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The place of practical wisdom in science education: what can be learned from Aristotelian ethics and a virtue-based theory of knowledge

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Abstract This conceptual paper aims to characterize science teachers' practical knowledge utilizing a virtue-based theory of knowledge and the Aristotelian notion of phronesis/practical wisdom. The article argues that a greater understanding of the concept of phronesis and its relevance to science education would enrich our understandings of teacher knowledge, its development, and consequently models of teacher education. Views of teacher knowledge presented in this paper are informed by philosophical literature that questions normative views of knowledge and argues for a virtue-based epistemology rather than a belief-based one. The paper first outlines general features of phronesis/practical wisdom. Later, a virtue-based view of knowledge is described. A virtue-based view binds knowledge with moral concepts and suggests that knowledge development is motivated by intellectual virtues such as intellectual sobriety, perseverance, fairness, and humility. A virtue-based theory of knowledge gives prominence to the virtue of phronesis/practical wisdom, whose primary function is to mediate among virtues and theoretical knowledge into a line of action that serves human goods. The role of phronesis and its relevance to teaching science are explained accordingly. I also discuss differences among various characterizations of practical knowledge in science education and a virtue-based characterization. Finally, implications and further questions for teacher education are presented.

Keywords Teacher knowledge · Practical wisdom · Teacher education · Phronesis

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The nature of teaching as a professional practice and the knowledge(s) that inform it remain a rich area for discussion. This paper hopes to contribute to discussions around teacher knowledge by presenting a virtue-based view of knowledge built on the Aristotelian notion of phronesis or practical wisdom. Earlier understandings of teaching as "practice" tended to adopt models from the natural sciences (Schwandt 2005), with a focus on theoretical and technical conceptions of teacher knowledge and of formal rationality as underlying decision-making (Dunne 2005). An alternative conception of teaching is modeled on the Aristotelian notion of praxis (Schwandt 2005). Praxis is defined as the right conduct in concrete situations, with action that is meaningful, morally committed, and value-based: Purviews of praxis are self-formation as well as achieving external goals for the collective good (Dunne 1993).

Praxis is informed by practical knowledge (Schwandt 2005). Practical knowledge is further characterized by the Aristotelian notion of phronesis (usually referred to as practical wisdom). Joseph Dunne (2005) outlined the following features of phronesis as an action orientating form of knowledge:

> its irreducibly experiential nature, its non-confinement to generalized propositional knowledge, its entanglement (beyond mere knowledge) with character, its need to embrace the particulars of relevant action-situations within its grasp of universals, and its ability to engage in the kind of deliberative process that can yield concrete, context-sensitive judgments (p. 375).

Underscoring the importance of phronesis is especially important in the current environment where teachers' judgment is being marginalized through top-down policies, and where discussions of teaching are bound with external measurements and evaluations (Alsop, Bencze and Pedretti 2004). One facet of top-down policies is research focused on producing *explicit, general,* and *universal* knowledge to be 'given' to teachers (Schwandt 2005) or to realize the ideal of practitioner-proof practice (Dunne 2005). For example, many of my students (novice urban teachers in a major US City) are currently asked to follow scripted curricula, and are reprimanded for altering those to address students' particular needs.

Phronesis though remains an elusive concept in need of further clarification (Breier and Ralphs 2009), especially in terms of its relevance and implications to science education. For one thing, phronesis has been interpreted in various ways in education leading at times to incompatible implications (Carr 2007). Jana Noel (1999) outlined three interpretations of phronesis in education: a rationality interpretation, where phronesis is a form of reasoning; a situational perception and insight interpretation, where phronesis is a form of situational understanding or knowledge; and lastly phronesis as cultivation of moral character, where what one does is inextricably connected with who one is. The various interpretations entail different contextual and ethical assumptions, with "tensions between discussions of phronesis from the perspectives of moral theory, rationality and logic, and the structure of psychological decision-making." (Noel 1999, p. 273).

Given the inherent complexity of teaching demands and situations, I agree with Noel when she suggests that phronesis in education requires a combination of different interpretations. Intuitively, we realize that our teaching actions and decisions are manifestations of what we know and who we are. In science education particularly, an interpretation of phronesis needs to afford content, reasoning, situational, and character aspects. For example, Carr (2007) used Aristotelian virtue ethics and phronesis to argue that the cultivation of 'morally good' character is not merely helpful in good teaching, but is constitutive of it, especially cultivating virtues such as honesty, justice, patience, and courage.

