JOURNAL OF CHEMICAL EDUCATION

Article

Cite This: *J. Chem. Educ.* 2020, 97, 56−65

pubs.acs.org/jchemeduc

Student Perceptions of Their Gains in Course-Based Undergraduate Research Abilities Identified as the Anticipated Learning Outcomes for a Biochemistry CURE

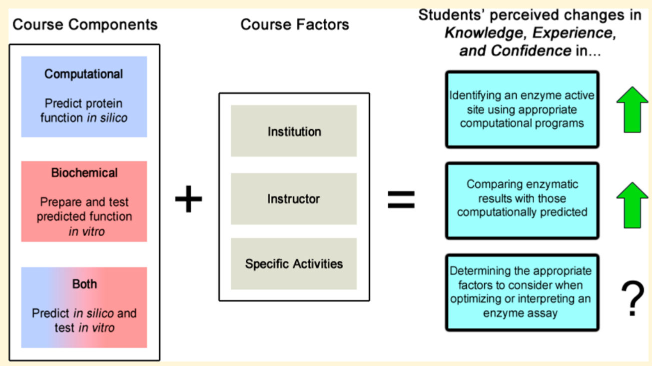
Stefan M. Irby,[†,‡] Nancy J. Pelaez,[§] and Trevor R. Anderson*,[†]

[†]Department of Chemistry, Purdue University, West Lafayette, Indiana 47907, United States

[§]Department of Biological Sciences, Purdue University, West Lafayette, Indiana 47907, United States

Supporting Information

ABSTRACT: A course-based undergraduate research experience (CURE) is a teaching approach aimed at developing students' ability to conduct novel research. Although students' perceptions of their learning during CUREs may not reflect actual student learning, such surveys provide a convenient and useful metric for course evaluation. Instructors can use survey findings both to improve instruction and to identify areas of student difficulty. Although various reports have presented data on student perceptions of CUREs, these have not delved deeply into students' perceived knowledge, experience, and confidence (KEC) regarding specific research abilities that instructors anticipate students will develop. This study addresses this issue by investigating changes in students' perceived KEC regarding previously identified anticipated learning outcomes (ALOs) for the biochemistry authentic scientific inquiry laboratory (BASIL) CURE. The following research questions were addressed: How do students' perceptions of KEC for specific ALOs change during a BASIL CURE course? How do student perceptions of their KEC regarding specific BASIL ALOs vary across different implementations of BASIL CURE courses? To answer these questions, a participant perception indicator (PPI) survey was used to measure students' KEC for the BASIL ALOs. Participants were students in one of 10 courses implementing the BASIL CURE at seven different academic institutions. Student pooled response data across all implementations showed significant gains in their KEC, with large effect sizes. Furthermore, differences in students' KEC were detected between course implementations. These findings will provide instructors of the BASIL CURE and potentially other CUREs with a useful framework for the focus of assessment design and the consequent identification and remediation of student difficulties related to the various research abilities or ALOs.



KEYWORDS: *Upper-Division Undergraduate, General Public, Chemical Education Research, Biochemistry, Curriculum, Laboratory Instruction, Inquiry-Based/Discovery Learning, Testing/Assessment, Proteins/Peptides, Computational Chemistry*

FEATURE: Chemical Education Research

INTRODUCTION

Course-based undergraduate research experiences (CUREs) are increasingly being incorporated into undergraduate programs to afford students more opportunities to develop their knowledge of how research is conducted.[1] CUREs have commonly been defined by the features or activities incorporated into them.[2] For example, Auchincloss et al.[1] describe CUREs as courses with the following features: collaboration, discovery, broad relevance, iteration, and use of science practices. These five features are reflected in the description of CUREs by others in the field.[3−9] In a recent study by our group[3] we have extended the definition, "as a course wherein students engage in activities resembling those done by scientists in a particular field to conduct novel investigations about relevant phenomena that are currently unknown". CUREs are reported to have a wide range of benefits to student learning; however, not all of these benefits are well-established.[1,2] In particular, it is often unclear in CUREs whether students simply get to repeat what researchers have already done and published or whether they actually get the opportunity to learn and experience what it means to do original research that could lead to publications.

This study focuses on the biochemistry authentic scientific inquiry laboratory (BASIL) CURE, which aims to develop students' ability to perform and produce original research about the function of proteins of known structure but unknown function.[3−5] BASIL does not involve repeating already published research. Instead, at the very least, the findings students obtain are novel and with time and over multiple

Received: May 9, 2019
Revised: October 10, 2019
Published: November 18, 2019

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

Table 1. Description of the Anticipated Learning Outcomes (ALOs) or Course-Based Undergraduate Research Abilities (CURAs) Studied Using the PPI Survey[a]

ALO Items	Description	BASIL CURE Components	BASIL CURE Protocol(s)
ALO1	Explain how the colorimetric enzyme assay works to allow detection of protein function	Biochem (B)	Enzyme activity
ALO2	Identify an enzyme active site using appropriate computational programs	Comp (C)	Pfam, ProMOL, PyRx
ALO3	Determine the appropriate factors to consider when optimizing or interpreting an enzyme assay	Biochem (B)	Enzyme activity
ALO4	Determine using computational software whether, and where, a ligand may be binding to a protein	Comp (C)	PyRx
ALO5	Compare enzymatic results with those computationally predicted	Both (B/C)	Not limited to any single protocol
ALO6	Design an enzyme assay to elucidate protein function	Biochem (B)	Enzyme activity
ALO7	Explain how the purification of tagged proteins work and ways the process can be optimized	Biochem (B)	Protein purification

[a]See refs 3 and 4.

iterations of the lab in some cases lead to original publications about the function of a particular protein. The BASIL lab activities[4,5,10] engage students with traditional protein lab techniques such as reading protocols, protein extraction, separation, purification, and enzyme activity assays using calibration curves. However, most notably BASIL extends beyond this to include the use of lab data as evidence to reason about protein function discovery such as ligand binding that may or may not result in the activation or inhibition of enzyme activity. The anticipated learning outcomes (ALOs) identified for the BASIL CURE (Table 1)[3,4] include both procedural knowledge and the use of scientific reasoning such as optimization, troubleshooting, or design of assays and protocols to specifically elucidate the mechanism of protein function.

In the present study we utilize a participant perception indicator (PPI) survey,[11] which specifically measures knowledge, experience, and confidence (KEC) for the identified ALOs and the research conducted (Supporting Information). This survey was informed by Bandura's work on self-efficacy theory.[12] In 1988, Berger and Carlson[11] introduced the PPI for knowledge, experience, and confidence (KEC) to measure self-perceptions of computer literacy. PPI surveys have since been adapted for measuring students' perceptions in chemistry (e.g., refs 13 and 14) and biology[15] contexts. In the current study, we adopt this approach to investigate student perceptions for specific course-based undergraduate research abilities that were identified in previous studies using the process for identifying course-based undergraduate research abilities (PICURA)[3,4] as the anticipated learning outcomes (ALOs) or course-based undergraduate research abilities (CURAs) for the BASIL CURE.[5,10] In this regard, as stated in our previous papers,[3,4] it is important to emphasize that knowledge of the biochemistry subject matter, as well as basic procedural (technical) knowledge, is important prerequisite knowledge for mastering these CURAs. However, in the current study we considered it unnecessary to construct ALO statements for everything that students needed to know, as ultimately lack of such basic knowledge would be revealed in student assessment of the CURAs. Instead, in the present study, we were exclusively interested in students' perceptions of their KEC with respect to the higher levels of expert-like research abilities or CURAs (Table 1).

