Learning about teaching and learning while learning physics: An analysis of 15 years of responsive curriculum development

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[This paper is part of the Focused Collection on Curriculum Development: Theory into Design.] Fifteen years ago, following recommendations from research on science education for prospective teachers and for students more broadly, *Physics and Everyday Thinking* introduced activities within an inquiry-based undergraduate physics course that explicitly focus on the nature of science and nature of learning. This component of the curriculum is referred to as learning about learning. Since then, this same team developed a series of other curricula. These later curricula, *Physics and Everyday Thinking* (2nd ed.), *Physical Science and Everyday Thinking*, *Learning Physics*, *Learning Physical Science*, and *Next Generation Physical Science and Everyday Thinking* all retain a focus on learning about learning as a priority. While similar theoretical grounding guided development across all these curricula, this particular component evolved considerably. These changes were motivated by practical considerations, developments in research, changes to the K-12 expectations, and changes in physics departments, as well as changes to the team. We introduce the term responsive curriculum development to describe the changes made to this aspect of the curricula. With responsive curriculum development, the development process is responsive to contextual, social, and policy factors so that the materials remain relevant and adaptable in diverse contexts and time periods.

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I. INTRODUCTION

Efforts to create K-12 curricula that emphasize science as a practice and as an “evidence-based way of understanding the world” have taken place since the mid 1800s (Ref. [1], p. 53). These efforts sought to engage students in inducing principles from data, using evidence to create models of

phenomena, and arguing from evidence, among other things. Otero and Meltzer [1] point out that while arguments to promote curricula that target these goals have been similar since the late 1880s, the terms used to describe these approaches have changed over time: “inductive method” [2], “project method,” “nature of science” [3], “scientific literacy” [4], and “scientific inquiry” [5]. The AAAS *Project 2061 Benchmarks of Scientific Literacy* promoted “cross-cutting themes” to capture concepts and procedures that cut across disciplines and they created an atlas of scientific literacy [4] that depicts these connections. Two decades later, the *Next Generation Science Standards* (NGSS) [6] included crosscutting concepts as one of three

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dimensions of learning, along with scientific practices and disciplinary core ideas.

Reform efforts with similar ideals have failed and recurred for many reasons, including that the K-12 teachers themselves often did not engage in the practices of science in their own science education [7,8]. As a result, when past reform efforts asked teachers to engage students in scientific practices, many teachers ended up teaching *about* scientific practices rather than teaching *through* them [9]. For example, the notion of *models* was presented as a decontextualized unit on its own rather than integrated within content such as the model of the atom or the model of magnetism, as intended by the varied reform movements throughout history. To address the former reform movements' limited impact on practice, the NGSS created *performance expectations* [6], which explicitly integrate scientific practices, crosscutting concepts, and core concepts so that teachers can understand and implement reform as has always been intended. From a historical perspective, the explicit integration of content and practices in performance expectations, together with the adoption of NGSS by many states in the U.S., makes the prognosis slightly better for the current NGSS reform movement than for its predecessors.

The physics community has developed many inquiry-based physics and physical science curricula for prospective elementary school teachers [10]. These materials engage students in many of the practices of science, for example, posing questions, developing and using models, carrying out investigations, analyzing and interpreting data, constructing explanations, and engaging in argument from evidence. However, learning content through engagement with practices is not sufficient either for those who will be teaching physics ideas to children or for helping physics students gain principled understandings of scientific practices. To effectively transform content knowledge into usable knowledge for teaching or into knowledge *about* science requires that content courses integrate “knowledge about science with knowledge about learning, pedagogy, and students” [5].

The curricula discussed in this paper address this by integrating activities that focus on principles of learning alongside activities intended to help students learn principles of physics. This integration of activities focused on principles of learning together with principles of physics was new, and it has required that curriculum developers were both able to learn from the community and to be responsive to their needs. Thus, over time, the curriculum evolved in response to the community, to findings from educational research, to changes in the K-12 educational context, to changes in the socioeducational climate of physics education, and to funding and changes in the development team.

In analogy with the concept of *responsive teaching*, which posits that teaching should be responsive by attending to the substance of student thinking [11], we propose

the idea of *responsive curriculum development*: that curricula must be responsive to a variety of factors so that they remain relevant and adaptable in diverse contexts and time periods. Responsive teaching “is to adapt and discover instructional objectives responsively to student thinking” [11]. Similarly, the curricular development discussed here responds to contextual factors and design research. The first part of responsive teaching elicits students' generative engagement around some provocative task or situation. From there, the teacher's role is to support that engagement and attend to it—watch and listen to the students' thinking, form a sense of what they are doing, and through this, identify productive beginnings of scientific thinking. In this way, the teacher may select and pursue a more specific target, in a way that recognizes and builds findings from their in-the-moment research. Similarly, responsive curricular development selects and pursues specific targets according to changes in sociopolitical contexts and findings from ongoing design research. For example, Swanson and Harlow [12] and Harlow *et al.* [13] found that by analyzing video of elementary students, Physics and Everyday Thinking (PET) students further developed and applied conceptual knowledge of physics to understanding children's ideas. This finding supported the decision to use activities explicitly focused on ideas about learning in a physics course for nonscience majors. Whereas responsive teaching takes place at the timescale of the moment in a classroom situation, responsive curriculum development takes place at longer timescales in response to the community. For example, in response to changes in national standards and benchmarks [4], various content was included or removed, and this component of the curricula took various forms.

This paper focuses on a set of curricular activities, referred to as *learning about learning* or *teaching and learning* (collectively referred to here as LAL), that intentionally and explicitly guide students through thinking about their own learning of physics and the contexts in which this learning occurs. While LAL activity development was motivated initially by a desire to meet the needs of prospective elementary school teachers, it was later adapted to the needs of a broader audience of physics students who could benefit from investigating the process of scientific investigation. Then, with the advent of the NGSS, activity development began to focus on helping teachers think carefully about the teaching and learning of young students, activities that can also aid learning through the development of greater metacognitive sophistication. Using children's ideas and thinking as a tool for learning has remained stable throughout the evolution of the curricular products, but the way it has been addressed changed several times in response to many factors. This paper examines the trajectory of the LAL component of the curriculum as the developers responded to and leveraged a variety of contextual and sociopolitical considerations and

changing language, substance, and context of reform. The process of responding to these factors is what we describe as responsive curriculum development.