Yet, an interpretation of phronesis as cultivation of moral character may not be sufficient in science education if it remains 'content-free:' for example, what does it mean to be 'courageous' as a chemistry teacher?

Content, nature of science, sociocultural aspects of science, and pedagogical content knowledge (PCK) are central themes in science education. In order to situate phronesis within the aforementioned traditions, it is necessary to further elucidate its meaning and its potential role in development of scientific knowledge and science teacher education. First, I outline general features of phronesis utilizing Aristotelian ethics and virtue epistemology. I then propose a multi-layered role for phronesis in science teaching and discuss differences among phronesis and characterizations of practical knowledge in science education. My discussion aims to broaden views of teacher knowledge and not to privilege any one view, rather I hope to highlight moral dimensions of science teaching practice from the perspective of virtue epistemology.

Theoretical framework: Aristotelian virtue ethics and virtue epistemology

Phronesis

In the *Nicomachean Ethics* (Trans. J. Sachs 2002), Aristotle distinguished virtues of character from intellectual virtues, with intellectual virtues being 'truth-disclosing' active conditions to determine the appropriate mean between excess and deficiency in a virtue (e.g., what is the appropriate level of courage in a certain situation). Different intellectual virtues are distinguished based on the different purposes and knowledge they seek (Eikeland 2006). Episteme or theoretical scientific knowledge concerns things whose first principles are *invariable*. On the other hand, phronesis (practical wisdom) and techne (craft and art) are virtues with which one contemplates things that can be *otherwise* (please refer to Table 1 for a summary of differences among phronesis, episteme and techne). Phronesis

Table 1 Differences among phronesis, episteme and techne

	Phronesis	Episteme	Techne
Purview	Mediate knowledge and virtues with an end of "living well," involves the ability to "actuate general knowledge with relevance, appropriateness, or sensitivity to context." (Dunne 2005, p. 376)	Produce knowledge of regularities and patterns allowing for prediction; it results in general principles, rules, or theorems	Oriented toward producing a design or something tangible
Features of knowledge	Tacit, transmitted through modeling and narrative Context dependent Involves knowledge of particulars Perceptual Value led	Declarative and theoretical, comprised of warranted assertion Context free Universal Conceptual Value free	Comprised of skills, can be learned and forgotten Context dependent Involves knowledge of particulars Skill-based Value free

is needed to deliberate actions in situations that are variable and context dependent. It is, according to Aristotle, the intellectual virtue that governs reasoned and capable action with regards to things that are good or bad for oneself and others. It necessitates knowledge of particulars as well as universals, "since it has to do with action and action is concerned with particulars" (Aristotle 2002, p. 109). Phronesis develops with experience by sharpening our perception and understandings.

Aristotle (1976) distinguished phronesis from both episteme (scientific knowledge) and from techne (art and craft). Episteme produces general principles that can be demonstrated, however judging the appropriateness of a general principle to a context requires phronesis (Dunne 2005). For example, episteme produces general principles that can be demonstrated to others about lines of questioning to extend student thinking and wait time suggested by research for better engagement. However, with a specific group of students, the teacher needs to engage phronesis to judge whether the 'demonstrated' line of questioning and wait time is appropriate to sustain a particular groups' engagement, promote understanding, and reduce frustration.

As for differences with techne, Aristotle stated that ends for *making* are different than those of *acting*. In 'making,' ends are in producing something tangible separate from the 'making.' Techne has well-defined end products, and means to achieving them are separate from the ends. With phronesis, means and ends are interconnected: "the considerations of the means is itself a moral consideration and it is this that concretizes the moral rightness of end" (Gadamer 1989, p. 319). For example, with techne, a teacher can train students to apply scientific algorithms correctly without conceptual understandings, and thus have them do well on tests requiring low intellectual engagement. The end of having students do well on tests is reached; means to reach it are *not* a consideration for techne. However, with phronesis ends pertain to several 'goods' that science teaching needs to serve: e.g., promoting students' understanding of concepts and appreciation of science, developing their sense of wonder about the world and understanding role of science in their lives, *and* helping them pass tests. Phronesis would be about finding the 'right' means to balance the various ends. Hans-Georg Gadamer (1989) added that techne can be captured in discrete skills, whereas phronesis is bound with images of how we see ourselves and our notions of right and wrong (e.g., empathy, open-mindedness, responsibility, fairness etc.). For example, a teacher can acquire skills in creating diverse assessments, choosing to use them or not based on the group of students or topic. However, a teacher cannot choose not to be responsible or fair without this bearing on how she sees herself as a person.