In the past, CURE curricula have primarily been evaluated by using various Likert-scale self-reported (perception) survey data as a rough indicator of CURE success. However, whereas typical survey items measure affective things like satisfaction,[16,17] interest,[16−18] experiences with mentorship,[16,17] communicating science,[19] and general feelings of confidence,[17,19] our PPI study is instead focused on measuring students' perceptions of their development of the scientific skepticism typically practiced when using data from research methods to make original claims about, in this case of BASIL, the function of proteins.[3−5,10] In this regard, when scientists explain mechanisms such as how proteins function, they use scientific reasoning about research methods and data to characterize what is known about the mechanism and how it works.[20,21] Thus, the current study could not be done using any of the methods reported in other published work such as to determine whether students self-identify as a scientist,[22] if students were confident with laboratory techniques,[7,23] or if they are satisfied and benefit according to items ranging from "lab reports" to "knowledge of basic modern biochemistry laboratory techniques".[23] It was not our goal to compare student experiences between computational and wet-lab CUREs in terms of course satisfaction,[7,24] interest in research project,[16−18] or sense of achievement.[24] Nor was our study intended to measure differences between CURE and non-CURE lab courses based on students' perceived degree of project ownership,[25] or perceptions of collaboration, discovery and relevance, and iteration.[26] Whereas the survey of undergraduate research experiences (SURE)[16−18] provides data on how a research experience might impact feelings of satisfaction (e.g., "I am very satisfied with this experience") and interest (e.g., "Research is more interesting than course work"), the enquiry-based learning (EBL) survey[27] links research experience to confidence (e.g., "As a result of the activities I am now more confident about my ability to establish my own research questions") and societal issues (e.g., "I can apply the concepts I have learned in this lab course in solving environmental issues in society"). Only the undergraduate research student self-assessment (URSSA)[19] explicitly asks how well students link research skills to theory and knowledge from the discipline (e.g., "Understanding the theory and concepts guiding my research project"). However, it uses general statements instead of directly measuring the application of scientific skepticism and problem-solving in a specific context like the elucidation of protein function. Thus, none of the above-mentioned surveys specifically targets the kinds of research abilities targeted by BASIL about how to practice the scientific skepticism needed to advance knowledge beyond what is covered in general biochemistry course work. In our view, only the PPI is suitable for this purpose and was why we used it in the present study in preference to any other published instruments. In addition, the PPI findings are intended to provide useful feedback on how to improve instruction for instructors who want to identify and

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

correct areas of student difficulty. They offer a convenient way to compare curricula and can help to identify areas that should be assessed further in specific courses.

Since courses from the BASIL CURE are being implemented at many different campuses, we do not know whether students are getting the chance to actually learn how to do this kind of research at each of the campuses. It could be that some instructors are taking students through the procedural steps (which are easy to assess) without giving students the chance to learn how to use evidence from their research. Thus, students' experiences during the BASIL CURE could range from taking the lead in a novel research project that investigates their protein of interest, to merely following step-by-step instructions like a technician. Since the PPI survey measures students' perceived KEC for the BASIL ALOs (Table 1), it will indicate if students believed they had the opportunity to develop actual research abilities, along with their knowledge of procedures. For example, if a student reports a gain in their KEC for *Explain how the colorimetric enzyme assay works to allow detection of protein function* (ALO1, Table 1), that would indicate that a student does feel they know how a colorimetric enzyme assay works, and they have gained experience and confidence with this technique after an authentic research experience during the enzyme activity module.[3,4,22]

■ RESEARCH QUESTIONS

The goal of this study was to collect data about students' perceived KEC regarding the identified ALOs (Table 1) and their opportunities for applying the relevant techniques and methods[3,4] that students encountered in their lab for doing research as part of the BASIL CURE.[3−5,10] Findings can indicate whether the features of specific implementations of the BASIL CURE actually afforded the opportunity for students to develop specific research abilities during each implementation. Toward achieving the above goal, the following research questions were addressed:

(RQ1)
How do students' perceptions of KEC regarding specific ALOs change after a BASIL CURE?

(RQ2)
How do student perceptions of their KEC regarding specific BASIL ALOs vary across different implementations of the BASIL CURE?

■ STUDY CONTEXT

The focus of this study was on the BASIL CURE[3−5,10] in which students use computational and biochemical (wet-lab) techniques to determine the function of proteins of known structure but unknown function. The CURE was molded after research conducted by scientists in this field[28,29] and is similar to other recent biochemistry CUREs (e.g., ref 30). More detailed information about the BASIL CURE has been previously published.[3−5,10,28,32] In brief, 11 lab protocols have been designed for the BASIL CURE in a modular fashion so they can be implemented flexibly as a set of computational techniques only (comp only), biochemical-wet-lab techniques only (biochem only), or in full (both). The BASIL protocols are freely available at basilbiochem.github.io/basil.[10]

Data for this study was collected from 10 courses from seven different institutions across the United States, representing a diverse range of institution types (Tables 2 and 3). All of the students were at least sophomores, and 84.4% of the students were either juniors or seniors (Table 4). Students self-identified as being a part of 10 different majors, with students identifying as majoring in biochemistry, chemistry, or biology, or a closely related major (e.g., biotechnology, Table 4). The specific demographics for courses with more than 10 students participating in both the pre- and post-PPI survey are reported in the Supporting Information.

The BASIL CURE has been designed to be flexibly implemented.[32] An example of how the BASIL CURE was implemented in four different courses is shown in Figure 1, which outlines how the components of the BASIL CURE, the constituent activities, as well as other meetings and presentations that students participated in were implemented. Only four of the 10 courses are highlighted in Figure 1 (MW2-2, NE3-7, NE3-8, and SW1-9; Tables 2 and 3) because they are

Table 2. Information for Institutions in This Study

Institution ID	Region	Carnegie Classification[a]
MW1	Midwestern	Baccalaureate College: Arts and Sciences Focus
MW2	Midwestern	Special Focus Four-Year: Other Health Professions School
NE1	Northeastern	Doctoral University: Moderate Research Activity
NE2	Northeastern	Master's, College and University: Larger Programs
NE3	Northeastern	Baccalaureate College: Arts and Sciences Focus
SW1	Southwestern	Master's, College and University: Larger Programs
W1	Western	Master's, College and University: Larger Programs

[a]See ref 31.

Table 3. Comparative Course and Participation Data

				Number of Students		
Institution	Instructor	Term[a] in 2018	Components	Pre-PPI	Post-PPI	Pre/Post Paired[b,c]
MWI	MW1-1	H	Both	6	5	5 (12)
MW2	MW2-2	S	Both	13	12	10 (12)
NE1	NE1-3	S	Both	9	7	7 (9)
NE2	NE2-4	S	Both	8	2	1 (28)
	NE2-5	S	Both	1	6	1 (11)
	NE2-6	S	Both	11	4	4 (20)
NE3	NE3-7	S	Comp only	12	11	11 (14)
	NE3-8	S	Biochem only	15	14	11 (16)
SW1	SW1-9	S	Both	19	15	11 (24)
W1	W1-10	W	Biochem only	8	5	3 (16)
			Total	102	81	64

[a]When the course occurred: H, first half of spring semester; S, spring semester; F, fall semester; and W, winter quarter. [b]Paired refers to students who completed both the pre- and the post-PPI survey in 2018 so their individual change in KEC can be tracked. [c]Number in parentheses represents total course enrollment based on instructor postcourse PPI survey; the pre/post student numbers may be different from the reported course enrollment because of students adding or dropping the course, incorrectly inputting their identification number, or choosing not to participate in either the pre- or the post-PPI survey.

