substances as nonpolar, slightly polar, or very polar based on their chemical structures, chemical formulas, or logP values.

◊ order two substances in terms of relative polarity or relative water solubility.

◊ use a substance’s polarity to make qualitative predictions about correlated biological properties: high or low rates of simple diffusion through cell membranes, receptors inside or outside the cell, high or low rates of filtration by the kidneys, or short or long persistence in the blood.
INTRODUCTION

As early as elementary school, science students are introduced to the classification of molecules as hydrophilic (water-soluble/very polar) and hydrophobic (lipid-soluble/relatively nonpolar) (1). This distinction is a staple of introductory biology courses, where students are generally taught that, because cell membranes are lipid bilayers, hydrophobic substances usually diffuse through them without assistance, while hydrophilic substances usually cannot. The distinction appears in lists of core concepts in such fields as biochemistry—as a “foundational concept of structure from chemistry” (2)—and physiology—as a key aspect of both the cell membrane (3) and cell-cell communication (4). It also manifests in concept-inventory questions for introductory biology (5), molecular and cell biology (6), and general biology (7).

Given the importance of molecular polarity, many published lessons cover it in one way or another. However, our review of the literature indicates surprisingly little overlap between our lesson and previously published approaches. For example, some lessons are laboratory-based (8), focus on electrostatic potential (“elpot”) maps (9), or present the material in a mostly didactic style, with only one non-rhetorical question about polarity (10). Of the published lessons we know, the one closest to ours in target audience and spirit is Schivell (11). Schivell’s lesson takes a nicely constructivist approach to polarity and related concepts. It leads students from the polarity of individual bonds to the polarity of whole molecules, as we do, but also emphasizes the relative locations of electrons, the resulting partial electrical charges, and the hydrogen bonds arising from these partial charges.

Schivell’s lesson (11), perhaps needing to fit within a single 50-minute class period, is entirely qualitative. As such, it helps students distinguish extremely polar molecules (e.g., glucose) from nonpolar molecules (e.g., hexane), but does not offer much guidance for judging the relative polarities of intermediate molecules (e.g., tryptophan). It is this issue, above all, that we address with the current lesson. Our premise is that if students can accurately assess the polarity of any molecule, they are then empowered to make numerous predictions of its biological properties: its ability to diffuse through cell membranes, as noted above, as well as its solubility in bodily fluids, the location of its receptors (at the cell surface or inside the cell), its rate of filtration by the kidneys, and the extent of its persistence in the blood.

Since molecular polarity appears challenging to many if not most biology students (11, 12), it arguably fits Loertscher et al.’s (13) definition of a Threshold Concept in potentially being troublesome (hard to understand), transformative (affecting scientific identity), integrative (connecting other concepts), and irreversible (hard to forget once mastered). This possible status as a Threshold Concept suggests the importance of teaching polarity clearly, engagingly, and inclusively.

With the stakes of understanding polarity being so high, and without awareness of other published approaches that fully address this mystery in a lecture setting for biology students, we offer the following lesson, which introduces the novel method of determining a molecule’s “C/fun” ratio—i.e., the number of carbon atoms per polar functional group—with lower ratios corresponding to greater polarity and greater water solubility.

Intended Audience

This lesson has been used in a sophomore-level human physiology course for pre-health sciences students (at a community college) and in an upper-level comparative anatomy and physiology course for biology majors (at a mid-size university). While these courses have been relatively small (15–45 students), we can imagine the lesson working in larger classes if TAs or peer facilitators are available to assist students with the worksheet. We can also imagine successful use of the lesson in advanced high-school biology courses whose students have had high-school chemistry.

Required Learning Time

As indicated in Table 1, the total time needed for Parts 1 through 5 is about 55 minutes for fast-working students and perhaps double that for slower students. However, most or all of the lesson can be completed as asynchronous homework (i.e., outside of class), if necessary.

