J Sci Teacher Educ (2013) 24:1–12
DOI 10.1007/s10972-012-9332-x

# On Acknowledging PCK's Shortcomings

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While reviewing journal manuscripts, conference proposals, and job applications over the past several months, I have been struck by the frequent mention of pedagogical content knowledge (PCK). Within science teacher education, PCK skulks about as a strangely persistent yet unfulfilling notion. PCK intrigued me when I first heard of it 25 years ago; today PCK is a source of considerable frustration because it sparkles, but offers little substance. For example, PCK helps me as a science teacher educator to explain how neither a strong grasp of subject matter nor the mastery of management skills is sufficient for classroom success. On the other hand, PCK lurks as an intellectual dead-end for those who might contemplate it as the foundation for a research agenda. How can something so useful in my science methods classes also be so ineffectual as a research paradigm? After all these years, I recognize that PCK is equivalent to a mirage in the desert or a mythical siren along the shore. Foolish passions cause us to imagine the fulfillment of our longings: a shimmering pool of water, a beautiful enchantress, or an explanation for the ambiguity of teacher expertise. And while not harmful in and of themselves, pursuing these seductions can lead us to becoming lost, shipwrecked, or stuck. My purpose in this essay is to delve into PCK to unpack its many problems while also considering what it might provide. By examining the stalled progress and historical ambivalence toward PCK, I offer a cautionary tale for those who might otherwise become ensnared.

I am not alone in being disheartened by PCK. There is unsteadiness about PCK within the research literature. Rarely does the construct capture and sustain any single scholar's work for an extended period of time, although there are exceptions (e.g., Abell 2008). My concerns escalate when a search for PCK in drafts of the national Framework for K-12 Science Education (NRC 2012) comes up empty. Furthermore, the term "PCK" does not appear in documents specifying exemplary tools and practices for science teachers (e.g., Wilson 2011; Windschitl et al. 2012).

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It is also troubling that the PCK literature is all but silent about diversity, multiculturalism, and equity. For those willing to be thoughtful about PCK, these inadequacies are warning signs. It would be less significant if my own naïveté or ignorance prevented me from making effective use of PCK. But that PCK is so narrow in scope and shallow in impact is obvious by looking across time and settings. Again, even though not loudly announced, many within science teacher education share this perspective about PCK.

A brilliantly crafted book review (Barnett 2003) highlights reasons for dissatisfaction about PCK through its deft descriptions of the "attempt to synthesize research … and to draw out implications for science teacher education" (p. 615) and gently portrays PCK as "difficult to unpack," "complicated," and "problematic" (p. 616). Barnett's commentary resonates with my impressions about the field of PCK: "An interesting characteristic of the book lies in the differing conceptions of PCK amongst the authors and editors themselves. … [A]lmost every chapter begins with a new, or slightly reworked, definition of PCK and its meaning. … Thus, the work clearly gives the reader a good feel for the problematic nature of the construct" (p. 616). This reviewer illustrates science teacher educators' inability to achieve consensus about PCK. Given this particular, I argue that it is time to look upon PCK with a suspicious and clear-eyed gaze. Through an honest consideration about the utility of PCK, we can redirect our energies away from this antiquated and overgrown trail in favor of new avenues and less traveled paths offering fresh potential to advance science teacher education research and inform science teacher preparation.

## Throwaway Term or Important Construct

> Here is where ordinary thinking and thinking that is scrupulous diverge from each other. The natural man is impatient with doubt and suspense: he impatiently hurries to be shut of it. A disciplined mind takes delight in the problematic, and cherishes it until a way out is found that approves itself upon examination.
>
> Dewey, 1929, p. 228