Phronesis seems to characterize important aspects of knowledge needed in good teaching. As educators we constantly try to act towards ends believed to be 'good' for our students and content, we also try to act in ways consistent with our character. Striving to realize what is 'good' (for others and ourselves) in teaching is in congruence with knowledge as phronesis. Essentially, phronesis is the ability to act well and reflect on practice, but goes beyond reflection to encompass growing as a moral practitioner.

Virtue epistemology

Inspired by and going beyond Aristotle's concept of intellectual virtues, Linda Zagzebski (1996) proposed a virtue-based theory of knowledge or virtue epistemology:

> A virtue-based theory of knowledge aims to bind knowledge with moral concepts: I define knowledge as cognitive contact with reality arising from … 'acts of intellectual virtues.' The theory gives a prominent place to the virtue of phronesis, a

> virtue whose primary function is to mediate between and among the whole range of moral and intellectual virtues. (Zagzebski 1996, p. xv)

Motivation for knowledge is connected to the development and enactment of intellectual virtues, and so knowledge is intimately connected to moral dimensions of living or practice. Virtue epistemology is distinguished from mainstream cognitively-based epistemology in two main ways. First, virtue epistemology is normative concerning itself with questions that go beyond how we cognize (e.g., remember, reason, inquire) to questions of how we *ought* to cognize and what constitutes *good* cognition (Turri and Sosa 2013). Secondly, virtue epistemologists move the locus of evaluation from individual beliefs and inferences to virtues and cognitive character held by the knower as agent (Zagzebski 1996). Virtues are defined as enduring *acquired* excellences of a person that provide motivation to produce certain desired end or action. Virtues relevant to teaching can be: responsibility, wholeheartedness, open-mindedness (Dewey 1933).

Virtue epistemologists' rationale for moving the focus from beliefs to virtues and understandings resulting from them is as follows: one does not necessarily deserve credit for believing a certain truth; for example they may not have been exposed to others. By contrast, you understand or know something only if you deserve credit for arriving at it through exercising intellectual virtues (Turri and Sosa 2013). A teacher may believe that 'science is not for everyone' and that an authoritarian/transfer teaching model is best simply because this is all she has experienced. However, if a teacher is exposed to different perspectives on science and science teaching, she would deserve credit for developing knowledge and skills that promote all students' meaningful learning, especially when such knowledge is motivated by intellectual virtues such as responsibility and intellectual honesty.

Virtue epistemology gives prominence to phronesis as the virtue that mediates among prior knowledge, virtues, and emotions. A primary function of phronesis is to determine the virtuous course required in a particular situation and to find an appropriate mean between excess and deficiency in a virtue. For example with intellectual carefulness: how much evidence is enough to support a belief? Another example is how empathic should a teacher be. The question is not to be empathic or not (as two extremes), but what degree is appropriate considering the student or situation at hand.

Second, phronesis mediates different virtues potentially relevant to a situation, especially when relevant virtues lead to different courses of thinking or actions. For example, a physics teacher's *responsibility* towards students' success on standardized tests may call for "test prep" practices with a strong focus on algorithmic and test-taking skills, whereas *intellectual honesty* towards physics call for meaningful inquiries into concepts. A teacher would engage phronesis to balance intellectual honesty *and* responsibility for test achievement to ensure that students develop meaningful understandings and are prepared for less intellectually based tests. Shirley Pendlebury (1995) described such balancing as perceptive equilibrium, where neither scientific inquiries are undertaken at the expense of developing test-taking skills; nor vise versa.