Prerequisite Student Knowledge

This lesson assumes that students already have a working knowledge of some basic cell biology and chemistry. Three aspects of chemistry are important starting points: (i) chemical bonds (covalent bonds, in which electrons are shared between atoms, and ionic bonds, in which electrons are transferred from one atom to another); (ii) the four basic ways of representing chemical compounds (empirical formulas, condensed formulas, Kekulé/Lewis structures, and skeletal/line-bond structures); and (iii) the distinction between water-soluble (hydrophilic) substances and lipid-soluble (lipophilic) ones. On the biology side, students are assumed to have some knowledge of (i) biologically important macromolecules (especially lipids and proteins) and (ii) cell-membrane structure (especially the lipid bilayer). Students who are taking biology concurrently with introductory chemistry may need to use chemistry topics (i) through (iii) in the biology course before they have been covered in the chemistry course; instructors should be prepared to offer these students extra help as needed.

Prerequisite Teacher Knowledge

This lesson includes aspects of general and organic chemistry that are not routinely used by most biology instructors. We believe that most of the relevant knowledge will be re-activated in instructors as they preview the lesson. Those wanting a review of functional groups in organic chemistry can consult any convenient organic chemistry textbook (e.g., 14). On the other hand, partition coefficients and logP values (P being the partition coefficient in a 1-octanol/water system) may be unfamiliar to many biology instructors, but these topics are ably reviewed by various chemistry education articles (15, 16).

Since logP is not familiar to many instructors, instructors should take the time to consider our rationale for using logP as a quantitative readout of polarity. Why not just use a simpler and more familiar property like solubility in water? It turns out that some very polar molecules have unusually strong intramolecular or intermolecular forces that make them reluctant to dissolve in water. For example, cellulose, a polymer of glucose, is very
polar, yet has such strong intermolecular forces that it is reluctant
to dissolve in any ordinary solvent, polar or nonpolar. Thus,
for such solutes, solubility in water is a misleading indicator
of polarity. Using logP alleviates this problem by indicating a
molecule's relative solubility; i.e., solubility in 1-octanol relative
to solubility in water. Cellulose has a very low logP value of
-4.7, properly indicating high polarity. Even in the absence of
such strong forces, logP is a more reliable indicator of polarity
than solubility in water. (This point can be made with students,
if desired, via Optional Part A.)

Importantly, instructors should also note that our “C(fun)
(i.e., carbon atoms per polar functional group) approach, by
itself, does not address the possibility that polar bonds could
cancel each other out spatially so that a molecule with polar
bonds is nonpolar overall. This is generally not an issue with
organic molecules, but our method would incorrectly classify
carbon dioxide (O=C=O) as very polar, not recognizing that
the dipoles of the two C=O bonds cancel each other out due
to the symmetrical (linear) geometry of this molecule. Given
the biological importance of carbon dioxide, this exception is
worth being aware of.

Finally, instructors should note that the “C(fun” method does
not apply to inorganic ions such as Ca²⁺, Cl⁻, H⁺, Na⁺, or K⁺.
Such ions can be judged as very polar simply by their charges.

SCIENTIFIC TEACHING THEMES

Active Learning

This lesson is a 5- to 8-part PowerPoint worksheet (Supporting File S1) that students can do individually or in
groups (recommended group size: 3–4 students, either self-
selected or instructor-specified), either during class or outside
class or split between the two. The worksheet can be
distributed and filled in as a physical printout (hard copy) or as
an electronic file. Its individual questions could be presented
in various formats (e.g., think-pair-share, clicker questions)
according to instructor preferences. Some answers should
initially be withheld so that students are encouraged to come
up with their own answers.

The lesson includes at least three novel opportunities for
active learning. First, in Part 3, students create graphs of two
different relationships to determine which ratio, “C/NO” or “C/
fun,” is a better predictor of polarity and thus is a better ratio to
use in subsequent parts. This aligns (at least partially) with the
scientific practices of modeling and quantitative reasoning (17).
Second, in Optional Part B, students could be presented with
eight TQTs, which match the instructor’s learning goals, TQTs’ highly structured format facilitates this task. Also, if the instructor commits to writing
actual test questions based on the TQTs, students may see the
value of being able to generate additional plausible test questions
(21). If desired, additional motivation could be injected with a
promise to include student-written questions on the test! Third, in
Optional Part C, students have the chance to reflect on whether
polarity is indeed a Threshold Concept, as suggested above. This
reflection is a form of metacognition, which may help maximize
the benefits of active-learning exercises (22).