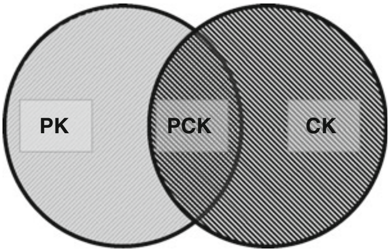
John Dewey often differentiated between hurried and reflective thought. Too often in education, we rush to an answer and remain satisfied by the solution. Among those who educate science teachers, we place a premium on being contemplative. Not only do we insist that our preservice teachers apply reflective thought to their practices, we also encourage them to build opportunities for their students to reflect during science lessons. We encourage metacognition, as it is one of three principles within *How Students Learn* (Donovan and Bransford 2007). Furthermore, empirical evidence has shown that the effect size of metacognition places it among the most potent strategies for supporting learning (Hattie 2012). This disposition toward disciplined thinking should be applied to PCK's somewhat dubious status. To be clear, among the many laudable outcomes within science education (e.g., self-confidence, career options and aesthetic awareness), none is more important than to have students learning science. Despite the tendency to toss PCK into conversation, we must exercise patience in order to determine why PCK is so bothersome.

When Lee Shulman first articulated PCK during his 1985 Presidential Address at the Chicago AERA meeting, it was not a fully formed idea. In fact, there were political reasons that he offered PCK as a special form of teacher knowledge. During that era, Shulman and colleagues were enmeshed in the development of new methods of testing teachers. Shulman (1986) expressed frustration by the gap between strong subject area knowledge and the skills of controlling a classroom. He nominated PCK as "subject matter knowledge *for teaching*" by arguing that: "the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice" (Shulman 1986, p. 9). He also described PCK as the "special amalgam of content and pedagogy that is uniquely the province of teachers" (Shulman 1987, p. 8). Shortly thereafter, PCK began being portrayed as an alloy, a blend of content knowledge (CK) and pedagogical knowledge (PK) as shown in Fig. 1. PCK contains a subset of content knowledge blended with particular aspects of pedagogical knowledge. And there the trouble begins: PCK is an alchemic material with unique properties, composed of the raw material from quality educational research as well as from intuitions arising from one's classroom teaching practices. The hybridization hints at its confounding flaws.

Useful representations capture key elements and illustrate those with a simple visual. I tend to bristle at Venn diagram's composed of three overlapping circles (Fig. 2) because they often lack adequate an accounting for all seven sections. One central section is formed at the overlap of all three entities and there are also three distinct areas with no overlap. There are three additional sections where two entities intersect while excluding the third. If all 7 sections don't signify something meaningful, then I become skeptical about such a representation and its authors. I accept that this might be an extreme disposition, but it provides context for how I respond to two-loop Venn diagrams.

Figure 1 represents much more than the belief that PCK resides at the intersection of PK and CK. There are portions of pedagogical knowledge (i.e., knowing how to teach) that are not specific to science or to a certain topic. I imagine this knowledge as the material covered in a general teaching methods course or as described in a generic "how to teach anything to anybody" book (e.g., Lemov 2010). The other non-overlapping loop contains content knowledge that does not

**Fig. 1** PCK as an amalgam



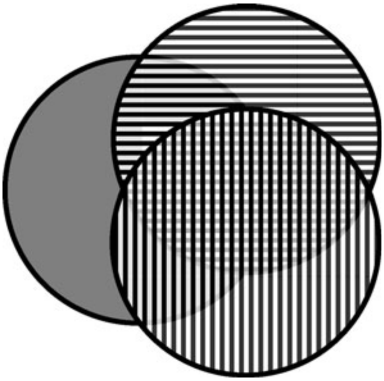


**Fig. 2** Generic Venn diagram with seven components

contribute to knowledge about science teaching. Personally, that knowledge could include the material that I learned in graduate level science courses: nice for me but not useful for teaching science in K-12 settings. This becomes one underappreciated difficulty arising from PCK, namely that there are certain things teachers know about science with no bearing on being an effective teacher of science. Admittedly, this is a bigger challenge than can be fully explored here. But in brief, the discrepancy is analogous to the disjunctions between which science courses the accreditation agencies require teachers to complete versus what the state and national standards designate as essential knowledge for a pre-collegiate scientific literacy. Using PCK to frame teacher knowledge muddies the situation, especially when it comes to distinguishing between the knowledge necessary for science teaching as compared to the knowledge about science beyond what science teachers need to know.