Finally, phronesis serves to coordinate prior knowledge, virtues, and emotions into a single line of action or line of thought leading up to action. A course of action resulting from phronesis is not rule-governed, involves indeterminacy, and goes beyond what can be inferred from available evidence (Gadamer 1989). It is partly so because "there can be no anterior certainty concerning what the good life is directed toward as a whole" (p. 318). In teaching particularly, indeterminacy emerges, according to Pendlebury (1995), because conditions change over time (e.g., with changing policies) and situations can be very particular to a specific situation or group of students. Furthermore, emotions in teaching can themselves be ways of knowing: good teachers cultivate their emotional responses to serve students and the content. Teaching situations entail many ‘goods’ to be served through different means; choices among them entails a level of subjectivity based on a teacher’s perception and emotions about what is important for a particular group and/or honesty towards a science discipline.

Relevance of phronesis to science education

Practical wisdom and virtue epistemology can be relevant to science education on different levels: (a) several intellectual virtues such as intellectual open-mindedness and sobriety can be perceived as underlying science practices and aspects of nature of science; (b) phronesis, with its perceptual nature and ends for realizing human goods and society’ wellbeing (e.g., healthy being, environmental stewardship, etc.) can help us understand sociocultural nature of science and augment students’ personal connection to science; and finally in relation to teaching in general (c) cultivation of intellectual virtues can contribute to science teachers’ pedagogical growth and consequently their classroom actions.

Nature of science, science content and phronesis

Virtue Epistemology attempts to provide a framework for understanding knowledge development, where intellectual virtues involve a general motivation for knowledge, for seeking reliable procedures in attaining knowledge, and the development of specific skills that enable the acquisition of knowledge (Zagzebski 1996). Intellectual virtues suggested as relevant for development of scientific knowledge are: impartiality; intellectual sobriety including careful inquiry and accepting what is warranted by evidence; intellectual humility; intellectual courage including perseverance, determination and thoroughness; and fairness in evaluating the arguments of others. The above intellectual virtues can be seen as underlying science practices (NGSS Lead States 2013) and certain aspects of nature of science (NOS) outlined by Norm Lederman (1999) and Fouad Abd-El-Khalick (2012). Next Generation Science Standards focus on science as a set of ‘practices’ as opposed to skills to stress that scientific inquiry requires *coordination* both of knowledge and skill simultaneously. Additionally, practices highlight the role of communication, critique, and argumentation in science in addition to experimental investigation (NGSS Lead States 2013). Phronesis can serve to coordinate knowledge and guide conducive modes of ‘obtaining, evaluating, and communicating information.’ For example, both intellectual humility and perseverance are important when facing disconfirming evidence or anomalies: a balance between the two virtues maintains the tentative nature of science along with constructive communication, argumentation, and evaluation of information. Excess in humility and deficiency in perseverance may lead to premature abandonment of ideas, whereas excess in perseverance and lack of humility may lead to dogmatic attachment to ideas: phronesis would determine appropriate means between excess and deficiency. Table 2 shows correspondences among aspects of NOS, scientific practices and intellectual virtues that potentially underlie them.

Even though individuals or groups of scientists may not always realize the above virtues either due to partiality towards a theory (theory-laden) or due to social or cultural pressures (e.g., ignoring or fabricating evidence to gain funding or publish), the scientific community

Table 2 Aspects of NOS, scientific practices and corresponding intellectual virtues

Aspect of NOS	Scientific practices	Intellectual virtue
Tentative	Asking questions Engaging in argument from evidence Obtaining, evaluating, and communicating information	*Intellectual humility* *Intellectual courage*/perseverance/determination/thoroughness *Fairness* in evaluating the arguments of others
Empirical	Planning and carrying out investigation Analyzing and interpreting data	*Intellectual sobriety* including careful inquiry and accepting what is warranted by evidence *Intellectual courage*/perseverance/determination/thoroughness
Inferential	Engaging in argument from evidence Obtaining, evaluating, and communicating information	*Intellectual sobriety* including careful inquiry and accepting what is warranted by evidence *Intellectual courage*/perseverance/determination/thoroughness *Fairness* in evaluating the arguments of others
Creative	Asking questions Constructing explanations Developing and using models	*Intellectual courage*/perseverance

attempts to cultivate them through intersubjectivity and calls for validation and replicability.