The series of curricula discussed here were developed by the Goldberg team, headquartered at San Diego State University. Fred Goldberg is an early adopter of physics education research-based curriculum development and his ideas have carried forward as new collaborators including colleagues from other universities and his own graduate students, and their students, became involved. While the central philosophy guiding the curricular approach has remained consistent (including a focus on learning, using children's ideas as an observable phenomenon, and structural coherence with the curricula within which the LAL activities are embedded), significant changes have occurred in subsequent instantiations of the curricular products.

The design of all versions of the curriculum followed the same theoretical and research-based design principles: learning is a complex process, guided by prior knowledge, mediated by interaction with tools and interactions with peers, and is structured by norms and expectations (see Ref. [14] for discussion of design principles). However, specific design decisions were also guided by factors such as observations of how particular activities and complete units performed when implemented during field testing, and practical and contextual considerations. For example, the initial curricula were designed for small seminar courses, which afforded sustained group interaction and discussion. Adapting the curricula for lecture style courses necessitated changes to the activity structure to function in the new classroom context and to reduce the time burden on instructors responsible for possibly hundreds (instead of dozens) of students. The next section provides context for these curriculum development efforts and describes the curricula. Section III describes the associated LAL activities in detail. Sections IV and V discuss the interrelated factors that influenced the team's curricular innovations. We conclude with a discussion of responsive curricular development and how it can be adapted for other curricular development.

II. THE ORIGINS AND EVOLUTION OF PET AND THE LAL ACTIVITIES

Physics for Elementary Teachers [15] was the first curriculum developed by the Goldberg team that included LAL activities. However, earlier efforts laid the foundation for PET. Constructing Physics Understanding in a computer-supported learning environment (CPU) was among the first curricula developed by this team [16]. While the CPU curriculum followed the inductive method (i.e., students induced principles from data and collaborated to generate consensus about the principles that explained the data), it did not explicitly address scientific practices or learning. During the 1990s and 2000s, research increasingly demonstrated that unless the nature of science and

epistemology of science are addressed explicitly and embedded within content instruction, students may leave their physics class either with notions of science knowledge as relative, unstable, and untrustworthy [17], or as facts that are handed down from authority and not relevant to their lives [18]. It was also during this era, and in response to *A Nation at Risk* [19], that publications such as the AAAS *Project 2061 Benchmarks of Scientific Literacy* [4] and the *National Science Education Standards* (NSES) [5] began promoting the inclusion of the nature and practices of science in all science classrooms and curricula.

With *Physics for Elementary Teachers*, the Goldberg team responded to these reform efforts by explicitly addressing concepts having to do with learning about one's own learning, learning about the learning of others, and learning about scientists' learning (the nature of science, scientific practices) directly in the physics curriculum. That is, the scope and sequence of the curricular materials included activities in which students were expected to induce principles about the nature and process of learning from video data and literature regarding various people's learning of physics. Specifically, video of children discussing and learning physics presented children's ideas as observable phenomena about which PET students could make evidence-supported claims. These activities existed alongside those in which students were expected to induce principles about physics via data from observations of physical phenomena. Thus, three ideas, (1) parallel pedagogy, (2) focus on learning, and (3) use of children's ideas as an observable phenomenon, held true to the inductive method and continued through all of the subsequent curricula developed by this group. *Physics for Elementary Teachers* [15], *Physics and Everyday Thinking* [20], *Physical Science and Everyday Thinking* (PSET) [21], *Learning Physical Science* (LEPS) [22], and *Learning Physics* (LEP) used this parallel pedagogy in similar ways, but adapted it to diverse educational contexts ranging from audiences of in-service and preservice elementary teachers to undergraduate students taking their first (and sometimes only) general physics course in both small- and large-enrollment contexts. The current instantiation, *Next Generation Physical Science and Everyday Thinking* (Next Gen PET) [23] is aligned with the NGSS and marked the next dramatic change: in addition to addressing the principles of physics alongside principles of learning physics, principles of *teaching physics* were now included. In the following section, we describe the three primary instantiations of the LAL activity components.

III. CURRICULAR DESIGN STAGES

The learning about learning components were developed within the context of the changes to the broader curricula, which occurred in three primary stages (see Fig. 1), which we call LAL-1, LAL-2, and LAL-3. As is described below, each of these iterations were developed with specific physics and physical science curricula. LAL-1 is associated

FIG. 1. Evolution of curricular materials.

with PET and PSET; LAL-2 is associated with LEPS and LEP; and LAL-3 is associated with LEP and Next Gen PET.

LAL-1 was developed as part of PET and PSET, which were developed for implementation in small courses (30–40 students) that included physics and physical science content, respectively. However, the small class size and studio or lab format of PET and PSET were not feasible in many institutional contexts. In response to these and other concerns, LEPS and LEP were designed for larger classes or “lecture” rooms that are poorly configured for hands-on experiences and group discussions. The same research-based design principles that guided the development of PET and PSET [14] were used to design LEP and LEPS, but they were implemented differently to respond to the needs of the different setting [24]. The curricular modification required corresponding changes in the LAL activities, resulting in LAL-2. The third iteration began in LEP by transitioning to focus explicitly on NGSS. The most recent version, Next Gen PET, aligns more fully with the three-dimensional structure of the NGSS. The structure of Next Gen PET was also changed with the goal of providing more flexibility in both structure and content. These changes resulted in changes to the LAL component. LAL-3 not only features activities on LAL, but also includes activities in which students learn about the teaching of physical science (see Fig. 1). The structure and function of the LAL activities responded to a changing audience for the LAL component. In the second iteration of PET, as well as PSET, LEPS, and LEP, the anticipated audience was nonscience majors enrolled in an introductory undergraduate physics course, specifically prospective elementary school teachers. The function of LAL was to help this audience establish metacognitive awareness as well as to learn scientific practices. The modular nature of Next Gen PET allowed for a more direct focus on helping students learn about and enact the NGSS. This component was now optional so that Next Gen PET was still relevant to the introductory physics population (for whom the optional LAL could be omitted), and now also for training future and in-service teachers. Table I summarizes the differences between iterations and the subsequent three sections

describe the curricular context (the physics or physical science curricula) of each of the three instantiations of LAL and the LAL component in more detail.

A. LAL design cycle 1: PET and PSET

The original name *Physics for Elementary Teachers* [15] reflects the intended audience of undergraduate and graduate students preparing to become teachers. However, field tests found that the curriculum including the LAL activities was valuable to the general population of physics students, particularly those not majoring in physics. In response to this, the name of the second edition was changed to *Physics and Everyday Thinking* [20]. Also, through field tests, faculty user feedback revealed a need for a similar course in physical science. In response, PSET was developed, which cut some of the physics content and added small particle theory, physical changes, and chemical changes.

