Are Learning Progressions a Useful Pedagogical Tool for Instructors?

By Charlotte R. Reed and Adele J. Wolfson

Learning progressions (LPs) present a potential tool to guide students toward deeper understanding of core concepts as they move through a curriculum. In addition to providing a theoretical scheme for education researchers, LPs can provide a powerful framework for instructors and students in organizing curricula. We have developed the outline of a learning progression on acid/base chemistry from general chemistry through biochemistry. We interviewed peer instructors, faculty, and chemistry students to determine how instructors could use LPs or how students could incorporate LPs into their own learning. The interviews suggest that students may struggle to get the most value out of LPs because they misunderstand them as topics lists rather than progressions, and they may interpret them as exhaustive rather than as guides. However, when carefully presented to students and woven into the curriculum, LPs could allow instructors to revisit concepts with more complexity rather than simply repeating information. This approach will likely be most useful for experienced instructors with deep pedagogical knowledge. Our results provide additional evidence that professional knowledge content, like that acquired over time by faculty members, is necessary for effective use of LPs and other such tools.

Learning progressions (LPs) have become a model for understanding student thinking (National Research Council, 2007), as well as tools in support of curricular and instructional design (Alonzo, 2011; Black et al., 2011; Duschl et al., 2011; Furtak, 2012). These progressions represent a structured acquisition of general skills and knowledge (Salomon & Perkins, 1989; Perkins & Salomon, 1989) combined with the mastery of transformative concepts in the discipline (Cooper et al., 2012; Cousin, 2006; Duncan & Hmelo-Silver, 2009; Neumann et al., 2013; Ross et al., 2010; Wilson, 2009). Students’ movement through these pathways is dependent on both their engagement and their attachment to pre-existing conceptions (Perkins, 2006; Salomon, 1988) and is facilitated when students generate explanations of concepts on their own (Talanquer, 2010). The language of learning progressions has entered the K–12 lexicon, and there have been some descriptions of learning progressions at the college level (Claesgens et al., 2009; Cooper et al., 2012; Cooper & Klymkowsky, 2013; Romine et al., 2016; Sevian & Talanquer, 2014).

Although LPs provide a useful framework, they are not universally embraced. One of the major criticisms of LPs is that they assume a student’s path through a discipline is linear. This is not always the case, as has been demonstrated, for example, by careful mapping of students’ conceptions about molecular interactions (Johnson, 2013; Sevian & Stains, 2013), structure of matter (Talanquer, 2009), and celestial motion (Plummer & Maynard, 2014). In fact, exposure to the language of the discipline and quantitative interpretations may impede student progress through a progression (Sevian & Stains, 2013; Wolfson et al., 2014). Other objections to LPs are that they assume a particular framework for learning (Sikorski & Hammer, 2010) and that they are generally not longitudinal in following individual students from course to course (Duncan & Gotwals, 2015; Taber, 2017).

Additionally, LPs are more often a tool for education researchers than for classroom instructors (Bernholt & Sevian, 2018). The theoretical nature of the literature on LPs may be off-putting to instructors. Especially at the college level, faculty may take for granted that prerequisites for their courses have allowed students to reach the “lower anchor” for their subject.

We sought to address the question of whether and how LPs could serve classroom instructors by presenting both faculty and peer instructors with the outline of a learning progression about acid/base chemistry from general chemistry through organic chemistry to biochemistry. We asked both of these groups how such an LP could fit with their learning objectives and course design. Alongside these interviews with instructors, we also interviewed students in college chemistry courses; although the interviews with students were conducted in order to validate the LP we were constructing, we also asked the students about the utility of LPs for their own learning. Our results indicate that only instructors with deep content knowledge can make the best use of LPs.
Methods

Outline of acid/base learning progressions

We began to develop a hypothetical learning progression (Wolfson, 2019) using empirical studies on student understanding of acid/base chemistry, professional society guidelines, and common biochemistry texts.