As science educators, it seems important to cultivate the above virtues ourselves *and* model them to students. Ms. Yasmine, a science teacher in Salloum and Abd-El-Khalick (2010) was adamant that students build and observe models to demonstrate Pascal's principle stating that "it was not 'nice' for students" to just be told that the formula is so. She insisted that students observe the results themselves. Ms. Yasmine may not realize a model contemporary 'inquiry-based' teaching approach, but given the highly prevalent authoritarian, teacher-centered, and test driven approach in Lebanese public schools and emphasis on rote learning, her practice attempts to realize a level of intellectual sobriety, which she values. Trying to have students 'do' science' rather than 'tell' them about science' can be seen as a manifestation of a teachers' intellectual sobriety. When teachers adopt careful inquiry in their science teaching (as opposed to more teacher-centered approaches), they are highlighting for students the empirical nature of science and the importance of investigation and evidence for knowledge development. Phronesis would mediate teachers' intellectual humility, sobriety, and open-mindedness to enable them to teach science through inquiry, where they would need to give up aspects of their authority to allow students themselves to inquire and communicate findings.

Moreover, recognizing phronetic aspects of science helps us understand sociocultural perspectives on science and refute the Myth of 'The Scientific Method' [the belief that "there is a recipe-like stepwise procedure that typifies all scientific practice" (Abd-El-Khalick 2012, p. 357)]. Jay Lemke (2001) proposed understanding science as a very human activity with interests and theoretical dispositions that are "very much a part of and not apart from the dominant cultural and political issues of the day." (p. 298). Such highlighting of humanistic dimensions of science goes along recognizing the role of phronesis in science and how scientific knowledge is used.

From a science education perspective, Myron Atkins (2007) suggested that relevance of science curricula can be enhanced by underscoring humanistic and phronetic dimensions of science. Particularly significant is highlighting the role of human beings with their strengths and their frailties in the history of science, as well as the development of key ideas and theories and emphasizing the role of science in improving the human situation and tackling social and social justice issues. Another possible value in highlighting phronetic aspects of scientific knowledge would be in connecting indigenous worldviews (which typically entail inhabiting and taking action in the world, similar to phronesis) with scientific knowledge (i.e., episteme or knowing how the world works as a disconnected knower) (Aikenhead 2008).

Finally, many students, especially students from underrepresented groups, perceive school science as disconnected from their daily lives (Osborne, Simon and Collins 2003). Both downplaying sociocultural perspectives on science and an emphasis on teaching science as bare facts or *episteme* may contribute to students' personal disconnect from science (S. Alsop, personal communication, November 11, 2012). Highlighting phronetic (in addition to epistemic) aspects of scientific knowledge with the aim of realizing human and society's wellbeing can potentially enhance students' personal connections to science. Questions in science classrooms would go beyond how things work to include questions on how scientific understandings contribute to our wellbeing as individuals and society; for example: "What does genetics mean in a racialized society?", "how can knowledge of heavy metals help protect us from risky contaminations?" or "how is scientific knowledge disseminated and utilized by different groups of people?"

Phronesis and science teacher knowledge

Phronesis and PCK

Pedagogical content knowledge (PCK) has been a major framework informing conceptualizations of science teacher knowledge and remains a generative paradigm raising new questions about teacher knowledge and development (Abell 2008). Lee Shulman (1986, 1987) conceptualized PCK as a "particular form of content knowledge that embodies the aspects of content most germane to its teachability" (1986, p. 9). PCK includes knowledge of what makes specific concepts difficult, and explanations and representations most powerful in enhancing comprehensibility. Shulman (1987) originally outlined at least four major sources of teacher knowledge: (a) scholarship in content, (b) material and settings of the institutionalized educational processes, (c) formal educational research and scholarship, and finally (d) wisdom of practice, which is the "least codified" of other sources. Wisdom of practice is explained as the "maxims that guide (or provide rationalizations for) the practices of able teachers" (p. 228). Of the four sources, 'wisdom of practice' is the one most closely related to the Aristotelian notion phronesis (Shulman 2007), even though in the earlier work it was not framed as such explicitly.