Assessment

Optional Part B of this lesson includes four TQTs, which
provide additional opportunities for formative assessment
while also foreshadowing the subsequent summative
assessment. Having an explicit template for possible test questions empowers students to keep practicing a given
type of problem—creating their own additional examples,
if desired—until they are satisfied with their understanding.
TQT examples are presented here as short-answer questions
to emphasize scientific reasoning, though they can easily be
rewritten in other formats (e.g., multiple-choice) if desired.

Inclusive Teaching

The Guide to Inclusive Teaching at Columbia (23) defines
five principles of inclusive teaching, the first of which is,
“Establish and support a class climate that fosters belonging for
all students.” This principle is addressed by the Prelude of this
lesson, a dialogue between two fictitious students, Nora and
Yasmine. The vignette, in which Nora discloses her negative
outlook on chemistry, is meant to acknowledge that students
come to biology courses with diverse levels of knowledge
and enthusiasm for chemistry. However, the vignette also
suggests that even “chemistry-phobic” students can succeed in
this lesson with appropriate support from peers and instructors.
Optional Part C revisits this theme at the close of the lesson,
asking students whether they can see themselves as people
who use chemistry knowledge to solve biology problems.

This lesson also reflects the Guide’s second principle: “Set
explicit student expectations.” As with a previous lesson (19),
this one uses TQTs (Optional Part B) to provide transparent
alignment of learning goals, learning objectives, and potential
test questions. This approach, like other thoughtful ways of
“teaching to the test” (24, 25), should be especially helpful
to students who are uncomfortable with high-stakes testing,
students who lack test-savvy study partners, and students for
whom reading and writing in English is difficult.

LESSON PLAN

This lesson consists of a carefully designed worksheet,
presented here as an editable PowerPoint file (Supporting File
S1), for students to complete with instructor oversight and
guidance. Aside from the Prelude, the worksheet is divided
into the following parts:

- Part 1: Polar and Nonpolar Bonds
- Part 2: Polar Functional Groups
- Part 3: Polarity of Whole Molecules
- Part 4: Polarity Predicts Solubility in Bodily Fluids and Diffusion Through Membranes
- Part 5: Polarity also Correlates with Other Biological Properties
- Optional Part A: An Additional Exercise
- Optional Part B: Summary with Test Question Templates
- Optional Part C: Reflecting on Polarity

The first five parts may be grouped conceptually as follows:
Parts 1 and 2 introduce polarity as a property of individual
bonds and of parts of molecules. Part 3 is the heart of the
worksheet, helping students use authentic data to evaluate two
alternative methods of predicting a molecule's polarity. Once students determine that the “C/fun” ratio is the better predictor of polarity, they apply that knowledge to biological properties in Parts 4 and 5.

We offer several hierarchical levels of support for instructors who may wish to use this lesson:

- The overall flow of the lesson is summarized in Table 1, with additional general comments below in the main text.
- Part-by-part tips are provided in Table 2.
- More fine-grained advice and answer keys (specific to individual slides) are provided in the Presenter Notes section of each slide of Supporting File S1.

The worksheet is written to be relatively self-explanatory and self-contained, with minimal additional lecturing required. However, this self-containment comes with at least two caveats. First, the worksheet contains several key explanatory passages (e.g., on slides 6, 11, 17, and 20) that students may or may not be able to digest; instructors should decide whether these passages suffice as explanations, or whether to lecture about them. Second, since the worksheet is long and builds upon itself, it should be periodically interrupted with opportunities for students to ask questions and check their progress. This is especially important during or after the lesson’s pivotal Part 3, which introduces the critical concepts of logP and the “C/fun” ratio. As noted in Table 2, students are unlikely to be able to google their way to an understanding of these terms, so give them ample opportunity to discuss them with peers and with the instructor.