The initial framework was developed using literature on high school- and college-level mastery (Banerjee, 1991; Calatayud et al., 2007; Cartrette & Mayo, 2011; Cooper et al., 2016; Lin & Chiu, 2007; McClary & Talanquer, 2011; Orgill & Sutherland, 2008; Pan & Henriques, 2015; Romine et al., 2016; Stoyanovich et al., 2014; Tümay, 2016; Watters & Watters, 2006); guidelines from professional societies (American Chemical Society, n.d., 2015; American Society for Biochemistry and Molecular Biology, n.d.; NGSS Lead States, 2013); and common biochemistry course texts (Berg et al., 2002; Voet et al., 2004; Nelson & Cox, 2008). Steps on the progression were categorized as occurring after high school, general chemistry, organic chemistry, and biochemistry. The steps are summarized in Table 1.

As is generally the approach for development of LPs, we attempted to test this hypothetical framework using our own assessments, collection of data, and interviews with faculty, other content experts, and students (Stevens et al., 2009). However, the LP as presented to students and faculty for this study was not represented as fully validated, but rather as a starting point for discussion.

Interviews with students, peer instructors, and faculty

As part of the validation process of the hypothetical LP, we interviewed students at two institutions (one a liberal arts college and the other an R1 state university) who had completed courses in general chemistry, organic chemistry, or biochemistry.

After asking a set of questions to probe the students’ understanding of acid-base concepts (Wolfson, 2019), we showed the students our current outline of the acid/base LP and asked if they had ever seen such a scheme and whether they thought it might be a useful tool.

The central part of this study was a set of open-ended interview questions to peer instructors who had responsibility for Supplemental Instruction (SI) in general and organic chemistry. SI is a form of peer tutoring (Blanc et al., 1983) that attempts to remove the perceived stigma of seeking help in a difficult course. SI leaders sit in on classes, model good student behavior, and organize one or more sessions per week to complement lectures.

Peer instructors were queried on the following topics:

1. How they plan supplementary sessions and where they focus the most attention
2. How a learning progression might fit into (faculty) lectures
3. Comparison of content lists and learning progression
4. Common misconceptions held by students

The larger set of questions is summarized below:

1. Do you use anything like a learning progression in planning SI sessions? Do you think it would make you a more effective SI leader?
2. How do you prevent yourself from passing on common misconceptions in chemistry? Could you see yourself using a learning progression for this purpose?
3. Do you think students would benefit from having learning progressions? If so, how would you recommend using them?
4. Do you think professors could incorporate learning progressions into lecture? If so, how? In what ways could you see it benefiting students?
5. How does a learning progression compare to the list of topics some professors include in their syllabus?

Based on the peer instructor responses, we developed a set of open-ended questions for faculty and interviewed several who teach at any level in the chemistry curriculum. Faculty were specifically asked about the following:

- The contrast between topics lists and LPs
- How LPs might be incorporated into their courses
- Whether they had suggestions for reorganization or edits of the draft LP

Both peer and faculty interviews were coded for themes by two investigators.

Results

LP compared to checklist

Peer instructors often conflated LPs with checklists:

“Basic concepts you should know, and I feel like it would have been helpful to me to check them off throughout semester.” —Peer instructor for general chemistry course

And many students described the LP as a checklist:

“I think it would help since such a chart as this pretty much—at least for acid-based chemistry—summarizes the main points of each topic.” —Student in biochemistry

On the other hand, most faculty and a few peer instructors were able to distinguish a progression:

“You really can only master them [steps on progression] after you
### TABLE 1
Hypothetical learning progression for acid-base chemistry.