The physics and physical science activities in both versions of PET and PSET follow the same cyclic structure that reflects the design principles. After reading about the purpose of the activity, students respond to questions designed to elicit their *initial ideas* about the phenomenon addressed. This is followed by *collecting and interpreting evidence* in which students collect data from hands-on experiments or simulations. Students then complete *summarizing questions*, which are intended to help them generate a set of principles from their data, which can account for all of their observations. Consistent with the practices of scientists, they then engage in a *consensus discussion* intended to generate class consensus on the central physics principles of the chapter. *Scientists’ ideas* readings are provided to students at the end of each chapter. Typically, they have generated most of these ideas through summarizing questions and their consensus discussion; however scientists’ ideas present terminology and symbolic representations that students would likely not generate on their own. The curricula also have a set of social scientists’ ideas to reflect the principles of teaching and learning that students generated through their LAL activities.

In PET, each LAL activity is focused mainly on one of three aspects of learning: learning about our own learning

TABLE I. Focus, format, and characteristics of learning curriculum elements across design cycles.

Iteration	Part of	Focus	Format	Characteristics
LAL-1	PET, PSET	Three types of activities focused on learning about one's own learning, learning about scientists' learning, and learning about the learning of others (elementary students).	In-class activities, pencil and paper homework	Focus on students generating sensitivity to their own learning process by examining the process of others and connecting it to the practices of science.
LAL-2	LEPS	The activities were expanded to include a focus not only on children's learning, but also how undergraduates were learning physics and on how scientists develop new science ideas (nature of science).	In-class activities (end of unit) and online homework; multiple-choice questions practices	Inclusion of analysis of undergraduate ideas Online Extension activities Group writing assignments
	LEP	The version of LAL associated with LEP was a transitional stage, changing to reflect the explicit alignment with the NGSS.	In-class activities (end of unit) and online homework; multiple-choice questions; group assignments	Interviews of children Introduced engineering Added readings about NGSS
LAL-3	NGP	The module was fully aligned with the three strands of the NGSS. Connections between students' own learning, and the learning and teaching of children in elementary school. Extensive NGSS focus, including engineering design. Renamed to be teaching and learning to reflect expanded focus on teaching.	In-class activities (end of unit) and online homework; multiple-choice questions; group assignments	Used Engineering is Elementary videos. Analysis was of both students' ideas and teacher's moves to support development of these ideas. Activities to address all strands of the NGSS (disciplinary core ideas, practices, crosscutting concepts).

(focused on students' own learning of various physics concepts), learning about scientists' learning (focused explicitly on scientific practices), and learning about the learning of others (focused on the learning of young students). Learning about the learning of others activities were intended to help all students gain sensitivity and tolerance of their own learning process by becoming sensitive to the learning process of younger learners. All LAL activities follow the same structure and pedagogy as the content activities in which students induce principles from data. However, in LAL activities, the principles are principles of learning and scientific practices and the data are videos of students' learning or readings that summarize educational literature. Research on the undergraduates' discussion during LAL activities provided evidence that the video analyses were useful not only for helping the undergraduates value the science ideas, but that they developed and refined their understanding of the physics concepts through discussing children's ideas [25]. These findings influenced subsequent LAL design cycles.

The learning principles addressed in LAL activities and listed in Table II are scaffolded and developed iteratively

throughout all chapters of the PET and PSET curriculum. These principles, which remained consistent throughout all iterations of the curriculum are (1) students have preinstructional ideas, (2) preinstructional ideas play a major role in the further development of knowledge, (3) understanding evolves over time, (4) knowledge generation is a social process that includes articulation of one's own ideas, consideration of the ideas of others, generation of knowledge through group discourse, and development of science ideas through consensus, and (5) there must be a fit between learners' explanations and available evidence, whether the learners are scientists or students.

An example of a PET and PSET LAL activity intended to address learning principles 1 and 3 is found in the PET and PSET unit on forces and energy. PET and PSET students watch a video of younger students (elementary school age) answering the same question that they answered about the forces on a soccer ball during and after it is kicked. They typically notice some similarities between their own initial ideas and the ideas of young students. Then, the summarizing questions help PET and PSET students explore why these ideas might make sense to the children and how the

TABLE II. Principles of learning and teaching used in LAL.

Principle of teaching and learning	Description
1. Students have pre-instructional ideas [26]	Students' preinstructional ideas are generally built on experience and make empirical and logical sense to the learner, even though they are often not consistent with scientists' ideas.
2. Students' ideas must be taken into account [27]	Preinstructional ideas (as well as different states of knowledge throughout the learning process) play a major role in the further development of knowledge. Instructors may interpret these ideas as being problematic and resistant to change or as resources for further learning.
3. Understanding evolves over time [28]	At any given time, the teacher and learner should recognize partial understanding of a particular concept. This objective is coupled with the idea that big ideas have many components. This view is in opposition to the common belief that "you either know it or you don't." Partial understanding is valuable even though it may feel confusing to the student and may look incomprehensible initially to the teacher.
4. Knowledge generation is a social process [29]	This includes articulation of one's own ideas, consideration of the ideas of others, generation of knowledge through group discourse, and development of science ideas through a process of consensus.
5. Fit between learners' explanation and available evidence [30]	There must be a fit between learners explanations and available evidence, whether the learners are scientists or students.

children's ideas are similar and different from their own ideas. This activity is intended to help students gain a greater sensitivity to knowledge in creation and that all learners have preinstructional ideas that evolve over time. An example of PET students' comments when discussing the summarizing questions is shown below.

Just as I was thinking that the kids were, that they knew that something was transferred and keeping it traveling, but really that was energy but we were using the word force just like they were. We were saying that this is probably the first like time for both the kids and for us in this class—they really just never been exposed to a certain vocabulary, you know? And so sometimes that's a little tricky, like weeding out exactly what you mean by force or energy and like I saw the same thing in both the video and in like this class and the way I learn too. (transcript from an observation of a PET course)

The fifth learning principle is addressed in PET's chapter titled Model of Magnetism. After developing and revising models to ultimately establish a domainlike model of magnetism, PET students complete a LAL activity focusing on the historical development of the model of magnetism among scientists. PET students consider four historical models of magnetism: Gilbert's harmony and discord model, Descartes' particles and pores model, Aepinus's magnetic fluid model, and Coulomb's magnetic entities (domain) model. They are then asked to consider a set of observations that they made during the physics portion of the unit and to decide if the historical model could explain each observation. Finally, students are asked why Coulomb's model ended up being accepted by the community of scientists. It is hoped that they recognize that

Coulomb's model could explain more observations than the other models, consistent with learning principle 5.