TEACHING DISCUSSION

A primary goal of education is to enable the transfer of knowledge to novel contexts (26). This lesson had its origin in the frustrating observation that while GJC’s students entered his classes already familiar with terms like hydrophilic and hydrophobic, only rarely could they apply that knowledge to novel molecules. For example, they may have learned to recognize steroids based on their four-ring signature, and they may also have learned that steroids are considered hydrophobic and have biological properties related to that hydrophobicity. However, if these students then encountered another hydrophobic molecule, such as a prostaglandin, they often failed to recognize this molecule as hydrophobic, and thus likely to share certain biological properties with steroids. Therefore, this lesson aims to help students develop a general understanding of polarity that they can apply to any molecule.

As summarized in Table 3, the current lesson is much changed from the original (2018) version. We believe that the current version is both more chemically correct and more accessible to undergraduates, reflecting valuable input from coauthors TSE (a chemist) and SDG (an undergraduate). Perhaps most critically, TSE compiled data showing that a molecule’s number of functional groups was a better indicator of polarity than its number of N and O atoms, upon which GJC had focused. TSE also noticed that the electronegativity values GJC had obtained from the Internet needed to be updated to more modern data. Meanwhile, SDG offered insights into what fellow students might find overly challenging or manageable. For example, GJC was hesitant to ask students to recognize functional groups, as opposed to simply counting N and O atoms; SDG provided reassurance that this was not unreasonable. Conversely, SDG pointed out that the lesson was unnecessarily confusing in its treatment of amphipathicity, which was subsequently removed.

Student Feedback and Performance

We have not formally studied students’ responses to this lesson. Informally, both sophomore pre-nursing students and junior/senior biology majors have varied in their ratings of its difficulty, with most finding it appropriate for their respective courses but some finding it a bit too easy. This range of reactions seemed to correlate with chemistry experience, as we would expect. Students were also asked whether the lesson helped demonstrate that an understanding of chemistry was helpful in biology, and they generally agreed, though with varying degrees of enthusiasm. Three of the six students who submitted written open-ended comments also specifically said that the Test Question Templates (Optional Part B) were helpful as a summary of the lesson, consistent with other published feedback on TQTs (21).

We have not formally studied the impact of this lesson on students’ understanding of polarity-related properties. This impact (if any) is not easily isolated because the classroom instructor (GJC) has simultaneously made related curricular changes, i.e., reemphasizing polarity in subsequent units about the brain, digestive, and urinary systems. GJC’s anecdotal impression is that the combination of the polarity worksheet and reinforcement in subsequent units has led to more students understanding polarity by the end of the course.

Possible Modifications

Like most worksheets, this one is amenable to modification according to instructor and student needs. Since the worksheet is relatively long, requiring more than 50 minutes, one can ask whether a shortened version could be pedagogically useful. Aside from omitting Optional Parts A–C, there are at least two reasonable ways to trim the worksheet. First, Part 3 could be made less exploratory and/or less quantitative by leaving out “C/NO” and logP, simply teaching students to determine “C/fun” ratios and to understand the range and meaning of possible values. Second, the content of Parts 4 and 5 could be deferred until these biological properties come up later in the course.

Instructors who use the long version of Part 3 should consider whether to uphold its use of a specific “C/fun” cutoff value as a boundary between very polar and slightly polar molecules. Polarity is best considered a continuum rather than an either/or property, and no specific cutoff value will be universally accepted. For example, the hormones ecdysterone (C₁₇H₂₄O₅) and thyroxine (C₁₅H₁₁I₃NO₃) are generally considered hydrophobic; yet, by our method, their “C/fun” ratios of 3.75–3.85 are below the worksheet’s cutoff value of 4.5, which would suggest that these molecules are very polar. On the other hand, we have found that if no specific cutoff value is provided up front, many students, accustomed to binary either/or sorting, will ask for one.

Optional Parts A, B, and C are modular, meaning that any of them can be used independently of the others. In brief, Optional Part A is essentially an extension of Part 3 that has
students determine how well water solubility correlates with “C/fun” ratio and logP value. Optional Part B helps students and instructors transfer the worksheet's main ideas into formats suitable for further formative and summative assessment. And Optional Part C offers students the chance to reflect on their learning by raising the question of whether polarity meets the criteria of a Threshold Concept.

