Chapter 15
Developing Intellectual Sophistication and Scientific Thinking—The Schemes of William G. Perry and Deanna Kuhn

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Introduction

William G. Perry proposed a theory of the stages of intellectual and ethical development that he identified from work with undergraduate college students. At the time when his work was proposed, it seemed to be most relevant to young adults who would be expected to have successfully passed through the stages of cognitive development that had been identified by Jean Piaget in his work with children and adolescents. However, it is now clear that the stages of development discussed by Perry are very relevant to the school science curriculum, and so to the types of thinking often now expected from school students when studying science.

Deanna Kuhn has worked with children exploring the development of scientific thinking and developed a model of the development of critical thinking that has strong links to the scheme proposed by Perry. One interpretation suggested by comparing their work is that school science now routinely challenges pupils to demonstrate a level of epistemological sophistication that was often still being formed in many undergraduate students in the mid-twentieth century.

Cognitive and Moral Development

It is widely recognised, indeed it is commonplace experience, that development from a neonate through childhood and adolescence into adulthood is not simply a matter of physical growth. A young child does not access all the kinds of thinking available to a mature adult. Part of development is acquiring new modes of thinking about the world, as, for example, when language is internalised (see Chap. 19). There have

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been a number of key theorists who have studied and sought to understand the nature of how such development occurs.

Jean Piaget (see Chap. 10) focused on the development of cognition. He posited a complex stage theory that had four main stages characterised by increasingly sophisticated levels of thinking (Piaget, 1970/1972). In Piaget's model, the fourth stage was called formal operations. This implied that a person was capable of highly abstract thinking and able to undertake mental operations on internal mental representations. This was very relevant to learning science as many science topics taught in school involve theoretical abstractions that students are expected to engage with, and indeed apply, in the absence of the natural phenomena from which those ideas were initially abstracted. Examples might be clades in biology which concern the evolutionary relationships between organisms (which do not necessarily all exist at the same time or place); notions of flux density in magnetic fields (which are not visible but may be represented by visualising imaginary field lines); or oxidation states used to represent redox processes (understood in terms of shifts in electron density that are conceptualised as partial electron relocations in molecules, that is, subtle modifications in particles theorised to exist at a scale many orders of magnitude removed from direct observation). Given that many secondary school learners are not considered to have fully developed formal operational thinking, it was argued that learning difficulties students face in school science may often result from a mismatch between the demands of the curriculum and the level of cognitive development of many of the students (Shayer & Adey, 1981).

Another key thinker, Lev Vygotsky (see Chap. 19), considered that adult ways of thinking could be understood as a culturally developed resource (that is, a resource that had been developed historically within a cultural group), into which young people could be inducted by mediation from more advanced members of the community, supported by such tools as language and other shared forms of symbolic representation. Even in a scientifically literate society, children will not develop conceptions that closely match canonical scientific concepts without formal instruction or other mediation (e.g. through books, websites, documentaries, etc.).

Other theorists considered a different aspect of development, related to moral growth (Kohlberg, 1973) (cf. Chap. 5). Cognitive development related to the ability to think in more sophisticated (and abstract) ways, whereas moral development related to the development of a system of values. This was more concerned with making 'good' or 'wise' choices when taking practical action, rather than being able to solve logical puzzles or apply technical concepts. When Benjamin Bloom (see Chap. 11) set out taxonomies of educational objectives to guide pedagogy, he developed distinct taxonomies for the cognitive domain (Bloom, 1968) and the affective domain (Krathwohl, Bloom, & Masia, 1968). To be characterised at the highest level of the affective domain required "an internal consistency to the system of attitudes and values at any particular moment" that gave a 'predisposition' or "basic orientation which enables the individual to reduce and order the complex world… and to act consistently and effectively in it" (Krathwohl et al. 1968, p. 48). Such an individual would develop a worldview that offered a coherent philosophy of life that guided judgements across all domains (Taber, 2015).

Piaget's work was strongly linked to the development of the kinds of concepts met in school science and mathematics, and its relevance to science teaching was clear. As the affective domain concerns values, rather than conceptual understanding, it can appear to be more relevant to learning about areas of the curriculum traditionally associated with values—the arts and humanities—yet an authentic science education must introduce learners to the values inherent in science (open-mindedness, seeking evidence and so forth) and teaching about the applications of science in relation to public policy engages value judgements as well as knowledge.

Considerations of moral development are less about evaluation of the specific moral decisions a person makes (i.e. whether one might agree with a person's decisions or consider they have behaved in a good way), but more about the sophistication of the thinking, and the coherence of the value system that underpins this. Arguably, fundamentally, the thinking skills being applied are not distinct from those that pertain when evaluating cognitive development. Perry (1985) proposed a theory of the development of student thinking that encompassed intellectual and ethical development within the same scheme.

Development Beyond Piaget's Formal Operations and Scientific Thinking

Piaget's scheme considered cognitive development to be complete with the acquisition of formal operations. However, there were suggestions that there might be further progression beyond the Piagetian scheme. For example, Arlin (1975) explored the idea that whilst formal operations provided the ability to engage in successful problem-solving, further development was needed to be an effective problem-finder—development that might be considered a fifth stage. This skill is clearly important in scientific work: a key feature of research is in identifying, and conceptualising, potentially productive questions. In science, logical thought works in coordination with creative thinking (Taber, 2011), and this becomes especially salient when school science is expected to engage students in enquiry activities (see Chap. 23).