<table>
<thead>
<tr>
<th>Students should:</th>
<th>Before general chemistry</th>
<th>After general chemistry</th>
<th>After organic chemistry</th>
<th>After biochemistry</th>
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<tbody>
<tr>
<td><strong>pH and pKa</strong></td>
<td>(May) be familiar with pH scale and associate it with acid/base</td>
<td>Know pH scale is from 0–14 and &lt; 7 is acidic, 7 neutral, &gt; 7 basic</td>
<td>Know general trends of pKas by structures and estimate pKas of groups</td>
<td>Can predict ionization states from pKa/pH relationship</td>
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<tr>
<td></td>
<td>(May) know pH scale is from 0–14 and &lt; 7 is acidic, 7 neutral, &gt; 7 basic</td>
<td>Can convert between [H+] and pH [OH–], and pOH (pH + pOH = 14, pH = −log[H+])</td>
<td>Predict direction of equilibrium given pKas</td>
<td>Predict function as a result of structure due to pH (rxn mechanism of enzymes)</td>
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<td></td>
<td>Recognize that pH scale is log, and difference between whole units is 10x</td>
<td>Recognize that pH scale is ratio between H+/OH–</td>
<td>Recognize that pH scale is ratio between H+/OH–</td>
<td>Predict stability and solubility as a result of structure due to pH environment (folding, IMFs)</td>
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<td>Know pKa is the −logKa, and the &lt; the pKa, the stronger the acid</td>
<td>Know pKa is the −logKa, and the &lt; the pKa, the stronger the acid</td>
<td>Know pKa is the −logKa, and the &lt; the pKa, the stronger the acid</td>
<td>Know of microenvironment as it relates to pH and pKa (enzyme active site pockets)</td>
</tr>
<tr>
<td><strong>Acid/base models</strong></td>
<td>Define by Arrhenius model and see acids as containing H+ and bases as containing OH–</td>
<td>Define A/B by Bronsted-Lowry model and see acids as H+ donors and bases and H+ acceptors</td>
<td>Bronsted-Lowry H+ movement and Lewis model electro/nucleophiles</td>
<td>N/a</td>
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<td></td>
<td>Will describe A/B by macroscopic stereotypes: acid is red and sour, base is blue and bitter</td>
<td>Recognize Lewis model and see acids as e acceptors and bases as e donors</td>
<td>N/a</td>
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<td><strong>Ionization</strong></td>
<td>N/a</td>
<td>Able to identify conjugate pairs, protonate and deprotonate, but without mechanism</td>
<td>Able to identify conjugate pairs, protonate and deprotonate with arrow pushing mechanism</td>
<td>Understand ionization as it applies to a population of molecules</td>
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<td>Able to define strong/weak acid/base (fully dissociates, etc.) but difficulty identifying/recognizing examples beyond periodic trends and memorization</td>
<td>Identify strongest/weakest acid/base from structure through periodic trends, electronegativity, inductive effect, resonance, etc.</td>
<td>Predict structure due to ionization (protonate/deprotonate, effects on IMFs)</td>
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<td>Know that the stronger the acid, the weaker the conjugate base, and vice versa</td>
<td>Identify strongest acid/base that can exist in given solvent</td>
<td>Pick acid/base to protonate/deprotonate a given group</td>
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<td>Can define a polyprotic acid, but may not be able to identify one</td>
<td>Can identify and predict action/mechanism of polyprotic acids</td>
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“fully understand the previous ones.” —Faculty instructor for organic chemistry course

“It outlined what students learn and gain along the chemistry track, so what they might come in with, and then leaving general chemistry, an understanding of the pH scale, but still basic or general, and then as they move on getting more specific, and they just add on what they’ve already gained.” —Peer instructor for organic chemistry
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Even when peer instructors understood the nature of LPs, they were concerned that students might not use them appropriately:

“I wonder if students ever would hyper-focus on it—like a checklist—and maybe miss things in between.” —Peer instructor for general chemistry

Utility for students

There was some concern that the LP in its entirety might provide too much information for students:

“It’s so many points that it would be overwhelming.” —Faculty instructor for biochemistry course

However, some students recognized that the LP could be a useful tool to gain a broader perspective:

“I think if you handed it all out at the beginning of the semester for each topic, it would be overwhelming.” —Peer instructor for general chemistry

“So like, it’s cool to like see that you learn this now and then you learn more about it later and then you can apply it to something else.” —Student in biochemistry course

“I think, for a multi-course thing, it might be like a little overwhelming for me, just like all at once.” —Student in biochemistry course

Sources

Before general chemistry: Calatayud et al. (2007); Lin & Chiu (2007); Bernholt & Parchmann (2011); Pan & Henriques (2015); NGSS Lead States (2013).