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

Table 4. Student Demographics for All Paired Data from 2018 Used in the Analysis for RQ1[a,b]

Major	Academic Rank, N			
	Sophomore	Junior	Senior	Total
Biochemistry	1	5	9	15
Biochemistry and Molecular Biology	3	8	3	14
Biology		10	2	12
Biology and Chemistry	1			1
Biomedical Sciences		1		1
Biotechnology			2	2
Chemistry		2		2
Health Sciences	1	3	6	10
Neuroscience	1			1
Zoology	3	3		6
Total	10	32	22	64

[a]RQ1 asks "How do students' perceptions of KEC regarding specific ALOs change after a BASIL CURE?" [b]Demographics for each individual course with 10 or more paired responses are provided in the Supporting Information.

representative of the different ways BASIL has been implemented, are from different institution types (Table 2), had at least 10 student paired responses to the PPI survey (Table 3), and implemented the BASIL curriculum differently (Figure 1). Two of these courses MW2-2 and SW1-9 (Tables 2 and 3) employed all portions of the BASIL CURE (Figure 1). In comparison, course NE3-7 only implemented the computational portions, and NE3-8 only implemented the biochemical portions of the BASIL CURE (Figure 1, Tables 2 and 3).

PARTICIPANT PERCEPTION INDICATOR (PPI) SURVEY

Developing the PPI Survey

This PPI survey contained three categories for participants to rate their perceived KEC. The first category was the seven ALOs that were previously selected from 43 ALOs for the BASIL CURE.[3,4] These ALOs were also referred to as course-based undergraduate research abilities (CURAs) and were identified by the PICURA.[3,4] For the present study, we selected the seven ALOs (Table 1) that were rated the highest by the current

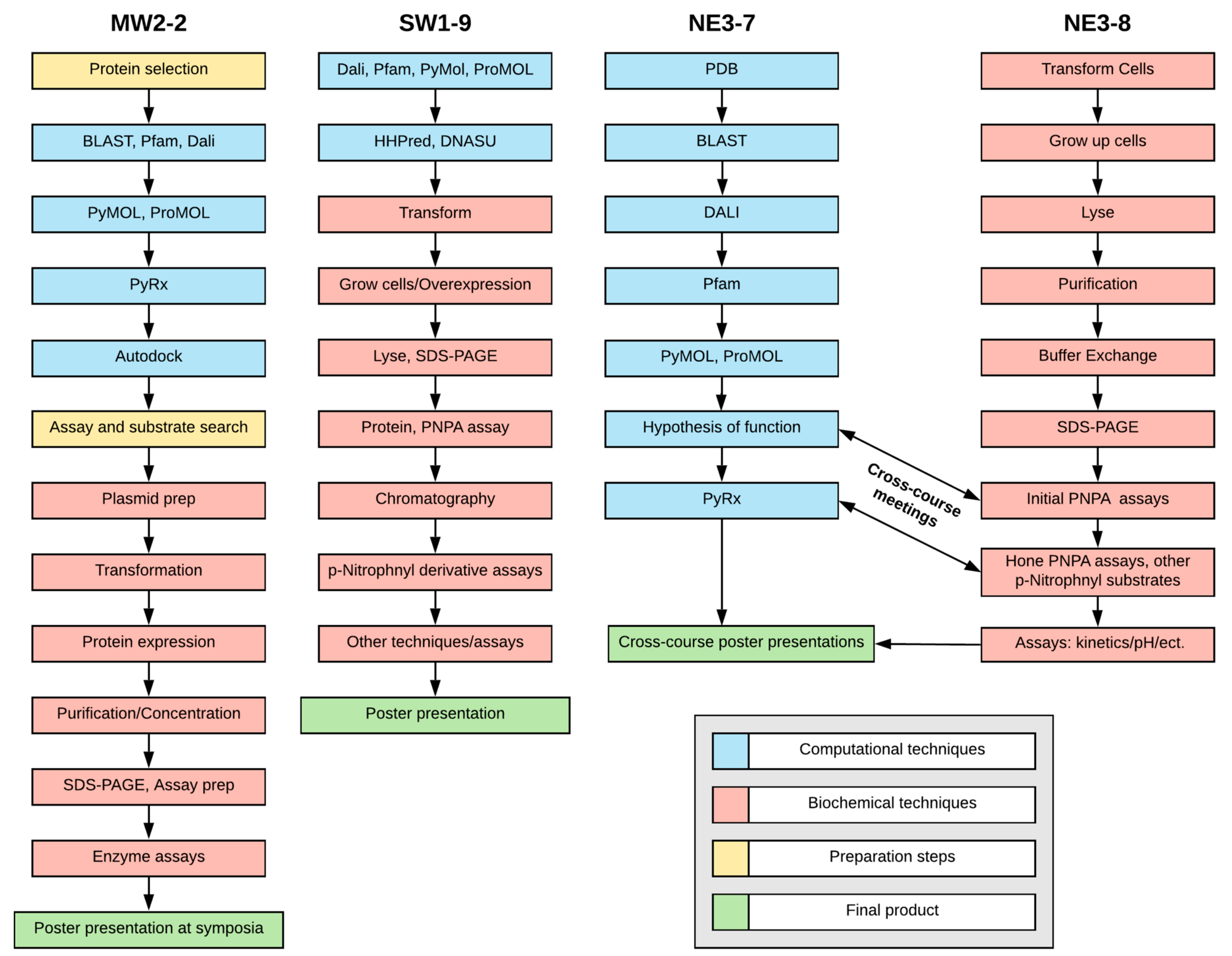


Figure 1. Outline of four different BASIL CURE courses and how each implemented the BASIL curriculum. The courses either implemented both the computational and biochemical components (MW2-2 and SW1-9), only the computational components (NE3-7), or only the biochemical components (NE3-8) of the BASIL curriculum. The two courses (NE3-7 and NE3-8) that only implemented half of the BASIL curriculum were at the same institution, during the same semester (Tables 2 and 3). Courses NE3-7 and NE3-8 had cross-course meetings during the semester to share what they have learned about the proteins of interest and to put together and give a joint poster presentation.