B. LAL design cycle 2: LEPS and LEP

Significant structural changes were required in adapting the LAL-1 activities for *Learning Physical Science* and *Learning Physics*, which were designed to be taught in large classes. Lecture halls with hundreds of students arranged in rows limit students' opportunities for hands-on experiences and group discussions. As faculty who taught in such classrooms sought out opportunities to integrate active engagement and inquiry into their instruction, the development team responded by adapting PET and PSET for this classroom format. In-class questions with student response systems ("clickers"), video demonstrations of experiments, online class modules, and online group discussions were used to maintain inquiry-based instruction within the constraints of a lecture hall style classroom. The class activities were structured with the instructor using slides to keep the class moving at the same pace. To produce a feasible grading load for instructors of large classes, LEPS and LEP replaced paper and pencil homework with online homework activities. LEPS included physical science content similar to PSET. LEP, which was developed after LEPS, included only physics topics; however, the physics content in LEP differed from that of PET. The choice of topics in LEP was made to align with early drafts of the NGSS.

When developing the learning about learning component of LEPS and then LEP, the development team, responding to changes in the larger curriculum, leveraged the same technological affordances of student response systems, online class modules, and online group discussions that were used for the content activities. In LEPS, students were

introduced to the LAL activities at the end of the first unit. As in earlier curricula, LEP and LEPS students made predictions about children's ideas regarding the topic of the chapter and then analyzed video of children talking about their ideas. However in LEP and LEPS, students responded to multiple-choice questions in class rather than open-ended questions, as was typically done in LAL-1 activities. Also, preprogrammed feedback was provided through the computer-based homework modules. Once students selected an answer, feedback about the preferred answer was presented, a much more directive strategy than in LAL-1 activities developed for small class settings.

Another difference between the LAL activities in PET and PSET and LEP is that, in addition to videos involving younger students, LEPS used videos of undergraduate students talking about physics. In these activities, LEPS students viewed videos of other undergraduates responding to the same questions to which they had recently responded. The developers reasoned that videos of their peers would also be relevant to helping students reflect on their own learning. Consistent with the technology-facilitated large class size, the format of these activities also differed. LEPS students watched videos of the undergraduate or elementary students and responded to clicker questions. Implementation data indicated that this addition was less engaging than the focus only on elementary children, so the videos focusing on undergraduates were dropped from the subsequent curriculum, *Learning Physics*. See Ref. [24] for a more detailed comparison of LEPS and PSET.

LEP followed a similar structure to LEPS. However, it was developed later, at the same time the initial drafts of the NGSS were released, allowing for intentional links to this new set of standards. Although the structure of the learning about learning activities were similar to those in LEPS, there were three major differences: (1) there were no longer videos from undergraduate classrooms, (2) some of the homework activities included interviewing children and writing reports, and (3) a set of homework activities was developed to explicitly introduce students to the science and engineering practices and crosscutting concepts of the NGSS (but these were mostly just informative readings). This version was not published and was only tested by project staff.

PET, PSET, LEPS, and LEP provide four combinations of content (physics or physical science) and implementation format (studio or lecture). Also, they responded to the standards at that time (the *National Science Education Standards* [5] and *AAAS Project 2061 Benchmarks* [4]). However, new requirements for content and associated professional development arrived with the most recent version of the nationally recognized standards (the NGSS). These contextual considerations prompted the development of the *Next Generation Physical Science and Everyday Thinking* curriculum. These materials were based on the previous curricula, and incorporated many

lessons learned during the preceding decade of development and implementation.

C. LAL design cycle 3: Next Gen PET

Next Gen PET was designed to meet three goals: (1) achieve close alignment with the NGSS (including a focus on engineering design), (2) provide instructors with more flexibility in designing their own courses with respect to content and implementation format, and (3) provide pedagogical and structural consistency across the whole set of curriculum materials. The Next Gen PET materials include a studio class version for small lab and discussion classroom environments and a lecture class version for lecture rooms and/or time-limited classes. These versions maintain the same activity structure as PET and PSET and LEPS and LEP, respectively. The two versions include the same content in the same sequence, consisting of five modules, and share a common set of homework activities, allowing instructors to choose materials suitable for their course format.

In Next Gen PET, the LAL activities built on all of the former curricula. Like PET and PSET, Next Gen PET activities help students make explicit connections between their own learning, the learning of children, and the learning of scientists (scientific practices) and add a focus on teaching moves that support learning. To reflect this additional new focus, the component of the curriculum was renamed *teaching and learning* (however, we will refer to this component as LAL when discussing the activities collectively). Like LEP, Next Gen PET made connections to the NGSS. However, the connection to NGSS is significantly expanded in Next Gen PET to include activities around each of the science and engineering practices, crosscutting concepts, and disciplinary core ideas. See Refs. [32,33] for information about how Next Gen PET aligns with the practices and crosscutting concepts. Another innovation in Next Gen PET is that nature of science activities are explicitly integrated into the structure of the Next Gen PET activities.

In Next Gen PET, there were other major changes from previous versions of LAL. (1) Classroom videos were selected from the Engineering is Elementary professional development project [34], rather than being generated and edited by the curriculum developers; this afforded foci on the learning of children, the strategies of the teachers, and on the engineering design process within a classroom context and to connect to the engineering-focused activities conducted in the content activities. (2) The set of teaching and learning activities was contained in its own module which complemented the content modules. (3) The number and structure of homework activities involving working with children were enhanced, scaffolding the kinds of interactions Next Gen PET students had with the children as they progressed through the curriculum.

FIG. 2. Content and teaching and learning (LAL) components of the magnetism unit. Note that the studio version has one additional content extension entitled Exploring Another Magnetic Phenomena.

The LAL activities, now contained in the teaching and learning module, contains ten in-class activities, two aligned with each of the five content modules, and 19 out-of-class extension activities. Within each content module, LAL in-class and out-of-class extension activities are organized into a coherent cluster. Each cluster includes video analysis of teachers engaging children in NGSS-aligned instruction related to the corresponding content module, focused exploration of one or two practices and one crosscutting concept, and an extended out-of-class activity to interview children on their ideas about the content area or lead them through a small learning activity. As with previous LALs, activities are scaffolded so that undergraduates' experiences become more complex over time. For example, in the activity associated with the magnetism module, students interview a child about their ideas about magnetism. This interview is largely guided by an interview protocol, although the undergraduates do add a few original questions. The second interview activity (which occurs in a subsequent content unit) is more complex in that the undergraduates interview children to elicit their ideas about both energy and their understanding of data. The last three extended out-of-class activities require students to implement a short lesson, beginning with one created for them and ending with them designing their own lesson based on how children's conceptual ideas change through active engagement.