Identifying the content knowledge for science majors versus the science knowledge essential for science teachers could be resolved by attending to what is absent from almost all PCK discussions: students' science learning. A few PCK researchers are forthcoming in that they are not especially concerned about what the children learn but instead concentrate on teacher learning. We can respect this stance as academicians. But as science teacher educators, I maintain that the measure of our worth is the extent to which our efforts contribute to improvements in science learning. We should provide the best preparation possible so our future science teachers are able to advance the learning of their pupils. Before dismissing this as test-driven mentality, I advocate that deep conceptual understanding of science is the ultimate goal (saving for another forum the debate about how this is best measured). After all, shouldn't "the test" of what science content teachers need to know be in the evidence of student learning? The corollary becomes that any science knowledge (i.e., the CK) that does NOT advance children's understandings does not belong within PCK.

Perhaps none of this represents a fatal flaw with using PCK to think about science teacher education. The reason I raise these concerns is because such complications were not obvious when I first encountered PCK. Furthermore, the challenges created by PCK are not faults with Shulman's original conceptualization. Instead, these problems emerge as unintended consequences of PCK. As a science teacher educator, I feel an increasing obligation to be vigilant about the knowledge I pass along to science teachers while guarding against advice that is unlikely to enhance their students' science learning. We might quibble about whether certain assessments adequately characterize how much science a student knows or how effectively she can apply her scientific knowledge. However, I have difficulty imagining how a science teacher educator with integrity could argue against the value of equating science teacher effectiveness with her students' science learning. Viewed in this light, PCK does not offer sufficient direction about how to proceed. But in the process, despite PCK's failings, it has brought other issues to the surface that might lead us in a productive direction. In reality, Shulman introduced the question about whether PCK was "usefully wrong" at the 1987 AERA meeting, suggesting that the inadequacies of PCK reinforced the need to reexamine our definitions and assumptions about the development of teachers.

## Evidence Desired to Evaluate Claims

> The questionable becomes an active questioning, a search; desire for the emotion of certitude gives place to quest for the objects by which the obscure and unsettled may be developed into the stable and clear.
>
> Dewey, 1929, p. 228

The ambiguities and difficulties arising from PCK might well encourage active questioning and better research. Without thoughtfully designed studies to interrogate PCK, any and all implications for science teacher education remain speculative. Conscientiously pushing at the weak spots within PCK will lead to territory that is more fruitful than if PCK had never been proposed. Similarly, uncritical devotion to PCK will certainly prevent progress. What follows are a few ideas equivalent to the engineering challenges familiar in many secondary schools. For example, by assigning students the task of building a truss bridge from craft sticks and white glue, everyone knows that at some critical load, the system will collapse. The learning comes from *analyzing the causes of failure* to inform future efforts. In a similar way, actively questioning PCK has the potential to advance the field toward a much more stable intellectual foundation.

One teacher knowledge puzzle is the relationship between what a science teacher knows and the influence this knowledge exerts on his or her students' science learning. What combinations or qualities of science teachers' content knowledge contribute to gains in students' science understandings? Is there a minimum amount of knowledge a teacher must have in order to be effective? This would be valuable information for those working with typical preservice elementary teachers who tend to not have a strong science background. Phrased in a very concrete way, armed with a valid and reliable assessment of elementary school students' knowledge about the water cycle (Krnel et al. 1998), what might we uncover by comparing their teachers' knowledge of evaporation and condensation to their students' abilities to explain fogged up windows? The flipside might also be intriguing: is there a point at which a teachers' science content knowledge is so strong that it interferes with the capacity to transmit the knowledge to students? Ordinarily we presume that more content knowledge means a teacher is more effective—until we come across a remarkable study like Stacy Olitsky's (2007) that shows out-of-field teaching violating this belief. In addition, in his meta-analyses, Hattie (2012) reported that teacher subject matter knowledge has an almost insignificant relationship to student achievement (an effect size of 0.09). Investigating the relationships between teacher knowledge and student outcomes is long overdue within our field and a logical extension beyond PCK.