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

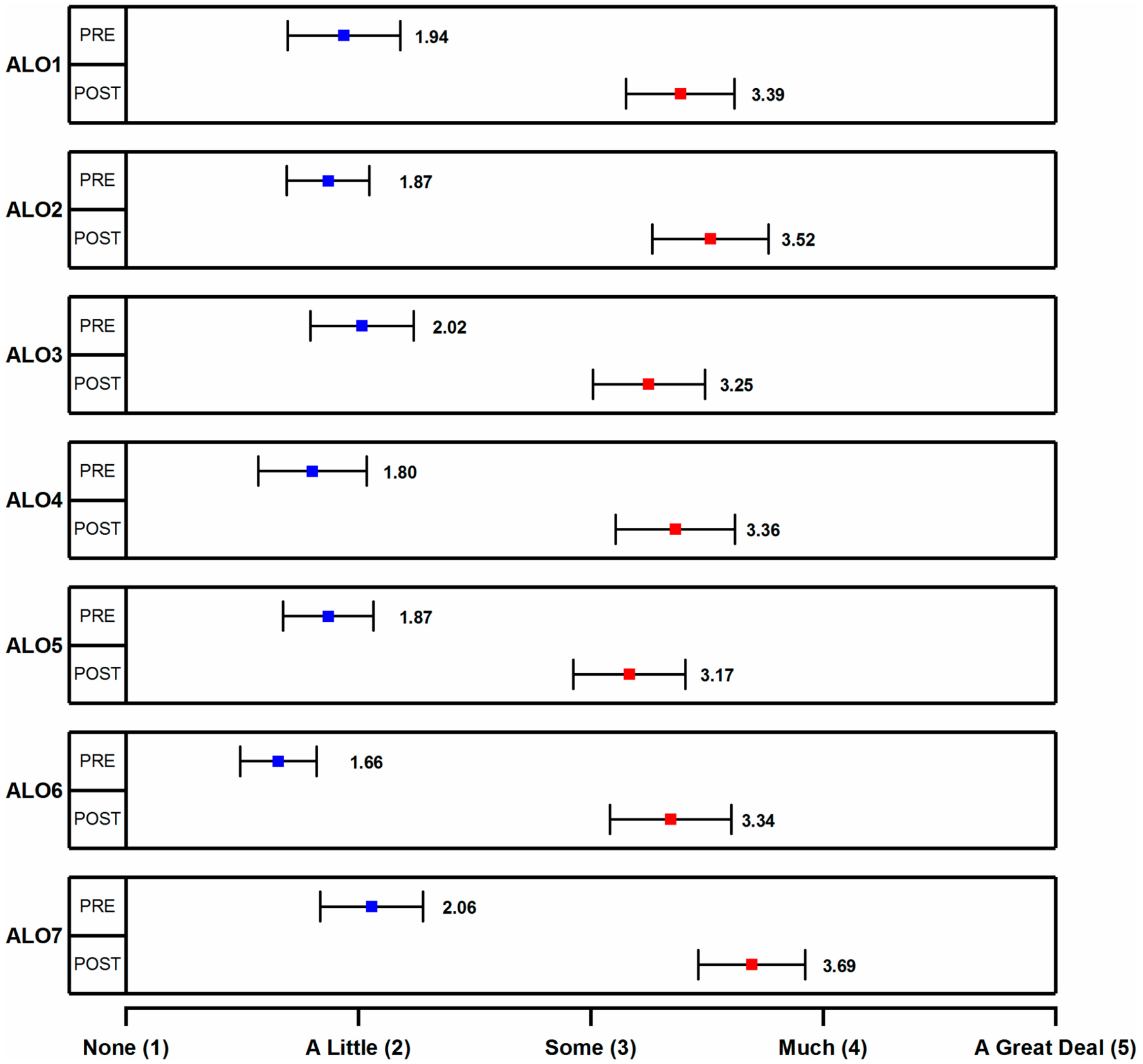


Figure 2. Plots of the pre-PPI (blue) and post-PPI (red) KEC ratings for the seven BASIL specific ALOs (Table 1) showing all of the paired PPI data for all courses from spring 2018 ($n = 64$). In all of the plots the square dots indicate the average and the whiskers represent the 95% confidence interval.

BASIL instructors based on how unique they considered the ALOs to be to the BASIL CURE and how important they were to the functioning of a scientist in this field of research.[3,4] Also, in Table 1, the seven ALOs are aligned with the BASIL CURE components and protocols[4] that directly correspond to them (Table 1). The course component and protocol categories list the computational and biochemical (wet-lab) techniques identified by the instructors as being present in their version of the BASIL CURE. All the items in the PPI survey are provided in the Supporting Information.

Conducting the PPI Survey

Data collection took place during the first half of 2018, after being piloted during the previous year. To match student responses, students generated their own unique participant ID number, keeping their true identity anonymous. Instructors asked students to take the online PPI survey at the beginning and end of their course implementing the BASIL CURE. The only inclusion criteria were that students had to be a part of a BASIL CURE course, complete both the pre- and post-PPI survey, and enter the same participant ID number that they generated so that their responses could be paired together. Table 3 shows when each participating course was taught, which BASIL CURE components were part of the course, and how many students participated.

In the spring semester and winter quarter of 2018, there were a total of 64 students that participated in both the pre- and post-PPI survey (Table 3). Instructors also took the PPI survey and had to self-identify in order to link student responses to instructor responses. The instructors were able to indicate the specific components and techniques their course implemented. The student averages for their KEC on the computational and biochemical ALOs were based on only those reported by instructors as being important for their course. In the case of NE3-7 (comp only) and NE3-8 (biochem only), students only directly used either the computational or biochemical techniques. However, since they had cross-course interactions (Figure 1), the ALOs students should have encountered were determined by responses from both instructors.

When taking the PPI survey, participants rated their knowledge, experience, and confidence regarding each item on the following scale: 1 = "none", 2 = "a little", 3 = "some", 4 = "much", and 5 = "a great deal". Participation in the survey was voluntary, and no compensation was given, nor were the instructors able to access any of their results until after final grades were submitted. This was in accordance with the protocol

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

Table 5. Comparison of Changes in Students' KEC Scores from Pre to Post on the PPI Survey for Four Different Individual Implementations of the BASIL CURE