The magnetism module depicted in Fig. 2 is used below to illustrate the coherence and complexity of the teaching

and learning activities within Next Gen PET. The model of magnetism module is located at the beginning of the curriculum and provides an initial experience developing models. This shared experience of developing and revising models can be referenced and built upon throughout the curriculum as students develop increasingly sophisticated understandings of science and engineering practices. Within each content unit, the LAL activities explicitly focus on one or two of the NGSS practices. The magnetism unit focuses on NGSS practice 2: developing and using models. Figure 2 depicts how the LAL activities fit within the sequence of in-class and homework activities of the magnetism unit. The readings at the beginning of the unit provide language and an organizing structure to refer to throughout the LAL activities and provide guidance on interviewing children, an activity repeated throughout multiple units of Next Gen PET. The LAL activities specific to magnetism begin with a homework assignment in which the Next Gen PET students interview children about their ideas about magnetism. At a subsequent class meeting, students discuss their interviews in small groups and compare the models of magnetism the children expressed to a set of images of other children's models of magnetism. They later also analyze video of children designing and constructing a maglev system, an activity similar to the one in which they engaged as the culminating "engineering design" activity in the magnetism unit.

This final homework activity is an example of how the activities support the Next Gen PET students' analysis of

both the children's ideas and the teachers' actions that support learning. As an example of the questions focused on teaching, the Next Gen PET students identify the type of information (e.g., recalling vocabulary, explaining observations) elicited by statements made by the teacher during the video, such as, "So we figured out stacking all the magnets, what did I just see happen?," "Who knows what that force field is called?," and "Now you saw, flip it again, it did not come back on its own. Can you figure out a way for that to come back on its own? Not by touching it, but by using the magnets?" This video analysis within the homework activity, like the earlier LAL activities, also provides students with opportunities to apply their developing understanding of physics content by posing questions such as, "What properties of magnets did [the children] use when making suggestions to improvements [of their maglev train design]?" In this video analysis, the Next Gen PET students continued to focus on models, but from the perspective of how engineers use models by looking at the models that the children drew of their maglev train designs. In this way, students explore the core ideas of magnetism, the cross-cutting concepts of cause and effect and systems and system models, and multiple practices including developing and using models and designing solutions. Moreover, students are able to examine how children learn and use these ways of thinking, knowing, and doing in authentic classroom contexts, and how teachers can promote them.

The following sections consider how the curricula has maintained its commitment to design principles (Sec. IV) and the factors that influenced how these design principles were actualized in each instantiation (Sec. V).

IV. DESIGN COMMITMENTS ACROSS CURRICULA

The evolution of curricula from CPU through Next Gen PET included changes in content and structure in response to a variety of factors. The first major transition was from CPU to PET, where principles of learning about one's own learning, the learning of others, and scientists' learning was moved from being addressed implicitly by the physics curriculum to being addressed explicitly via special activities integrated into the curriculum at the unit level. The second shift from PET and PSET to LEPS and LEP was largely structural to accommodate larger courses with a broader audience. Finally, the shift to Next Gen PET included these activities as an optional module and increased the learning about learning component to include not only learning about learning, but also about the pedagogical structures and teacher moves that supported learning, and to align with K-12 expectations in ways that were made clear to the Next Gen PET students. This move, in effect, increased the audience and adaptability of the curriculum, and also made it easier to omit these components in courses not intended for teachers. One trade-off is that the teaching and learning content, since it was

explicitly targeted toward teachers, was no longer appropriate for the general physics audience.

In this section, we describe how the LAL components of each of these curricula changed in response to the curricular context within which it was situated in ways that both retained long-standing strands along which all curricula maintain consistency while also responding to external factors. Those factors that remained consistent are (1) principles of learning and teaching, (2) structural coherence, (3) children's ideas as phenomena to observe, and (4) development of ideas related to learning. These are discussed below.

A. Principles of learning and teaching

The principles of learning and teaching listed in Table II are addressed in all instantiations of the curriculum. These principles were derived from classic educational research and theory. These principles of teaching and learning are addressed similarly to the way the principles of physics are addressed. As with physics principles, in the LAL activities students induce these principles about teaching and learning from evidence and data come from video and from scripts of students' thinking instead of from experiments. All versions of the curriculum held true to this method.

B. Structural coherence

All of the learning about learning components were designed to be structurally coherent with the content activities of the curricula within which they were embedded. That is, the LAL activities looked like the content activities and followed the same design principles. At the activity level, the LAL activities were organized similarly to the content activities (i.e., initial ideas, collecting and interpreting evidence, summarizing ideas). During classroom implementation, similar behavioral norms were also maintained. In all cases, students were expected to be actively engaged with the content (physics or learning), construct their own ideas, and discuss ideas with peers. How this was accomplished depended on the specific curricula. In PET and PSET, students worked in small groups during in-class activities and wrote short responses based on their discussion. In LEPS and LEP, discussions occurred between students seated near one another and responses were accessed through clicker questions. Similarly, content and LAL activities expected students to support claims with evidence—from observations of physical phenomena (content) or words spoken by children in videos (LAL). The content activities of all the curricula are designed to scaffold students' development of science content ideas and their ideas of science practices over time. The learning about learning and teaching and learning activities in all curricula are designed to scaffold students' development of concepts of learning, with Next Gen PET adding a focus on the development of ideas about teaching.

C. Children's ideas as a phenomenon to observe

The curricula all maintain a commitment to using children's ideas as something that can be observed, analyzed, and interpreted, in much the same way that we treat physics phenomena. The goal of these activities was to help learners gain sensitivity to the learning process, have patience with themselves as learners, and appreciate that scientists go through a very similar process. How children's ideas were captured and presented, however, changed over time. In the early curricula, students were presented with edited recordings from a mix of contexts: interviews, after school programs, and classrooms, as well as written summaries of research on students' naive conceptions. However, some of the undergraduate students expressed doubt that the type of children's talk represented in the video would happen in a typical classroom, attributing it to contexts developed and facilitated by the project staff. While we do not concur with this (and there were early LAL video contexts that were designed by the elementary teacher involved and not by the project staff), the latest version of the curricula (Next Gen PET) did strive to include contexts that were clearly not developed by the project staff and, therefore, not as clearly aligned with the activities completed by the undergraduates in their own classes. As mentioned earlier, video clips from the extensive Engineering is Elementary video resources were added along with new activities that tasked the undergraduates with setting up a situation (e.g., setting out materials that would either be attracted to a magnet or not) and interviewing children about their ideas. This allowed undergraduates to not only learn about student ideas that others have accessed, but to learn valuable teaching strategies for accessing student ideas themselves.