After general chemistry: Banerjee (1991); Watters & Watters (2006); Romine et al. (2016); Cooper et al. (2016); Cartrette & Mayo (2011); Orgill & Sutherland (2008).

After organic chemistry: Cooper et al. (2016); Stoyanovich et al. (2014); Cartrette & Mayo (2011); Orgill & Sutherland (2008); American Chemical Society (n.d.); McClary & Talanquer (2011); Tümay (2016)

After biochemistry: Orgill & Sutherland (2008); American Chemical Society (2015); Villafañe et al. (2011); Berg et al. (2002); Nelson & Cox (2008); Voet et al. (2004); American Society for Biochemistry and Molecular Biology (n.d.).

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<td>Students should:</td>
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<td>Equilibrium, Buffers, Henderson-Hasselbalch</td>
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of things. So something like this, where it says, ‘Recall Ka [as] acid dissociation constant,’ and just what that means, is helpful.” —Student in organic chemistry

Utility for instructors

Although instructors were not sure if the complete LPs should be shared with students, they certainly saw the value in LPs for themselves. LPs can allow instructors to reflect on course structure:

“Seeing how it is mapped out might help me think about how to best organize and structure acids and bases as a topic for students.” —Faculty instructor for general chemistry course

Faculty might carefully introduce students to LPs and ask them to consider LPs as a framework:

“I think there would probably be value in giving it to students who are starting on this adventure together, right as you’re initiating a discussion of acid/base chemistry and possibly give it to them at the end.” —Faculty instructor for general chemistry course

“To get students to reflect a little bit on what they learned would be valuable.” —Faculty instructor for general chemistry course

Use of LP as an iterative process

Faculty who teach more than one level of the curriculum were particularly interested in how LPs could help make connections across courses and subdisciplines:

“I have sometimes been known to say that particularly with acid/base chemistry, it’s the third time you see it that it starts to click.” —Faculty instructor for general chemistry course

“I’m making the connection of how they’re [steps on the progression] building to each other because I’ve had to work with them in that way.” —Faculty instructor for biochemistry course

One peer also recognized that applying concepts to different course levels improved students’ understanding:

“When I was a [peer instructor] for [gen chem], I was taking biochem at the same time. And so I saw how concepts were going to relate to amino acids. So—this semester I used some of those biochem problems as practice ones for them. Because they had all the knowledge and they were challenging, but I think that . . . you kind of knew what was coming, and you had to be comfortable with that information that you were now teaching to another class.” —Peer instructor for general chemistry course

Students also mentioned that using an LP throughout multiple courses would help it become a useful tool for organizing their learning:

“But maybe if I saw it like multiple times, I would pay attention to it.” —Student in biochemistry course

Pedagogical knowledge

While the faculty we interviewed were reflective about how they could apply the LP to improve their teaching, faculty do not necessarily possess the pedagogical components that are part of peer instructor training.

Some peer instructors mentioned the importance of group work, a teaching style that is stressed in peer instructor training, for helping students learn new topics:

“I mean, group problems that were long multi-parts, where really they had to work together and get things done in the hour. Like making people work together was really helpful, because then they would discuss things.” —Peer instructor for organic chemistry

Another peer instructor discussed how a passion for pedagogy inspired them to learn additional teaching methods:

“I realized, like a few weeks into being a [peer instructor], that I really loved what I was doing and that I wanted to work at it, because I wanted to maybe incorporate this into my life, moving forward, maybe be a professor one day. So I would often look up different methods of reinforcing material and what other teachers use for review.” —Peer instructor for organic chemistry