In science education, PCK was originally designated as an aspect of science teachers' craft knowledge/techne, defined as "integrated knowledge which represents teachers' accumulated wisdom with respect to their teaching practice" (van Driel, Verloop and de Vos 1998, p. 674). Recently, Mulhollad and Wallace (2008) stated that even though definitions of PCK have evolved, PCK epitomizes *cognitive* or 'knowledge-base' aspects of teacher knowledge. It is conceived as theoretical transferable knowledge or a form of episteme rather than phronesis or techne. For example, PCK, unlike practical knowledge, is suggested as enabling teachers to develop transferable expertise adaptive to multiple settings since it is less personal/situated (Schneider and Plasman 2011). I note that the authors conceptualized practical knowledge as merely "knowledge of classrooms and the complexities of teaching" (p. 533) without reference to moral dimensions.

Science teacher's practical knowledge

Shifts from theoretical views of knowledge have been undertaken in science education (Tobin 1996) and non-theoretical forms of teacher knowledge have emerged as important. Practical forms of knowledge have been characterized as practical knowledge (van Driel, Beijaard and Verloop 2001), practical-moral knowledge (Salloum and Abd-El-Khalick 2010), and personal practical theories (Smith and Southerland 2007). Van Driel, Beijaard and Verloop described practical knowledge as "the integrated set of knowledge, conceptions, beliefs, and values teachers develop in the context of the teaching situation" (p. 141). However, upon examining literature on practical knowledge in science education, I note that Mulholland and Wallace (2008) and van Driel, Beijaard and Verloop (2001) associated practical knowledge with craft/techne rather than phronesis. Craft has been broadened to include reflective practice entailing virtues such as responsibility, open-mindedness, and wholeheartedness. Craft is important, however, it may not adequately capture teachers' strong judgments to serve goods of practice, nor does it encompass cultivation of virtues and character (Carr 2007). I suggest that teachers' practical knowledge extends beyond techne and may be better encompassed by phronesis (Salloum 2013).

In science education literature, knowledge as phronesis resembles to a *certain extent* Allan Feldman's (2002) conceptualization of teaching as a way of being, and Mulholland and Wallace's (2008) metaphor of teaching as complexity. Feldman suggested 'teaching as being' as a more holistic framework for teaching compared to knowledge-base, practical reasoning, and social constructivist models. He maintained that the above models assume a direct linkage between cognition and action and separation of mind, body, and the world. Teaching as being rejects such separation, where teachers exist as meaning makers immersed in educational situations composed of "weblike connections between and among what was and what is, out of which we project ourselves into the future" (p. 1039). Understanding is developed through meaning making related to that being-in-the-world and through a shared, social background that is the foundation for intentional human activity. According to Feldman, understanding is neither explicit (like episteme) nor tacit knowledge (like phronesis and techne).

Knowledge as phronesis, unlike Feldman's conceptualization, is simultaneously a way of being and a form of knowledge and understanding without clear separations (T. Schwandt 2008, personal communication). As a virtue, phronesis is enduring to ones character and being; at the same time phronesis is a form of understanding that mediates motivation for knowledge, skill development, and action. Accordingly, phronesis mediates other virtues leading to enhanced knowledge and understandings of content, students and context. The following intellectual virtues are suggested as relevant to teaching (not a comprehensive list): responsibility, wholeheartedness, open-mindedness (Dewey 1933); wide-ranging inquiry and reflection on potential of such inquiry for the development of oneself and students (Carr 2007); the social virtues of being communicative and candid (Zagbeski 1996); and intellectual honesty (attempting to represent a discipline authentically) (Ball 1993). I add empathy, fairness and striving for equity. The above intellectual virtues are simultaneously character traits (being) and can motivate a teacher to build knowledge and develop new skills to improve practices. For example, a chemistry teacher's intellectual responsibility for students' meaningful learning would motivate a careful inquiry into students' difficulties in understanding abstract topics, and into developing multiple representations of concepts to insure access points for *all* students (building aspects of her PCK).