D. Development of ideas related to learning

Across all the curricula, students develop a deeper understanding and appreciation for ideas related to learning. Consistently, this learning occurs from active engagement in both doing physics and accessing children's thinking about physics, discussions with peers to develop models, developing evidence-based explanations, and changing ideas about physics and learning physics. Yet, the focus on learning shifted across subsequent versions of the curriculum from using children's ideas to help undergraduates think about their own learning toward undergraduates using children's ideas to design learning opportunities that support learning for children. This shifts the focus from undergraduates as merely learners themselves to undergraduates as beginning to develop expertise in teaching, thus further enhancing their pedagogical content knowledge for the more specific population of preservice and in-service elementary school teachers.

In the earlier LAL activities, the developers were intentional about not including discussion about teaching. PET was developed as a content course appropriate for

nonscience majors and was intended to be taught by physics faculty. Great efforts were made to ensure that physics faculty would be comfortable with the content and that the curriculum did not resemble a science methods course that would be taught in an education school.

As described above, a significant structural change in Next Gen PET was the division of the curriculum into stand-alone modules. This provided flexibility in course format and for faculty to select which content to include in their course. The curriculum development team provided recommendations for appropriate groupings of modules, but faculty can tailor their course by selecting different modules (or units within modules). In Next Gen PET, the LAL component is now its own module, and is optional. In PET, PSET, LEPS, and LEP, the LAL activities were integrated into the content. While faculty could intentionally skip these activities, in the default course arrangement, all students in all courses completed these activities.

This change in structure afforded new opportunities and new ways of using LAL. Because time spent on LAL took away from time on physics, the LAL component was limited in earlier curricula because of the expectation that all faculty would spend time on the LAL activities. This also required attending to the needs of students from a variety of majors who might be enrolled in these courses. The LAL activities were developed with the goal of addressing the needs of teachers while also appealing to students who were not intending to pursue teaching.

Next Gen PET leveraged the modular nature to assume that those choosing to implement the LAL module were teaching students who intended to pursue teaching or who were already practicing teachers. Targeting the module to this population meant that the materials could be more intentional about meeting the needs of future teachers. In addition, moving the LAL to its own module provided space to expand the materials and more fully address the LAL learning objectives.

However, moving LAL to its own module had trade-offs. As described above, the development team is committed to the idea that learning about how people learn and reflecting on one's own learning is critical to understanding that the process by which scientists develop new ideas about science is the same as how people learn. Learning about learning is beneficial to all students. However, the move to expand LAL in its own module means that students enrolled in Next Gen PET courses that do not use this module miss this opportunity.

As mentioned above, adding an explicit focus on teaching countered a decision that was made in the development of PET. Indeed, despite the unwavering commitment to helping students learn about their own learning, the 15 years of curriculum development by the Goldberg team has seen dramatic shifts, most notably in the recent inclusion of learning about teaching *and* learning, both as components of this process. In the following

section, we describe the factors that led to the evolution and development of the LAL curricular materials.

V. FACTORS INFLUENCING THE INCLUSION OF LEARNING ABOUT LEARNING AND TEACHING

Looking back on the 15 years of development, we note there were two development stages that resulted in significant changes to content. In both cases, these changes were in response to policy changes, new findings from educational research, and the climate of physics education. The first was moving from CPU to PET and the second was developing Next Gen PET. In addition to the team's commitment to helping students examine their own learning process, there were several other factors that led to the inclusion and revision of LAL activities over time. These factors are discussed here.

A. Findings from educational research

Abd-El-Khalick and Lederman [35] conducted a comprehensive review of the literature involving instruction on various scientific practices by comparing implicit to explicit methods of instruction. In implicit instruction, students engaged in scientific practices while learning about core concepts, but did not explicitly reflect on these practices nor did teachers explicitly call out these practices. In contrast, explicit contexts were those in which the practices in which students engaged, such as modeling, were explicitly discussed and students were asked to explicitly reflect on these practices as they pertained to the content (e.g., model of the atom). The authors concluded that the explicit approach was much more effective in helping learners adopt sophisticated understandings of the practices of science, and that the implicit approach generally did not assist in students' understandings of the nature and practice of science. Akerson *et al.* [36] found positive gains in students' understanding of scientific practices that were taught explicitly in a science methods course for prospective teachers. However, they also noted that the course was not fully successful in meeting its goals for helping these teachers internalize and embrace all of the scientific practices that were the subject of the course. They pointed out that these topics needed to be more directly embedded with core concepts of instruction, particularly in actual science courses. They stated that instruction on scientific practices is "mostly nonexistent in the agendas of the mostly traditional science content courses offered in disciplinary departments" (Ref. [36], p. 313).

The PET and PSET curricula responded to the call for explicit instruction on the practices in the inclusion of LAL activities alongside physics activities that implicitly included scientific practices. In a national study of the implementation of PET and PSET in diverse contexts, Otero and Gray [37] demonstrated that PET and PSET students in both large- and small-enrollment environments

shifted to more expertlike views of the nature of science and the nature of learning science and that students' interest in physics vastly increased over the course of the term.

Hammer [18] demonstrated that in a traditional physics course, a majority of students left with views of science knowledge as a set of disconnected facts and symbols to be memorized and forgotten after the test. His study also showed that students frequently reported views having to do with science knowledge as coming from authority and from the textbook. In a study comparing PET implemented in a high school environment to a more traditional high school physics course, Schrode [38] showed that when asked where science knowledge comes from, 100% of the students from the traditional course said that the "teacher tells me," and in the PET course 66% stated that evidence tells them and only 32% mentioned the teacher.

Additional research in education pointed to the value of not only integrating explicit discussion of the nature of science and learning into content, but intentionally connecting pedagogy and content, especially for current and future teachers. In 1986, Shulman [39] coined the term pedagogical content knowledge to mean "subject matter *for teaching*." Pedagogical content knowledge is a type of knowledge that teachers possess that combines content and pedagogical knowledge and is not acquired effectively in either specific content courses taught in disciplinary departments or in pedagogy courses in education departments. This idea was built on and spawned an area of research in how teachers transform content knowledge for teaching [40,41]. Work in this area began to suggest that the existing model for teaching these ideas in separate disciplines might be ineffective for teachers. In fact, in 1996, the *National Science Education Standards*, published by the National Academies, included not only the standards for science content described elsewhere in this paper, but also standards on professional development, which included teachers' undergraduate preparation. Two of the standards on professional development, which in this context can be taken as guidelines for university curriculum development, included "the learning of science content through inquiry" and "the integration of knowledge about science with knowledge about learning, pedagogy, and students."