Conclusion
As described, this lesson is a worksheet, but one that attempts to overcome typical limitations of many worksheets (27). In particular, our lesson is built to address two common negative perceptions of biology students: chemistry is difficult, and chemistry is irrelevant to biology. In the lesson, we acknowledge the possibility of challenging content and negative emotions (Prelude and Optional Part C), clearly lay out the specific chemistry facts to be mastered (Parts 1–3), provide multiple problems explicitly highlighting the extensive connections between chemistry and biology (Parts 4–5), and offer students a mechanism for generating additional practice problems, if desired (Optional Part B). We hope that, as biology students work through this material, the concept of polarity provides a gateway to new biochemical vistas, perhaps serving as a Threshold Concept. Maybe students discussing the worksheet will even point at a problem and exclaim, “See? Fun!”

SUPPORTING MATERIALS
• S1. Polarity in Biology – PowerPoint Worksheet

ACKNOWLEDGMENTS

We thank the Everett Community College Foundation for a grant supporting SDG’s work, Lauren Gautier for creating the worksheet’s artwork, and GJC’s students for useful feedback on the lesson.

REFERENCES
Table 1. Lesson plan timeline for using a molecule's polarity to predict its biological properties.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Estimated Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students review background information</td>
<td>If needed, students review the biology and chemistry concepts listed under Prerequisite Student Knowledge. This could be done in class or outside of class (via video lectures, textbook readings, etc.).</td>
<td>5–40 minutes</td>
</tr>
<tr>
<td>Students do Parts 1–2 (slides 3–9 of Supporting File S1)</td>
<td>Students explore the polarity of individual bonds and learn to recognize polar functional groups. This material is relatively straightforward and could be done as pre-lecture homework.</td>
<td>20–40 minutes</td>
</tr>
<tr>
<td>Students do Part 3 (slides 10–15 of Supporting File S1)</td>
<td>Students explore the polarity of whole molecules, in part by looking up logP values in PubChem and generating graphs by hand or using software such as Excel. Part 3 is especially conducive to group work and/or real-time guidance from the instructor.</td>
<td>20–40 minutes</td>
</tr>
<tr>
<td>Students do Parts 4–5 (slides 16–22 of Supporting File S1)</td>
<td>Students use a molecule's polarity to predict biological properties from its polarity. This section is meant partly as a preview of the course's “coming attractions” (e.g., using structure to predict hormones' effects, nutrients' absorption mechanisms, and solutes' filtration in the kidneys).</td>
<td>10–20 minutes</td>
</tr>
<tr>
<td>Optional add-ons (slides 23–28 of Supporting File S1)</td>
<td>At the instructor's discretion, students can explore water solubility and logP data (Part A), practice further via the TQT framework (Part B), and/or reflect on whether polarity acts as a Threshold Concept (Part C).</td>
<td>0–60 minutes</td>
</tr>
</tbody>
</table>
A Simple Method for Predicting a Molecule's Biological Properties From Its Polarity

Table 2. Tips for instructors on using the PowerPoint worksheet.