I use an example from work with my students (Salloum, Jennings, Arrabito, Schmidt, McCall, Frederick, Cross and Benn-Scantlebury 2010) to show how open-mindedness, along with empathy, can motivate a science teacher to expand her knowledge of content, learn ways to validate students' ideas, and teach them how to build arguments based on evidence. Gizelle (pseudonym) is a high school science and special education teacher in an urban school. She conducted a teacher inquiry on how to engage students, especially students with special needs, in inquiry-based science. Her inquiry was not only driven by her valuing of careful inquiry as ways of knowing, but also a desire to learn about students' personal meanings of 'inquiry.' When teaching about the endocrine system, she took active steps to learn about students' experiences and interests, and enhanced her knowledge of the subject matter. With students' input, she developed an inquiry unit on the "science of falling in love." Students were encouraged to develop their own meanings and definitions of 'love' and discuss them. They also explored physiological aspects of emotion by reading scientific articles and seeing documentaries on interactions of hormones and emotions. Students critiqued articles and suggested experimental designs for further explorations. They posed questions about love and explored how some questions can be investigated in ways similar to the articles and how some questions cannot. Students presented and defended their stances and designs. Gizelle continually learned from students' responses and enhanced her skill in facilitating presentations and discussions. Gizelle's practical wisdom on what is 'good' for all students mediated virtues such as open mindedness, careful inquiry and empathy helping her develop new competencies to further students' learning.

Implications for teacher education: apprenticeship, mentoring, and inquiry

Phronesis requires experience and its mode of transmission is indirect "through narrative, modeling and experience, both verbally and non-verbally." (Breier and Ralphs 2009, p. 485). We cultivate Phronesis by interacting with individuals who possess and exercise it, and by attempting to exercise it ourselves and critically reflecting on our thinking, perceptions, emotions and ensuing consequences. When teacher knowledge is conceptualized as only episteme, new teachers are given *explicit, general, and universal* knowledge to *apply* in teaching situations. On the other hand with phronesis, theory and practice are interconnected and formulated and reformulated in relation to each other through a critical reflective process.

One way of cultivating phronesis in teacher education would be to *immerse* teaching candidates from the outset in complex teaching situations through well-planned apprenticeships, working collaboratively with teacher educators and mentor teachers: observing, co-planning and co-teaching (Tobin and Roth 2005), and critically and collaboratively reflecting on perceptions and actions (Korthagen, Loughran and Russel 2006). Apprenticeships can provide candidates with rich and safe contexts to observe intricacies of teaching and ways mentors engage their practical wisdom to serve students and content. Rich apprenticeships offer teaching candidates chances to gradually take on more teaching responsibilities that help them understand demands of teaching. Safe apprentices start with low risk tasks and decisions to look back on and learn from [e.g., legitimate peripheral participation (Lave and Wenger 2002)].

Moreover, Stephen Kemmis (2010) suggested that "Action research can help us learn phronesis, the disposition to live wisely and well, by facilitating our reflection on our individual and collective praxis." (p. 422). According to Aristotle, we become more fair or courageous by doing fair and courageous acts. Teacher inquiry can help candidates engage in and understand virtuous acts conducive to good and equitable teaching, ultimately cultivating their practical wisdom and virtues that will hopefully inform their practice. Disciplined documentation and critical reflection can help teachers see science and teaching situations from students' perspectives and enhance their awareness of preconceptions and biases, where teachers better understand interactions among virtues and theoretical knowledge (e.g., science and pedagogical content knowledge).

In the teacher inquiry courses I teach, candidates generate and conduct analyses of various forms of data: classroom observations and talk and students' work (graphic and written). They describe data in non-judgmental language first (e.g., students' ideas and concrete events). Afterwards they interpret and analyze data. Candidates also critically reflect as a group to understand and question judgments, decisions, perceptions, and interpretations. For example, they examine how concepts were presented, relevance and appropriateness of materials and assessments, and how students' needs were addressed. Most candidates find classroom talk analysis and graphic-based work to be particularly eye-opening about students' thinking and understandings of topics, thus becoming better attuned to students' needs. As important, they develop better understanding of science concepts and demands of different levels of learning within a concept (e.g., conceptual, relevance to life, and algorithms and convention).

Concluding thoughts

Finally, "a knowledge base for teaching is neither fixed nor final" (Shulman 1987, p. 232). The view presented here is not meant to be privileged or replace other views, but to enrich our understandings of the complexity of science teacher knowledge and practice and the central role of teacher judgment. Phronesis and virtue epistemology can provide a framework for understanding the moral dimension of science teachers' knowledge and their intimate relation to content knowledge and pedagogical knowledge.

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