These findings from education research, physics education research (PER), and on the curricula all supported the initial explicit integration of the nature of science and learning about learning into PET, PSET, LEPS, and LEP, and then later, in response to research on teacher preparation, integration of pedagogical ideas into Next Gen PET.

B. Changing U.S. K-12 education context

University-level content courses for prospective and practicing elementary teachers should provide a preparation matched to the expectations of the K-5 classroom. This common sense guideline requires that curriculum developers attend to expectations and standards for K-5 learning.

In the U.S., these standards are set by states and historically have varied considerably from state to state. Over the past three decades, national proposals and guidelines for what science should be learned in elementary school have trended toward more fully developed national recommendations and greater consistency among states.

In 1993, the American Association for the Advancement of Science (AAAS) released the *Project 2061 Benchmarks for Science Literacy*, to address “what all students should know and be able to do in science, mathematics, and technology by the end of grades 2, 5, 8, and 12” [4]. The AAAS *Project 2061 Benchmarks* influenced subsequent state and national science standards, specifically the *National Science Education Standards* [5], published by the National Academies in 1996.

During the development of PET, PSET, LEPS, and LEP, the socioeducational context continued to change, providing a new landscape within which Next Gen PET would be developed and released. Fifteen years after the NSES, in 2012 the National Research Council published *A Framework for K-12 Science Education* [43], which articulates expectations for K-12 students. While the framework was similar in some respects (scope, detail) to the earlier NSES, the framework was then translated into the detailed and specific *Next Generation Science Standards* [6]. NGSS was released in 2013 and has become the basis for K-12 science standards in many states. According to National Science Teaching Association, “nearly two-thirds of U.S. students live in states that have education standards influenced by the Framework for K-12 Science Education and/or the Next Generation Science Standards” [44]. This includes 38 states that have either adopted NGSS or developed their own standards based on the framework.

The framework and NGSS describe three dimensions of learning: disciplinary core ideas, science and engineering practices, and crosscutting concepts. Importantly, it is emphasized that these dimensions should not be independent. Rather, students should explore disciplinary core ideas “by engaging in practices... and should be helped to make connections to the crosscutting concepts” [43]. More detail on the standards can be found at the NGSS website [45]. The AAAS *Project 2061 Benchmarks* emphasized core concepts, crosscutting concepts (called common themes), and scientific practices (called nature of science and habits of mind), and the NSES were similar. The NGSS explicitly integrated these areas into their performance expectations. Also, the NGSS were specifically “adopted” by states, anticipating assessments would be developed that would measure how well students met these standards, creating an urgency to prepare teachers to implement the NGSS effectively, and popularizing a language used nationwide about practices, crosscutting concepts, and disciplinary core ideas.

While the framework and NGSS are intended for K-12 science education, university science courses that prepare

future teachers should be consistent with the framework and standards, including the integration of content, practices, and crosscutting concepts [43]. The curriculum and policy landscape described above was essential in the iterative development of the sets of materials discussed in this paper. In response to the changing K-12 policy documents and standards, the organization and structure of each curriculum, learning objectives, and changes in content emphasis throughout were revised.

C. Changes in the socioeducational climate of physics education

We argue that the climate among the physics community has also changed significantly over the past 50 years and that this change in climate made possible the inclusion of activities explicitly about learning and teaching physics in physics content curricula. While physicists were deeply involved in the national dialog regarding the teaching and learning of physics at both the high school and college level in the late 1800s and early 1900s, they largely disappeared from the discussion at the beginning of the First World War [46]. Thus, by 1915, not only was physics teacher preparation no longer being influenced by physicists, physicists were also not being influenced by discussions regarding the teaching and learning of physics. It was in 1950 when the National Science Foundation was established and began to provide substantial funds for elementary and secondary educational innovation, that physicists became reengaged. Shortly thereafter, physics education research increasingly became a part of physics departments, and focused specifically on research and innovation in education (see, for example, Refs. [47,48]). As physics graduate students began to receive their doctorates specifically in PER and departments began to hire PER faculty specifically, some changes began to take place in the norms and practices regarding open discussions about teaching, learning, and curriculum among physics faculty.

In the late 1990s, the number of physics bachelor’s degrees granted in the U.S. decreased by roughly 20%, reaching a recent low in 1999 (from which the number has subsequently more than doubled) [49]. Against this backdrop, and recognizing the importance of the education of future physics teachers for the health of the profession, the American Institute of Physics and many of its member societies, including the American Physical Society (APS) and American Association of Physics Teachers (AAPT), issued a joint statement on the education of future teachers [50]. This statement urges physics faculty and departments “to take an active role in improving the pre-service training of K-12 physics/science teachers.” In 1999, a National Task Force on Undergraduate Physics was established by the American Physical Society [51] to answer the question of why some physics departments thrive in terms of numbers of majors and others do not. This was the beginning of a host of national efforts to better understand and influence

the landscape of physics education. In 2001, PhysTEC was established as a collaboration between the APS and AAPT. PhysTEC is designed to address the shortage of physics teachers in the U.S., along with the many issues surrounding inadequate physics teacher preparation. A central concern of PhysTEC is to help physics faculty become more aware of, and responsive to, these issues [52]. To date, there are over 300 PhysTEC member institutions. PhysTEC has established an expansive community of physicists together with school of education faculty who meet annually to discuss the teaching and learning of physics.

Accompanying the changes in national recommendations and standards, there has been an increased focus on noncontent topics (e.g., attitudes and beliefs, nature of science) by the physics education research community, and an increased acknowledgement by physics educators of the importance of such noncontent topics in relation to their own physics courses. To assess such noncontent aspects, various instruments have been developed. For example, to examine students' expectations and beliefs about learning physics, instruments such as the MPEX [53] and CLASS [54] have been developed. Increasingly, studying such aspects as metacognition, epistemology, and scientific abilities or practices gained currency, with research in the PER community. This includes research on PET teachers' and preservice teachers' learning of both physics and content related to learning and pedagogy, contributing to the understanding of the role of such "noncontent" aspects in learning physics [13,54–57].