We could also examine science teacher knowledge about instructional materials and approaches to uncover how those relate to improved student knowledge. To illustrate, consider the topic of natural selection. Setting aside the challenges offered by religious beliefs (cf. Meadows 2009), imagine that we have available a robust measure of students' abilities to reason about biological phenomena via natural selection. Suppose we could also identify all the resources and techniques a biology teacher might know about that relate to natural selection: videos, hands-on activities, computer simulations, reading materials, etc. Would it not be useful to uncover the relative impact of these resources and techniques on student performance on the natural selection assessment? At a very fundamental level, we might discover whether having students search for different colors of toothpicks in the school lawn (McComas 1991) is time well spent within a crowded curriculum. Such a study might reveal the technologies most closely associated with gains in student understandings. We might even learn ideal sequences of activities and the best ways for teachers to deploy resources: is a video about the evolution of the eye best used early on in a unit to promote questions or as a forum near the end of the unit for students to apply their understandings about natural selection?

There is a substantial need for rigorous investigations of the influences of science teaching on science learning. The lack of satisfying progress could be because PCK is an artifact of a deeper problem with our profession. The ways in which we commonly conceptualize teacher knowledge may be an epistemological mistake for which PCK is just one example. If we insist on treating knowledge as an accumulation of information, then we might continue orbiting around a center that does not propel us to a more verdant place. This could explain why mathematics teacher education researchers have largely abandoned PCK in favor of actual teaching practices. The shift represents a recognition that "knowledge as a substance" is a stale metaphor and should be replaced with "knowledge as an activity"—if for no other reason than to see where that epistemological framing might lead.

## Framing as a Constraint or as a Support

> The scientific attitude may almost be defined as that which is capable of enjoying the doubtful; scientific method is, in one aspect, a technique for making a productive use of doubt by converting it into operations of definite inquiry.
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> Dewey, 1929, p. 228

During tussles over PCK, I have come to recognize that it has been wrong to be dismayed by a perceived lack of a theory base. My mistake was with ignoring the implicit view of knowledge and learning embedded in how others endorsed PCK. While I would prefer that authors plainly state their theory of knowledge or learning, I realize their presumptions were there even when not labeled as such. That realization is communicated here via an illustration.

For sake of discussion, consider Fig. 3 as a way of depicting the relationship between the mega-realm of scientific knowledge (at the top) and the final repositories of children's knowledge of science (at the bottom). In this representation, the teacher reinterprets the science so that it can be passed down to students. Since PCK is ordinarily regarded as topic-specific knowledge used by a teacher, the middle boxes (knowledge of the topic along with knowledge about teaching the topic) reveal the mediating role of the teacher. For certain PCK advocates, this diagram shows how subject matter is transformed and/or integrated such that students receive their dosage of science knowledge. Beyond capturing a typical description of PCK, "models" such as Fig. 3 allow us to uncover an implicit theory of knowledge and learning.

As presented here, science knowledge is a commodity. The "big bucket" at the top is the container of science knowledge and the teacher is responsible for directing the contents to the students. The science knowledge that is sprinkled, squirted or siphoned into the children's minds (the "little bottles") is under the control of the teacher. The teacher uses PCK to dispense and distribute knowledge. Different amounts of science knowledge accumulate in the recipient containers depending on the qualities of the teacher. Teachers who are less knowledgeable about topic-specific instructional practices will be less able to educate students compared to teachers with greater knowledge reserves. All of this follows from this "bucket-to-