Metric	ALO1 (B)[c]	ALO2 (C)[c]	ALO3 (B)[c]	ALO4 (C)[c]	ALO5 (B/C)[c]	ALO6 (B)[c]	ALO7 (B)[c]	Comp Tech	Biochem Tech
MW2-2: Both Components; $n = 10$									
Pre-PPI score[a]	1.13	2.70	1.37	3.07	2.37	1.33	1.17	1.72	1.47
Post-PPI score[a]	3.00	3.97	3.33	3.90	2.97	3.53	3.50	3.13	2.82
Change in score	1.87	1.27	1.97	0.83	0.60	2.20	2.33	1.41	1.36
Gain score, %	48	55	54	43	23	60	61	43	38
Cohen's d[b]	2.47[b]	2.16[b]	3.66[b]	1.12[b]	0.99[b]	3.54[b]	4.33[b]	4.11[b]	3.17[b]
t-Value[b]	5.59[b,d]	5.46[b,d]	9.21[b,d]	2.75[b,e]	2.21[b,e]	9.19[b,d]	9.04[b,d]	10.43[b,d]	8.84[b,d]
SW1-9: Both Components; $n = 11$									
Pre-PPI Score[a]	2.30	1.91	2.76	1.88	2.06	2.03	3.00	1.89	2.59
Post-PPI Score[a]	3.45	3.42	3.24	3.06	3.21	3.42	3.91	2.85	3.62
Change in Score	1.15	1.52	0.48	1.18	1.15	1.39	0.91	0.96	1.03
Gain Score,%	43	49	22	38	39	47	45	31	43
Cohen's d[b]	1.19[b]	1.97[b]	0.56	1.13[b]	1.26[b]	1.86[b]	0.97[b]	1.64[b]	1.43[b]
t-Value[b]	4.57[b,f]	5.84[b,d]	1.55	3.95[b,f]	5.30[b,d]	4.53[b,f]	5.21[b,d]	4.69[b,d]	7.23[b,d]
NE3-7: Computational Component Only; $n = 11$									
Pre-PPI Score[a]	1.85	1.39	1.88	1.18	1.94	1.55	1.70	1.22	1.97
Post-PPI Score[a]	2.27	4.00	1.91	3.88	3.12	1.94	2.76	3.50	2.47
Change in Score	0.42	2.61	0.03	2.70	1.18	0.39	1.06	2.28	0.49
Gain Score,%	13	72	1	71	39	11	32	60	16
Cohen's d[b]	0.41	3.61[b]	0.04	3.92[b]	0.97[b]	0.48	1.30[b]	4.39[b]	0.68
t-Value[b]	1.57	8.13[b,d]	0.12	9.94[b,d]	3.8[b,f]	2.08	5.05[b,d]	12.02[b,d]	2.03
NE3-8: Biochemical Component Only; $n = 11$									
Pre-PPI Score[a]	2.94	1.82	2.70	1.91	1.94	2.09	2.79	1.58	2.69
Post-PPI Score[a]	4.09	2.76	3.61	2.12	2.82	3.79	4.21	1.94	3.62
Change in Score	1.15	0.94	0.91	0.21	0.88	1.70	1.42	0.35	0.92
Gain Score, %	56	30	39	7	29	58	64	10	40
Cohen's d[b]	1.44[b]	0.88[b]	0.88[b]	0.17	0.88[b]	2.06[b]	1.52[b]	0.54	1.84[b]
t-Value[b]	3.98[b,f]	5.10[b,d]	2.98[b,e]	0.82	4.24[b,f]	5.42[b,d]	3.76[b,f]	4.59[b,f]	5.94[b,d]

[a]Scores reflect participants' ratings of their knowledge, experience, and confidence (KEC) regarding each item based on the following scale: 1, "None"; 2, "A Little"; 3, "Some"; 4, "Much"; and 5, "A Great Deal". [b]Considered to be a large effect size (Cohen's $d > 0.8$) or found to be significant ($p \leq 0.05$). [c]Indicates that an ALO pertains to techniques that are biochemical ("B", wet lab), computational (C), or both (B/C). [d]$p < 0.001$. [e]$p \leq 0.05$ [f]$p < 0.01$.

approved by Purdue University's Institutional Review Board (IRB 1604017549).

Data Analysis

Responses for knowledge (K), experience (E), and confidence (C) for each PPI item were averaged together to generate a "KEC" score for each item.[24] Initially, all of the 2018 paired data were analyzed together (Figure 2, Table S2), and then by individual courses with 10 or more paired pre/post-PPI responses (Tables 3 and 5). Significance between pre- and post-PPI responses was determined by performing a paired t test, with an α level of 0.05. Since the pooled data included students from various courses (Table 3), tests for normality were conducted, and no major violations of this assumption were detected (see Figure S3 for Q−Q plots). Lastly, since population sizes differed (from all pooled, large N, to an individual course, small N), a normalized gain of averages (gain scores) was calculated,[33] and the effect size was determined using Cohen's d (with a value > 0.80 considered a large effect).[34] This allows for more insight into the extent of perceived gains in KEC, rather than just if the changes in KEC are significant, because large effect sizes are not always associated with significant gains. These statistics were implemented to represent how students perceived their gains in KEC within the BASIL CURE and how different implementations affected their perceived gains. The findings were not used to directly evaluate the BASIL CURE or to make claims about how the BASIL CURE should be taught. Additionally, one limitation of this study is that our findings only apply to the specific small class sizes and implementation contexts described in this paper and, therefore, cannot be generalized to larger classes where the mode of instruction and TA support may be different. Further studies will be necessary to check for generalizability of our findings to larger class and other instructional contexts, as indeed it will be necessary to regularly update even the current findings whenever the BASIL curriculum changes or new instructors and materials are introduced.

RESULTS AND DISCUSSION

RQ1: Change in KEC for BASIL Specific ALOs

When analyzing all the PPI paired responses together ($n = 64$), students reported that their precourse KEC for the seven ALOs was between "none" and "a little" (Figure 2, Table S2). On the postcourse PPI, students reported that their KEC increased to be between "some" and "much" for all seven of the ALOs (Figure 2, Table S2). All of these increases were found to be significant ($p < 0.001$) and had large effect sizes ($d \geq 1.24$) for all seven of the ALOs (Table 1), with gain scores between 41% and 56% (Table S2). The ALO with the highest precourse (2.06) and postcourse (3.69) KEC score was for ALO7 (Figure 2) with a postcourse KEC approaching our "much" rating (Figure 2). This could be because protein purification and protein tagging is a common component of biochemistry courses and was

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

indicated by instructors of the BASIL CURE as an ability that students may experience in other courses, besides the BASIL CURE.[4] Thus, it is unsurprising that students entered the BASIL CURE with some KEC for ALO7, and that they would be able to build upon this ability by participating in this course. Additionally, ALO6 (Table 1) received the largest change in KEC score of 1.69, followed by ALO2 with an increase of 1.65 (Figure 2, Table S2). These two ALOs are integral to the BASIL CURE because they encompass two of the main activities: determining the active site (ALO2, Table 1) and identifying candidate ligands, followed by enzyme assays to assess the predicted protein function (ALO6, Table 1). The BASIL CURE as a whole was effective at increasing students' perceptions of their KEC for these seven ALOs (RQ1), across the BASIL courses (Figure 2, Tables 1 and 3, and Table S2). However, due to the modular nature of the BASIL CURE,[4,10,32] analysis of how specific implementations responded to the PPI survey is needed to understand how different activities conducted within the BASIL CURE impacted students' perceptions of their KEC for the identified items.

RQ2: Changes in KEC for Specific Implementations of the BASIL CURE

In this section, we focus on the implementation of the BASIL CURE as part of four different courses at three different institutions, with 10 or more student responses from each institution (Tables 2 and 3). Two of the institutions incorporated both the computational and biochemical components of the BASIL CURE (MW2-2 and SW1-9), while one course only included the computational components (NE3-7), and one only included the biochemical components (NE3-8; Figure 1, Table 3). In addition to the instructor responses to the PPI survey, course syllabi were examined to better understand the structure of these four courses, which is outlined in Figure 1.

For the two courses that included both the computational and biochemical BASIL CURE components (MW2-2 and SW1-9, Tables 2 and 3), the same general trends were observed as for all courses pooled and analyzed together (Table 5). However, some differences were detected for specific course implementations. For SW1-9, the change in KEC score for ALO3 (Table 1) increased but was not significant ($p = 0.15$) and had a medium effect size ($d = 0.56$, Table 5). ALO3 pertains to determining which factors are important for interpreting and optimizing enzyme assays. Findings show that, in contrast to the other biochemical (wet-lab) implementations, the students in SW1-9 had a relatively higher amount of prior experience with ALO3 (pre-KEC = 2.76, Figure 2, Table 5) resulting in a much lower gain score (22%). For the BASIL CURE, this ALO is typically associated with conducting a p-nitrophenyl acetate (PNPA) assay to detect protein hydrolase activity, which was the case for NE3-8 and SW1-9 (Figure 1). When looking at the courses that contained biochemical techniques (Figure 1), students in SW1-9 performed multiple types of assays in addition to the PNPA assays, namely, assays of other p-nitrophenyl derivatives, agarose electrophoresis, and thin-layer chromatography (TLC), to identify the particular type of hydrolase. In contrast, students in NE3-8 focused their attention on just the PNPA assay, running it multiple times while varying the conditions of the assay while in MW2-2 students selected and designed their own enzyme assays (Figure 1). Thus, since the students in SW1-9 had the opportunity to perform more types of assays, they may have had less time to spend on identifying important factors for optimizing or interpreting a given assay, resulting in a smaller change (0.48, Table 5) to the KEC score for ALO3 (RQ2).