<table>
<thead>
<tr>
<th>Worksheet Section</th>
<th>Notes for Instructors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1: Polar and Nonpolar Bonds (slides 3–5 of Supporting File S1)</td>
<td>• As noted in the worksheet, molecules can be drawn in ways that do or do not explicitly show and label all carbon and hydrogen atoms as such. You can check students’ understanding of these alternative representations and provide additional help as needed (see ref. 14).</td>
</tr>
</tbody>
</table>
| Part 2: Polar Functional Groups (slides 6–9 of Supporting File S1) | • In the table of functional groups, three of the rows show multiple general structures. Two of these rows group the charged and uncharged versions of a functional group (carboxylic acid vs. carboxylate; amine vs. ammonium); the third row groups aldehydes and ketones. Be ready to clarify that these distinctions allow us to call functional groups by their correct names, but are not otherwise essential to the method introduced in Part 3. (For example, carbonyl groups are treated the same in Part 3 regardless of whether they are aldehydes or ketones.)
• Some students may worry that they will forget the specific names of the functional groups. Reassure them that in Part 3 they simply need to count the functional groups; naming them is nice, but not strictly necessary. |
| Part 3: Polarity of Whole Molecules (slides 10–15 of Supporting File S1) | • Part 3, which introduces the “C/fun” ratio, is the pivotal section of the entire lesson. Therefore, if students do parts of the lesson outside of class, make sure they have opportunities to check in with you during or after this section.
• Students are especially likely to struggle with logP and the calculation of the “C/NO” and “C/fun” ratios, since these concepts are not easily googled. Information about logP is abundant but often highly technical.) Be ready with a conceptual bottom-line summary; e.g., “In the end, logP is just a number that indicates polarity, with lower numbers indicating greater polarity.” |
| Part 4: Polarity Predicts Solubility in Bodily Fluids and Diffusion Through Membranes (slides 16–19 of Supporting File S1) | • This part should be somewhat familiar to and somewhat straightforward for students. You can pitch it to them as, “Now that we’ve done some hard work to expand our knowledge of the relevant chemistry about polarity [in Parts 1–3], in Part 4 we will start applying this knowledge to biological problems!” |
| Part 5: Polarity Also Correlates with Other Biological Properties (slides 20–22 of Supporting File S1) | • Part 5 briefly highlights polarity-related physiology that you may or may not cover more fully later in your course. You can tailor this section according to your course’s content coverage.                                                                                                                                                                          |
| Optional Part A: An Additional Exercise (slide 23 of Supporting File S1) | • This is an optional extension of Part 3 with even more data. It further explores the difference between logP and water solubility, and would be most useful to instructors and students interested in this specific issue.                                                                                                                                 |
| Optional Part B: Summary with Test Question Templates (slides 24–27 of Supporting File S1) | • Test Question Templates (TQTs) are one practical way of showing students how this worksheet activity relates to possible test questions, with tests offering different details than seen before but covering the same knowledge.
• Since each TQT comes with multiple examples, you can do one example (in a video lecture or in person) as scaffolding for students, and let them do the second example.
• Unless you have previously introduced TQTs, students will not be familiar with them. If you want students to create an Example C, you should explain the structure of TQTs so that they can follow that structure in their example. Otherwise you could reduce jargon by deleting all references to TQTs and Example C, and you could simply call this part “Additional Practice.” |
| Optional Part C: Reflecting on Polarity (slide 28 of Supporting File S1) | • This part is less goal-directed than the other parts; its main point is simply to help students reflect on their learning. The general idea of a Threshold Concept may resonate with some individuals irrespective of whether polarity seems like a Threshold Concept for them. |

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Table 3. Evolution of a lesson on using a molecule’s polarity to predict its biological properties.

<table>
<thead>
<tr>
<th>Pedagogical Problem</th>
<th>Pedagogical Adjustment [time of change]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many biology students cannot determine the polarity of molecules, and thus cannot predict related biological properties.</td>
<td>An initial version of the lesson (what is now Parts 1 and 3) is created. [Winter 2018]</td>
</tr>
<tr>
<td>Students are not clear on how their understanding will be assessed.</td>
<td>A Test Question Template is added to the lesson. [Spring 2019]</td>
</tr>
<tr>
<td>The lesson’s data on electronegativities and bond polarity are found to be outdated.</td>
<td>Part 1 of the lesson is updated with modern electronegativity and polarity values. [Winter 2022]</td>
</tr>
<tr>
<td>Amphiphatic molecules are explained confusingly.</td>
<td>References to amphiphatic molecules are removed. [Spring 2022]</td>
</tr>
<tr>
<td>Students are instructed to assess polarity by comparing the number of C atoms to the number of N and O atoms, but “C/NO” ratios correlate only modestly with polarity.</td>
<td>The misleading approach is replaced by a more exploratory one (Parts 2–3) in which students look up logP data to compare the merits of “C/NO” ratios and “C/fun” ratios, in which students count polar functional (“fun”) groups instead of individual atoms. [Summer 2022]</td>
</tr>
<tr>
<td>The biological relevance of polarity does not become obvious until later in the course.</td>
<td>The Prelude and Parts 4 and 5 are added to show how polarity can be used to predict numerous biological properties of interest. [Summer 2022]</td>
</tr>
</tbody>
</table>