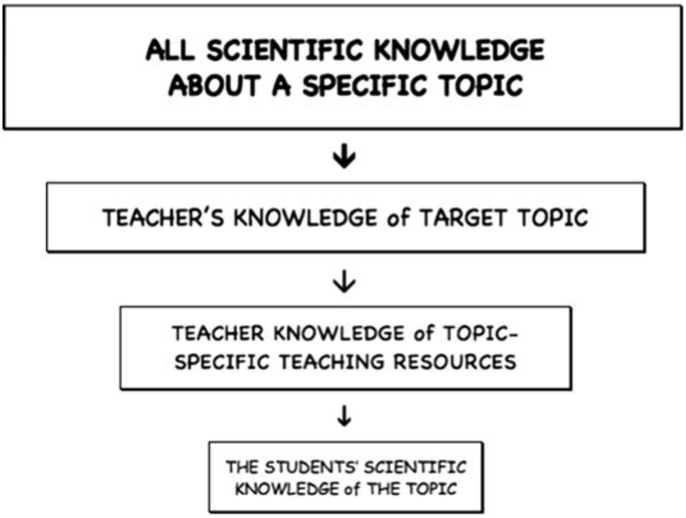

**Fig. 3** Path of science knowledge incorporating PCK

bottle" theory of knowledge. (Please recognize that this is not a philosophy that I am endorsing. Rather I am inferring the belief about learning typically held by PCK supporters.) This model is reminiscent of an antiquated view equating learning with the transmission and absorption of information. Whitehead (1929) famously labeled this as "inert knowledge" which he decried because it failed account for problem-solving or applying understandings to new situations. A more palatable view, as described by pragmatist philosophy, is that what counts as knowledge is only that which is put to use. Dewey expressed this view of knowledge as providing "an affirmation of the inseparability of thought and action" (West 1989, p. 98). Whether you, as a science teacher educator, find yourself more closely aligned to constructivism or community of practice—or even cultural historical activity theory, it is unlikely you endorse the knowledge transmission framework suffused throughout PCK as it is commonly presented.

The epistemological ramifications of PCK reveals its considerable limitations. In addition to being insufficiently supported by research, the construct of PCK has been relatively barren in terms of supporting evidence. A related difficulty is PCK's inadequacny for explaining science teaching and student learning. What affordances are provided via PCK to explain the ocean of studies about student misconceptions? How might PCK be leveraged to make sense of the widespread science achievement gaps? For a theory to have power, it should be useful for describing, explaining, and predicting a wide array of phenomena. Otherwise, the purported construct should be cast as fringe theory leaving room for central theories (Duschl 1990). This excoriation of PCK's tacit epistemology reinforces the need for intelligible, plausible and fruitful theories (Posner et al. 1982) to shape and inform our research and practices within science teacher education. Under the best of circumstances, a productive theory will support a research agenda; alternatively, a restrictive theory can effectively strangle the most earnest individuals and initiatives.

## From Whence Does PCK Arise and then Reside?

> No one gets far intellectually who does not "love to think," and no one loves to think who does not have an interest in problems as such.
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> Dewey, 1929, p. 228

Another issue with PCK is the "who" associated with this construct. Shulman posited that pedagogical content could arise from research but also from knowledge created within individuals during their teaching. Consider the individual versus collective dynamic. Is the science teacher education community prepared to believe that PCK is an idiosyncratic understanding arising within individual teachers as a consequence of their science teaching endeavors? Are we willing to accept the possibility of an agreed upon collection of demonstrably powerful instructional practices replicable across a variety of educational contexts? The first question appeals to the "teacher as artist" whereas the second endorses "teaching as a craft." How do we wish we could be as science teachers and who do we envision our students to become as science teachers? Are we content for science teachers to improve themselves by simply relying on creativity and intuition—or are we ready to sanction a professionalized ambition for teaching that is more purposeful and empirical than could be generated through on-the-job discoveries? Except for the hopeless romantics in our midst, I suspect science teacher educators would accept the argument that we can derive topic-specific instructional approaches that cut across contexts.

For science teachers and science teacher educators who have plied their craft in multiple settings, the adage that "context matters" is especially salient to the present discussion. Dramatic distinctions in student demographic profiles, the climates within science classrooms, the material resources provided by schools, and the relationships between the school and the surrounding community all exert profound influences on science instruction (Bryk et al. 2009). Science teaching and learning are no less embedded within sociocultural dynamics than any other aspect of contemporary life. When clumsily handled, "context" is treated as detracting barriers or detestable impositions interfering with efforts to educate children about science. For those who instead view context as a rich supply of resources, then low expectations for students are replaced by actions revealing underlying commitments to making science accessible to each and every child, independent of his or her background (Milner 2010). Even with the desire for science teachers to re-calibrate their instructional practices so those resonate with and are responsive to local contexts, there are nevertheless effective science teaching strategies that could apply in most settings. Returning momentarily to the teaching and learning of natural selection, a science teacher with admirable PCK would be acquainted with local scenarios to connect science content to her students' experiences as well as knowing about studies of learning progressions (e.g., Furtak 2012) to inform instructional decisions. In summary, PCK stretches to incorporate the idiosyncratic knowledge of individual teachers along with the empirically supported consensus knowledge about effective instruction.