Two other courses that were further analyzed, NE3-7 and NE3-8 (see Figure 1), were from the same institution (Tables 2 and 3). NE3-7 only covered the computational portions of the BASIL CURE, and NE3-8 only covered the biochemical-wet-lab portions (Figure 1). However, the two courses participated in cross-course meetings to share their results and experiences from the portions of the BASIL CURE they participated in (Figure 1). During these meetings, held at two different time points during the semester, students worked together to synthesize their results and to create a poster presentation on all the different components of the BASIL CURE that each of them conducted (Figure 1).

Unlike the courses that included all of the BASIL CURE components (MW2-2 and SW1-9), course NE3-7 (computational only) only showed significant increases in KEC scores, with large effect sizes, for the ALOs that pertained to the computational components of the BASIL CURE (ALO2, ALO4, ALO5) and the computational techniques (Table 5). This is unsurprising since these students did not directly participate in the biochemistry wet-lab components of the BASIL CURE. However, the NE3-7 students did perceive a significant gain in KEC for one biochemical-related ALO, ALO7 (Tables 1 and 5). The biochemistry-only course, NE3-8, did have significant increases across all items except for ALO4, a computational-related ALO (Tables 1 and 5), but had lower effect sizes and gain scores for the ALOs that related to computational abilities (ALO2 and ALO5, Table 1), in general, than for the biochemistry wet-lab items (Table 5).

The results from these two courses (NE3-7 and NE3-8) could be attributed to several factors. When the students from the two courses interacted, those in the computational course (NE3-7) may have provided more details about how they used the computational programs, whereas the students from the biochemical course (NE3-8) may have focused only on their results and not on optimization, troubleshooting, or design of assays and protocols conducted (RQ2). Therefore, conversations about the results from biochemical techniques did not impact the KEC of the biochemical-related ALOs (Tables 1 and 5). The one exception to this was ALO7 which, as discussed earlier, students may have already been familiar with prior to the course and could have made the biochemical students (NE3-8) more comfortable discussing this ALO with their computational peers (Figure 1, Table 5). The biochemical students (NE3-8) showed significant increases in KEC for ALO2 and the computational techniques, but with lower effect sizes (Table 5). This suggests that having exposure to the computational components of the BASIL CURE through the cross-course meetings afforded students the opportunity to learn about computational techniques, an area of chemistry that undergraduate students are often not taught (RQ2).

■ CONCLUSION AND IMPLICATIONS

In this study we addressed the following research questions: (RQ1) How do students' perceptions of KEC regarding specific ALOs change after a BASIL CURE? (RQ2) How do student perceptions of their KEC regarding specific BASIL ALOs vary across different implementations of the BASIL CURE? Across all implementations, there was an increase in students' perception of their KEC for all of the seven BASIL CURE ALOs (Figure 2, Table S2) that were previously identified[3,4] and used for this PPI survey (RQ1). In general, these gains were

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

significant and showed large effect sizes (Figure 2, Table S2) across all implementations of the BASIL CURE (RQ1). This suggests that the PPI yielded data that successfully demonstrated that students felt very positive regarding their development during the BASIL CURE of the ALOs corresponding to various research abilities. In addition, we found no evidence to suggest that any instructor focused only on procedural steps, and the PPI findings show that students actually feel they gained in knowledge (K), experience (E), and confidence (C) about how to conduct research. When focusing on the course sections with 10 or more paired responses (Table 5), the same general trend was observed for the courses implementing all components of the BASIL CURE (MW2-2 and SW1-9, Figure 1, Tables 3 and 5, and Tables S4–S7). However, the PPI survey was able to detect differences for specific course implementations. For example, SW1-9 did not show a significant increase in students' perceived KEC for ALO3. This could have been due to the students being exposed to more types of assays and with less time available for optimizing a particular assay, suggesting that students benefit from focusing on the details of a singular assay, or from being allowed to research and choose an assay, rather than being exposed to many different assays (RQ2).

Differences in students' perceived changes in KEC were observed depending on whether they participated in the computational (NE3-7) or the biochemical-wet-lab (NE3-8) components of the BASIL CURE (RQ2), suggesting that the PPI is a sensitive indicator of such differences. These differences are also an indicator that the students were reliably responding to the PPI (e.g., the computational-only course, NE3-7, only reported a perceived increase on the computational-related items, Table 5 and Table S6). Furthermore, there is some surprising evidence that students who participated in a course that only exposed them to the biochemical-wet-lab components and techniques of the BASIL CURE (e.g., NE3-8, Table 5 and Table S7) increased their perceived KEC for computational-related ALOs (Table 1) by learning about the computational techniques from their peers (Table 5) who were in the computational-only course (NE3-7, RQ2, Figure 1). However, the computational-only students (NE3-7) showed only a very small gain for the biochemical-wet-lab-related ALOs compared with students who were enrolled in the course that conducted the biochemical-wet-lab techniques (NE3-8; Table 5). Similarly, Clase et al.[15] reported that students did not perceive KEC gains for materials that they did not experience in class activities. When this is the case, instructors or researchers could either adjust the activities or modify the ALOs or assessment measures to align more carefully with what students actually experienced in the course. Like in the Clase et al.[15] study, the finding for NE3-7 of less gain for the biochemical-wet-lab ALOs acts as a form of negative control. It would not be expected of students who do not experience the wet-lab modules to show an increase in their KEC for these items. Thus, it would not be fair to target future assessment of biochemical-wet-lab ALOs within this particular implementation of the BASIL CURE.

The findings of this study have shown that the PPI is an effective instrument for revealing changes in students' perceived KEC with respect to key ALOs that focus on research abilities developed during the BASIL CURE. These are novel findings that complement other perception metrics (e.g., refs 7, 13, 16–19, 22–25, 27) used to study CUREs that focus on general lab-related abilities rather than research abilities such as discovery and problem-solving. This is because the PPI survey reported here provides no information about students' identity as a scientist,[22] their satisfaction with the research experience,[16,17] their feelings of project ownership[25] and perceptions of collaboration,[26] their experiences with mentorship and resulting interest in research,[16,17] or their experience with communicating their findings.[19] In summary, our findings demonstrate that the PPI complements, but does not replace, the usefulness of other already established survey instruments.