Recognizing the important role of physics faculty (non-PER) in adopting pedagogical strategies that can support students' success in and identification with physics, in 2002 APS, American Astronomical Society, and AAPT joined forces to expand the reach of AAPT's New Faculty Workshops. At these workshops, new faculty are introduced to effective instructional strategies that are based on research. More broadly, at the same time, more colleges and universities began developing programs and centers focusing on issues of teaching and learning. With additional faculty adopting such strategies, facilitating them within a standard curriculum became a priority. These efforts were well aligned with the development of the learning assistant model in 2001 at the University of Colorado Boulder and its national dissemination [58]. The broad appeal and impact of learning assistant programs meant that many physics departments began offering teaching and learning seminars, with faculty becoming more comfortable with considering such noncontent aspects of effective instruction and discussing them with their students. All the while, the physics community has generated a better understanding of how faculty adopt and adapt curriculum materials and the value in providing greater flexibility to instructors (versus expectations of "teacher proof" materials). Also, online resources such as ComPADRE [59] and PhysPort [10] have

compiled resources and made them broadly available and easily accessible.

These contextual and community factors have greatly influenced the structure and context of where learning about learning and pedagogy takes place. Working within this backdrop, the PET and Next Gen PET developers have felt increasingly confident in the physics education community's interest, willingness, and capacity for addressing the teaching and learning of physics within a physics course. These changes have been one factor influencing the inclusion and evolution of LAL as a curricular component.

D. Local changes in the team and funding

In addition to the broader changes in educational and physics education research, in the standards and expectations for K-12 schools in the U.S., and changes within physics departments, changes in the development team and funding landscape also influenced the iterative development of these curricula. In addition to the influx of educational funding that took place with the birth of the National Science Foundation in the 1950s, in the late 1990s, the funding available to support undergraduate course development connected to teacher education increased. In 1998, San Diego State University and the University of California, San Diego, were awarded a NSF grant to generate a doctoral program that integrated deep content understanding with education. The Center for Research in Math and Science Education was established to produce discipline-based educational researchers that were steeped in both content and pedagogy. The core group involved a unique union of faculty from the education school and faculty from physics, chemistry, biology, and math departments at both universities. This program produced students that were fluent in both their home discipline and the field of education. These students were exposed to vastly different norms and practices of their disciplines and schools of education. Some of these students took faculty positions in schools of education, ended up teaching science methods courses, and brought some of this knowledge back into the curriculum development team that developed PET and related curricula.

External funding, largely from the National Science Foundation, supported the development of the curricula discussed here (see the Acknowledgments). Support for the development of Next Gen PET was possible through the 100K in 10 organization [60] and the California State University, which has a historical and present-day focus on teacher preparation. The long-term process of development and revision would not have been possible without sustained funding. Without this support, the materials would have become dated and less useful due to the growing gulf between their focus and current needs. In addition, the grants that funded each new curriculum brought in additional faculty and students with new expertise, interests, and experiences. This, and other contextual factors

described above, permeated the group with different ways of thinking about what a physics curriculum could achieve, and how it could achieve it in ways that were responsive to the context within which it was situated. Taken together, all these factors made possible the inclusion of principles of teaching and learning *directly within a physics curriculum*.

VI. CONCLUSIONS

Just as we strove to teach science as practices and ways of understanding the world for centuries, we have sought to teach about learning as ways of understanding ourselves and the learning of others. In the physics education community, we are adding both new pedagogy and new learning goals to our physics content and often hope to do so without changing the essence of what it is to learn physics. Furthermore, physics curriculum is being contributed to by larger groups of developers who may need to adhere to coherent structure or principles while providing content that is adaptable for a wide range of learners and contexts [61,62]. Just as the PET curriculum changed in response to various factors over time while maintaining consistent principles, these and future curriculum development efforts will need to adapt and respond accordingly.

In responding to education policy changes and expanding the focus of the curriculum to new audiences, PET has evolved over time; however, the curriculum maintained consistent theoretical principles throughout these changes. Such principles include the theoretical framing of learning as a complex process that is guided by prior knowledge, mediated by hands-on explorations with tools and interactions with peers, and structured by norms and expectations. By describing how and why the learning about learning components have changed over time, we also were able to highlight the explicit principles that lasted through iterations. For example, Next Gen PET shifted in focus from undergraduates analyzing children's ideas to reflect on their own learning toward analyzing children's ideas to plan opportunities for learning (teaching). Through these changes, undergraduates still gather data on children's thinking and interact with peers to understand changes in ideas about physics concepts. Similar guiding principles could be applied to designing materials focused on physics teaching and learning, while allowing materials to adapt to various contextual changes. This process of adapting to contexts has relevance to how curriculum is developed and iterated over time. In our own retrospective view of the learning about learning curriculum development, we are able to inform new or revised curriculum that is adaptable to broader contextual changes, while maintaining consistent adherence to key research-based principles of what it means to learn physics.

Like responsive teaching, responsive curriculum development works hard to understand the substance of the context in which it resides and responds to that substance. As responsive teaching listens to students,

responsive curriculum development listens to the community. Like design-based research [63] and design-based implementation research [64], responsive curriculum development occurs through multiple cycles of research and development responding to data collected in the real and complex classroom environment. However, responsive curricular development has an additional and explicit focus of identifying and responding to the larger structural changes within which a curriculum is implemented.

Like instructors adopting a responsive teaching approach, curriculum development teams can integrate responsive curriculum development into their existing process. To do so first requires *listening to the community* to monitor the context including national and local policies, and the structures and formats that shape instruction. This step can include reading policy documents, position papers, and white papers authored by professional organizations, surveying the professional community to understand relevant directions in the sociopolitical contexts, and identifying trends in presentations at conferences about technology use and instructional formats.

This process of listening to the community should lead responsive curriculum developers to identify opportunities for development and changes and be aware of various trade-offs. Responsive curriculum developers use this information to determine directions and make changes to existing content, develop new content, or make the difficult decision to remove content that is no longer relevant. These decisions require careful weighing of relevance and balance between maintaining the goals of the community context and goals of the curriculum development team.

Curriculum development teams should also be cognizant of the ways that their users (other faculty who adopt the curricula) will implement the materials in ways that differ from those intended by the developers. As responsive curriculum development teams respond to the needs of the larger context, individual instructors respond to the needs of their local contexts [65]. Their needs may not align exactly with the trends identified through the listening stage of responsive curriculum development. Anticipating such idiosyncratic needs, curriculum designers may choose to create intentional mechanisms (such as modularizing curriculum) that support individual implementation differences that also retain the goals of the curriculum.

In conclusion, our responsive curriculum development team began with an initial goal of including learning about learning (and, later, learning about teaching and learning) within a physical science course. Our continuous research on our own curriculum and attention to the larger context confirmed that physical science courses were an important and appropriate opportunity for prospective elementary teachers to begin learning about the NGSS, the learning of elementary school aged children, and reflect on their own learning. In this way they can begin the development of

important aspects of their own pedagogical content knowledge in parallel with learning content.

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