This leads to a dispute within PCK research about canonical versus common-sense repositories of science teaching knowledge. To what extent can PCK be captured and disseminated as a canon of "best knowledge of science teaching" versus the degree to which knowledge is generated by and remain within each science teacher's mind? If PCK was written as a book or stored as a computer file, would that knowledge be accessible to a wide audience or is the knowledge secreted away by its owner? Actually, posing the question in this way denies the crux of the problem. The deeper issue is not whether PCK might be distilled into a form that could be embedded in curriculum or bestowed within a science teaching methods course. The core problem with PCK is that the knowledge is treated as information without sufficient regard for how it manifests itself as action. This is reminiscent of countless news clips where tearful parents deny that their child could have possibly committed a crime because the accused has strong religious beliefs. What a person claims to believe fades to insignificance if it is not displayed in how that person behaves. Likewise, what a science teacher knows is of little consequence unless it is leveraged into application in the classroom. The actions of science teachers should take precedence over any measure about what they seem to know. Unfortunately, because PCK research is bound to its knowledge-as-commodity construct, far too little regard has been given to what teachers actually do although we do come across occasional exceptions (e.g., Alonzo et al. 2012). Perhaps PCK researchers are stymied because teachers' knowledge is much easier to measure (e.g., with a conceptual inventory) compared with the overwhelming prospects of reliably and authentically capturing how teachers apply their knowledge while working with their students.

## How PCK's Shortcomings Might Still be Useful

> Being on the alert for problems signifies that mere organic curiosity, the restless disposition to meddle and reach out, has become a truly intellectual curiosity, one that protects a person from hurrying to a conclusion and that induces him to undertake active search for new facts and ideas.
>
> Dewey, 1929, p. 228

I find it troubling that PCK is not treated with sufficient skepticism. It's not that I fail to recognize PCK's allure because I do. Like many science teacher educators, I long for something to point to demonstrating that effective science teaching requires much more than downloading scientific knowledge. While it seems obvious that online video could never supplant the influence of an energetic and compassionate science teacher, I am chagrined that I cannot fully justify this hunch. The possibility that there is a distinct category of knowledge has great appeal. Further, that science teacher preparation programs instill such knowledge in their future teachers seems to move closer to the promise of teaching becoming a profession. But without a handy and compelling defense of my science teacher preparation efforts, I can only pout and fume when others promote their teacher residency programs, alternative routes to certification, and other shortcuts to becoming science teachers. Clearly, my professional ego would benefit from something profound and powerful. Nonetheless, the "restless disposition" invoked by Dewey forces me to claim that, despite the substantial desire for a solution, PCK will not save the day.

Among science teacher educators there is great ambivalence toward PCK. This is because this idea has not generated solid research to inform our science teacher education practices. In addition, there is very little about PCK that is compelling to policymakers. However, we should not abandon hope. The disquietude toward PCK within the mathematics education research community has offered new possibilities. PCK has been set aside in favor of "mathematical knowledge for teaching" (e.g., Hill et al. 2005; Loewenberg Ball et al. 2008). This is more than a semantic shift. A key departure from PCK has been the attention given to teaching actions and teacher moves rather than relying solely on what teachers store in their heads. Admirably, such studies by math educators do not shy away from the complexities of context. Instead, their research is strengthened by examining the teachers and students as they work with subject matter while giving due regard to the role of context. Such an orientation toward *subject matter knowledge for teaching* offers an excellent example for science teacher education research. Perhaps PCK will linger until the generation who first embraced it is replaced by scholars with fresh perspectives (a Kuhnian revolution through attrition, if you will). My preference is not to wait until PCK is gray and frail but instead begin right away to look toward more promising frameworks for studying and supporting science teacher education. Smart, ambitious and dedicated researchers in mathematics teacher education serve as role models. Like me, they regard PCK as an idea that was usefully wrong. Without PCK we may not have realized the nuances of teacher knowledge. From this elevation, we discover other routes that offer a much better view and reveal a greater variety of paths for us to traverse.

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