PPI surveys and the type of data they collect emerged from self-efficacy theory.[12,35,36] A PPI survey is an important metric to use as part of an assessment strategy because it can measure a sense of research ability,[11,13] not just hands-on lab skills,[14] which will, in turn, impact a student's actual ability and learning. If a student perceives that their KEC has increased, they may then also have a higher self-efficacy surrounding the abilities and techniques they learned from a CURE, which could make a student more likely to be willing and able to attempt to apply these abilities. Gains in a student's self-efficacy could, in turn, positively impact their actual research ability.[37]

Any self-reported data like that generated by the PPI survey can usefully complement other measures of student learning (e.g., open-ended assessments, student interviews, lab notebooks, etc.), because students can have an illusion of their understanding of a topic.[38] PPI surveys on their own may provide an accurate indication of students' procedural knowledge (e.g., ref 14), as students may be able to gauge their KEC for technical skill, such as using a volumetric pipet, but discovery-type knowledge has been reported to be subject to "illusions of understanding".[38] However, it is also crucial for students to learn to apply the scientific skepticism needed for research, such as the ability to optimize, troubleshoot, or interpret assays and protocols that they conduct as listed in Table 1, even though there may be a higher degree of the Dunning–Kruger effect in which students overestimate their research ability.[38−40] As an example of this, we previously published[4] a student's open-ended response to a question, that covered ALOs 1, 3, 5, and 6 (Table 1), about an enzyme assay for hydrolase (3H04) activity measured by colorimetric techniques, by the color change of the substrate, p-nitrophenyl acetate (PNPA), over time to indicate the rate of product accumulation. The students' KEC scores for these ALOs were between 4.33 and 4.67 on the post-PPI survey, indicating that the student reported having between "much" and "a great deal" of knowledge, experience, and confidence for these ALOs. In contrast, the student's open-ended response revealed that the student failed to suggest the need to track absorbance values of an appropriate concentration of PNPA in the absence of enzyme and did not suggest measuring the absorbance of trypsin in both the presence and absence of PNPA. Thus, the student had difficulty in particular with "appropriate factors to consider when optimizing or interpreting an enzyme assay" (ALO3). This assessment thus reveals that the student could still learn more about how to optimize an assay with better positive and negative control data to rigorously link these research methods to claims about the protein function. More studies are needed to compare and investigate both types of student data. This type of comparison and analysis will be the target of future research, because it is important for students to develop both a sense of research knowledge, experience, and confidence as well as actual ability and understanding about how to link biochemistry knowledge with data from research methods in the study of mechanisms.[20,21] Lastly, this illustrates why it is important to make the distinction between measures of perceived gains and direct measures of actual research competence.

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65

In summary, the PPI survey results of the current study on their own clearly indicate that students in the BASIL CURE perceived gains in their KEC for this set of specific ALOs (Table 1) and that these are now ready for direct assessment of student learning. This type of PPI survey provides instructors with deep insight into the specific research abilities students are developing, which allows them to know what to emphasize on other forms of assessment. Indeed, BASIL CURE instructors are already using the PPI survey as a guiding framework for assessment development to learn more about areas of difficulty students experience in their own BASIL CURE classrooms. To our knowledge, other surveys are not yet being used in this way to more carefully target how students link research methods to claims about explanatory mechanisms like protein function that are the focus of this specific CURE. Instead of surveying generalized attitudes and skills, the BASIL CURE PPI provides an explicit focus on opportunities students experience for linking research methods to claims about novel discoveries that are informed by theory and concepts from a particular discipline, which in this case is protein biochemistry to elucidate how a protein with known structure but unknown function might really work.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.9b00440.

Survey items, student demographics, and results (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: ander333@purdue.edu.

ORCID

Stefan M. Irby: 0000-0002-8959-2844

Nancy J. Pelaez: 0000-0002-6328-5010

Present Address

‡Department of Chemistry, University of Central Florida, Orlando, Florida 32816, United States.

Notes

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We would like to thank the Biochemistry Authentic Scientific Inquiry Lab (BASIL) project team and instructors for their participation in this study, as well as Kathleen Jeffery of the Visualization in Biochemistry Education (VIBE) Research Group for providing feedback during the early stages of this manuscript. The authors also thank the Statistical Consulting Service at Purdue University for helpful advice and discussions. This work was funded by the National Science Foundation (NSF) Division of Undergraduate Education (DUE) grants 1503798 and 1710051. Additionally, this paper was informed by the ACE-Bio Network (NSF grant 1346567).

■ REFERENCES

(1) Auchincloss, L. C.; Laursen, S. L.; Branchaw, J. L.; Eagan, K.; Graham, M.; Hanauer, D. I.; Lawrie, G.; McLinn, C. M.; Pelaez, N.; Rowland, S.; et al. Assessment of Course-Based Undergraduate Research Experiences: A Meeting Report. *CBE Life Sci. Educ.* **2014**, *13* (1), 29−40.

(2) Corwin, L. A.; Graham, M. J.; Dolan, E. L. Modeling Course-Based Undergraduate Research Experiences: An Agenda for Future Research and Evaluation. *CBE Life Sci. Educ.* **2015**, *14* (1), es1.

(3) Irby, S. M.; Pelaez, N. J.; Anderson, T. R. How to Identify the Research Abilities Instructors Anticipate Students Will Develop in a Biochemistry Course-Based Undergraduate Research Experience (CURE). *CBE Life Sci. Educ.* **2018**, *17* (2), es4.

(4) Irby, S. M.; Pelaez, N. J.; Anderson, T. R. Anticipated Learning Outcomes for a Biochemistry Course-Based Undergraduate Research Experience Aimed at Predicting Protein Function from Structure: Implications for Assessment Design. *Biochem. Mol. Biol. Educ.* **2018**, *46* (5), 478−492.

(5) Craig, P. A.; Anderson, T.; Bernstein, H. J.; Daubner, C.; Goodman, A.; Irby, S. M.; Koeppe, J.; Mills, J. L.; Pikaart, M.; McDonald, A. R.; O'Handley, S.; Roberts, R.; Stewart, R. Using Protein Function Prediction to Promote Hypothesis-Driven Thinking in Undergraduate Biochemistry Education. *The Chemist* **2018**, *91* (1), 1−8.

(6) Brownell, S. E.; Kloser, M. J.; Fukami, T.; Shavelson, R. Undergraduate Biology Lab Courses: Comparing the Impact of Traditionally Based "Cookbook" and Authentic Research-Based Courses on Student Lab Experiences. *J. Coll. Sci. Teach.* **2012**, *41* (4), 36−45.

(7) Shelby, S. J. A course-based undergraduate research experience in biochemistry that is suitable for students with various levels of preparedness. *Biochem. Mol. Biol. Educ.* **2019**, *47* (3), 220−227.

(8) Lopatto, D. *Science in Solution: The Impact of Undergraduate Research on Student Learning*; Research Corporation for Science Advancement: Tucson, AZ, 2009. https://www.grinnell.edu/sites/default/files/documents/science_in_solution_lopatto.pdf (accessed Oct 10, 2019).

(9) Weaver, G. C.; Russell, C. B.; Wink, D. J. Inquiry-Based and Research-Based Laboratory Pedagogies in Undergraduate Science. *Nat. Chem. Biol.* **2008**, *4* (10), 577−580.

(10) McDonald, A. R.; Bernstein, H. J.; Daubner, S. C.; Goodman, A.; Irby, S. M.; Koeppe, J. R.; Mills, J. L.; O'Handley, S. F.; Pikaart, M. J.; Roberts, R. A.; Sikora, A.; Craig, P. A. BASIL Biochemistry Curriculum. https://basilbiochem.github.io/basil (accessed Oct 10, 2019).