Even some of the students we interviewed for LP validation were familiar with pedagogical theories. One student mentioned Bloom’s taxonomy, while another noted the similarity of LPs to concept maps:

“I’ve seen it [an LP] in like a different format, but definitely not as detailed. But something similar . . . Like a concept map . . . I feel like this would be more useful because it’s more detailed.” —Student in biochemistry course

Additionally, the peer instructors recognized the importance of faculty reflection on their teaching:
“I mean, if a professor were to make that [an LP] and then use it for years and years, without updating or thinking about it, like maybe it would then become . . . I think it needs to be a live document.”—Peer instructor for organic chemistry

Discussion

Acid/base chemistry is a theme throughout the chemistry and biochemistry curriculum. Instructors often complain about having to re-teach elementary concepts in acid/base chemistry, even in advanced courses (Mercer et al., 2018). Part of the difficulty for students with acids and bases seems to be the way that topics are layered on top of one another (Demerouti et al., 2004; de Vos & Pilot, 2001), rather than logically building on a firm base. Fully developed LPs not only describe levels of student understanding but also have suggestions for pedagogical approaches (Alonzo, 2011; Stevens et al., 2009), so that a learning progression for teaching and learning about acids and bases could be of enormous utility to instructors and students. There have been several LPs proposed that include aspects of acid/base chemistry at the precollege level (Anderson et al., 2007; Johnson & Tymms, 2011; Liu, 2013), and some extensions to college courses (McClary & Talanquer, 2011; Roman et al., 2016), but little integration with biochemistry.

LPs, as well as teaching-learning sequences and concept maps, can help students organize their knowledge and can guide instructors in planning curricula, countering misconceptions, and solidifying foundations for further mastery (Bernholt & Sevian, 2018; Loetscher et al., 2018).

Inherent in any teaching plan or curriculum is the assumption that the instructor has a content knowledge base in the particular topic, as well as a set of other types of knowledge such as pedagogy, assessment, or student behavior (Carlson & Daehler, 2019; Gess-Newsome, 2015). It is important to note that content knowledge resides in the topic, not the overall discipline. In our case, instructors’ content knowledge of acids and bases, not just general chemistry knowledge, is key (Drechsler & Van Driel, 2008; Gess-Newsome, 2015).

Peer instructors, whether in the formal model of SI or otherwise, have been shown to contribute to high-impact practices and student learning (Kuh, 2008). Peer tutors are often well trained in effective pedagogy and interaction with class members. They may be particularly skilled in the two-way knowledge exchanges that are crucial for student learning (Carlson & Daehler, 2019). The peer instructor quoted above, who understood the need for constant renewal of a learning progression, was demonstrating her understanding of the “living” nature of any teaching tool. However, peer instructors cannot be expected to have the depth of content knowledge that faculty members possess. The crucial elements in teacher training, at least at the precollege level, have been shown to include disciplinary knowledge, teaching experience, and reflection on teaching (Drechsler & Van Driel, 2008; Schneider & Plasman, 2011). Even the formal program of reinforcing content knowledge described by Boothe et al. (2018) cannot, by its very nature, substitute for faculty members’ immersion in their discipline or years of teaching experience. Limited content knowledge necessarily leads to limited strategies for teaching (Rollnick et al., 2008).

Our results seem to indicate the following: All instructors, whether faculty members or peers, are not as familiar with learning progressions as are education researchers; instructors would benefit from a fleshed-out learning progression that includes teaching strategies and ways to avoid misconceptions; and faculty most able to take advantage of learning progressions are those who teach at multiple levels within the curriculum.

Given that most faculty members, especially those at large institutions with limited teaching assignments, are unlikely to teach at multiple levels, it is even more important that faculty within and across disciplines communicate about the degree of understanding achieved by students in their courses (Mercer et al., 2018). Learning progressions are just one way to organize that communication, but they may prove to offer an excellent framework to ensure that students deepen their mastery of a subject such as acid/base chemistry as they move from course to course.

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dominant types of explanations built by general chemistry students. 

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