(11) Berger, C. F.; Carlson, E. A. Measuring Computer Literacy of Teacher Trainers. *J. Educ. Comput. Res.* **1988**, *4* (3), 287−301.

(12) Bandura, A. Self-Efficacy: Toward a Unifying Theory of Behavioral Change. *Psychol. Rev.* **1977**, *84* (2), 191−215.

(13) Glazer, N. Student Perceptions of Learning Data-Creation and Data-Analysis Skills in an Introductory College-Level Chemistry Course. *Chem. Educ. Res. Pract.* **2015**, *16* (2), 338−345.

(14) Hensiek, S.; Dekorver, B. K.; Harwood, C. J.; Fish, J.; O'Shea, K.; Towns, M. Improving and Assessing Student Hands-On Laboratory Skills through Digital Badging. *J. Chem. Educ.* **2016**, *93* (11), 1847−1854.

(15) Clase, K. L.; Gundlach, E.; Pelaez, N. J. Calibrated Peer Review for Computer-Assisted Learning of Biological Research Competencies Received. *Biochem. Mol. Biol. Educ.* **2010**, *38* (5), 290−295.

(16) Lopatto, D. Survey of Undergraduate Research Experiences (SURE): First Findings. *Cell Biol. Educ.* **2004**, *3* (4), 270−277.

(17) Lopatto, D. Undergraduate Research Experiences Support Science. *CBE Life Sci. Educ.* **2007**, *6* (4), 297−306.

(18) Shaffer, C. D.; Alvarez, C. J.; Bednarski, A. E.; Dunbar, D.; Goodman, A. L.; Reinke, C.; Rosenwald, A. G.; Wolyniak, M. J.; Bailey, C.; Barnard, D.; et al. A Course-Based Research Experience: How Benefits Change with Increased Investment in Instructional Time. *CBE Life Sci. Educ.* **2014**, *13* (1), 111−130.

(19) Weston, T. J.; Laursen, S. L. The Undergraduate Research Student Self-Assessment (URSSA): Validation for Use in Program Evaluation. *CBE Life Sci. Educ.* **2015**, *14* (3), ar33.

(20) Trujillo, C.; Anderson, T. R.; Pelaez, N. A Model of How Different Biology Experts Explain Molecular and Cellular Mechanisms. *CBE Life Sci. Educ.* **2015**, *14* (2), ar20.

(21) Jeffery, K. A.; Pelaez, N.; Anderson, T. R. How Four Scientists Integrate Thermodynamic and Kinetic Theory, Context, Analogies, and Methods in Protein-Folding and Dynamics Research: Implications for Biochemistry Instruction. *CBE Life Sci. Educ.* **2018**, *17* (1), No. ar13.

(22) Shanle, E. K.; Tsun, I. K.; Strahl, B. D. A Course-Based Undergraduate Research Experience Investigating P300 Bromodomain Mutations. *Biochem. Mol. Biol. Educ.* **2016**, *44* (1), 68−74.

(23) Lefurgy, S. T.; Mundorff, E. C. A 13-Week Research-Based Biochemistry Laboratory Curriculum. *Biochem. Mol. Biol. Educ.* **2017**, *45* (5), 437−448.

(24) Kirkpatrick, C.; Schuchardt, A.; Baltz, D.; Cotner, S. Computer-Based and Bench-Based Undergraduate Research Experiences Produce Similar Attitudinal Outcomes. *CBE Life Sci. Educ.* **2019**, *18* (1), ar10.

(25) Hanauer, D. I.; Dolan, E. L. The Project Ownership Survey: Measuring Differences in Scientific Inquiry Experiences. *CBE Life Sci. Educ.* **2014**, *13* (1), 149−158.

(26) Corwin, L. A.; Runyon, C.; Robinson, A.; Dolan, E. L. The Laboratory Course Assessment Survey: A Tool to Measure Three Dimensions of Research-Course Design. *CBE Life Sci. Educ.* **2015**, *14* (4), ar37.

(27) Mutambuki, J. M.; Fynewever, H.; Douglass, K.; Cobern, W. W.; Obare, S. O. Integrating Authentic Research Experiences into the Quantitative Analysis Chemistry Laboratory Course: STEM Majors' Self-Reported Perceptions and Experiences. *J. Chem. Educ.* **2019**, *96* (8), 1591−1599.

(28) Craig, P. A. A Survey on Faculty Perspectives on the Transition to a Biochemistry Course-Based Undergraduate Research Experience Laboratory. *Biochem. Mol. Biol. Educ.* **2017**, *45* (5), 426−436.

(29) McKay, T.; Hart, K.; Horn, A.; Kessler, H.; Dodge, G.; Bardhi, K.; Bardhi, K.; Mills, J. L.; Bernstein, H. J.; Craig, P. A. Annotation of Proteins of Unknown Function: Initial Enzyme Results. *J. Struct. Funct. Genomics* **2015**, *16* (43), 43−54.

(30) Gray, C.; Price, C. W.; Lee, C. T.; Dewald, A. H.; Cline, M. A.; McAnany, C. E.; Columbus, L.; Mura, C. Known Structure, Unknown Function: An Inquiry-Based Undergraduate Biochemistry Laboratory Course. *Biochem. Mol. Biol. Educ.* **2015**, *43* (4), 245−262.

(31) The Carnegie Classification of Institutions of Higher Education. http://carnegieclassifications.iu.edu/ (accessed Oct 10, 2019).

(32) Roberts, R.; Hall, B.; Daubner, C.; Goodman, A.; Pikaart, M.; Sikora, A.; O'Handley, S.; Mills, J. L.; Craig, P. Flexible Implementation of the BASIL CURE. *Biochem. Mol. Biol. Educ.* **2019**, *47* (5), 498−505.

(33) Hake, R. R. Interactive-Engagement Vs Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *Am. J. Phys.* **1998**, *66* (1), 64−74.

(34) Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Lawrence Erlbaum Associates: Hillsdale, NJ, 1988.

(35) Lunenburg, F. C. Self-Efficacy in the Workplace: Implications for Motivation and Performance. *Int. J. Manag. Business, Adm.* **2011**, *14* (1), 1−6.

(36) Bandura, A. Exercise of Personal and Collective Efficacy in Changing Societies. In *Self-Efficacy in Changing Societies*; Bandura, A., Ed.; Cambridge University Press: New York, 1995; pp 1−45.

(37) Ross, J. A. The Reliability, Validity, and Utility of Self-Assessment. *Pract. Assessment, Res. Eval.* **2006**, *11* (10), 1−13.

(38) Rozenblit, L.; Keil, F. The Misunderstood Limits of Folk Science: An Illusion of Explanatory Depth. *Cogn. Sci.* **2002**, *26* (5), 521−562.

(39) Kruger, J.; Dunning, D. Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments. *J. Pers. Soc. Psychol.* **1999**, *77* (6), 1121−1134.

(40) Dunning, D. The Dunning-Kruger Effect. On Being Ignorant of One's Own Ignorance. In *Advances in Experimental Social Psychology*; Olson, J. M., Zanna, M. P., Eds.; Academic Press: San Diego, 2011; Vol. *44*, pp 247−296. DOI: 10.1016/B978-0-12-385522-0.00005-6

DOI: 10.1021/acs.jchemed.9b00440
J. Chem. Educ. 2020, 97, 56−65