School science had traditionally taught a model of 'the scientific method', that is, the use of control of variables to design experiments, and formal operations provided the means to use logic to apply hypothetico-deductive thinking in such 'fair tests'. However, it is increasingly thought that an effective science education (at school level, as well as in higher education) must have a strong focus on enquiry, where the earlier phases of investigations—such as recognising suitable research topics, refining research questions and then designing studies to address those questions—is as important as later applying logic to make deductions from experimental results (Riga, Winterbottom, Harris, & Newby, 2017). This could be considered to require the kind of 'fifth stage' that Arlin investigated.

It was also asked whether acquisition of formal operations was sufficient to treat knowledge as non-absolute, or to cope with contradictions (Kramer, 1983). This is especially relevant to school science in contexts where it is considered important that students not only learn some science, but also learn about the nature of science (Taber, 2017). Formal operations work when logic is sufficient to reach a conclusion—for example, in mathematical systems where the notion of proof applies. A modern understanding of science suggests that a naive positivism is misguided, and that all scientific findings should be seen as potentially provisional and open to reconsideration in the light of either new evidence or a new perspective to reconceptualise evidence. That is, scientific knowledge is not absolute and is theoretical (and so reliant on some commitments that have to be assumed a priori and cannot be demonstrated).

In much scientific research it is not even possible to draw absolute conclusions when working within a particular theoretical framework: scientific results are seldom unequivocal, as they are subject to both limitations of measurement and observation, and sometimes human error, and, moreover, nature is often more subtle and complex than the models being used to conceptualise and design studies. Scientists often have to deal with contradiction, and fuzzy data, and be able to make judgements about the extent to which robust conclusions can reasonably be drawn in the face of imperfect (in the sense of not entirely matching the predictions of any particular hypothesis) datasets.

The kinds of understanding of the processes of science that are set out as target knowledge in many national school systems rely then on learners exhibiting thinking that has been considered characteristic of a fifth stage *beyond* the formal operational level—when that stage itself is not thought to be fully acquired by all secondary school-age learners. Piagetian theory assumes a constructivist process where each stage is slowly built through experiences deriving from the regular application of the operations that have been acquired in the preceding stage (see Chap. 10): so (from this perspective) only students having fully acquired formal operations would be ready to start constructing a 'fifth stage' of post-formal operations. Development of such thinking skills is therefore a topic of great importance for curriculum development and pedagogy in school science.

Perry's Study of Undergraduate Thinking

Perry carried out his work in the mid-twentieth century with college students in the United States, that is, undergraduate students studying for degrees. Moreover, he worked with students at the elite Harvard and (to a lesser extent) Radcliffe Colleges, exploring their experience of engaging with the study of a range of subjects. (At the time of the work, Harvard College only accepted male students and Radcliffe College only accepted female students—the institutions later merged). So, Perry was working with young adults who had successfully completed schooling and had been admitted to prestigious degree courses. It should also be noted that undergraduate education in the United States is somewhat different to that in some other parts of the world, in that a first (bachelor's) degree course often comprises a wide curriculum, rather than being specialised within a single discipline such as anthropology, chemistry or zoology. Perry's team talked to students over the 4 years of their undergraduate degree. Perry characterised the data collection as 'open' interviews that sought to elicit the participants' ways of making sense of their experiences.

Perry (p. 48) reported finding a developmental pattern in the data "in the special sense originally derived from biology in that it consists of an orderly progress in which more complex forms are created by the differentiation and reintegration of earlier simple forms". He described this development as an ability to make sense of increasingly nuanced information or situations:

> In its full range the scheme begins with those simplistic forms in which a person construes his [sic] world in unqualified polar terms of absolute right-wrong, good-bad; it ends with those complex forms through which he undertakes to affirm his own commitments in a world of contingent knowledge and relative values. The intervening forms and transitions in the scheme outline the major steps through which the person, as evidenced in our students' reports, appears to extend his power to make meaning in successive confrontations with diversity (p. 3).

Perry's model differed from the kind of scheme offered by Piaget in that, although it represented a course of development, Perry noted that individual students could 'retrogress' at any point. That is, even when a student had demonstrated thinking characteristic of a higher position in the scheme, they might later offer thinking linked to an earlier position. In Piaget's scheme such 'décelage', where a student reverts to thinking typical of an earlier stage, might be explained as a lack of familiarity with a novel context or topic area. Perry's scheme by contrast was linked to developing a personal value system, and retrogression might reflect broader considerations (e.g. times of personal stress or contexts related to existential issues that may seem to threaten existing beliefs).

Perry characterised his scheme in terms of nine steps, and he offered two overviews of the sequence: either viewed from the midpoint or in terms of three major divisions (pp. 64–65). This is represented in Fig. 15.1. Point 5 represents a perception of knowledge and values as relative, contingent and contextual—representing the outcome of a slow shift from an earlier position where it is considered all knowledge claims or value positions can be simply judged true or false. From this central position of a generalised relativism, the individual develops personal commitments that are no longer considered absolute, but which are a suitable basis for making meaningful evaluations.

In the first part of development (positions 1–3), the individual slowly modified an absolutistic right-wrong outlook to begin to admit a degree of pluralism. In the second part (positions 4–6), there is a deepening appreciation of the problematic nature of laissez-faire relativism. In the final part (positions 7–9), the individual draws upon their experience to develop their own personal system of commitments. The reader is referred to Perry's (1970a, 1970b) own account for details of the nine positions.

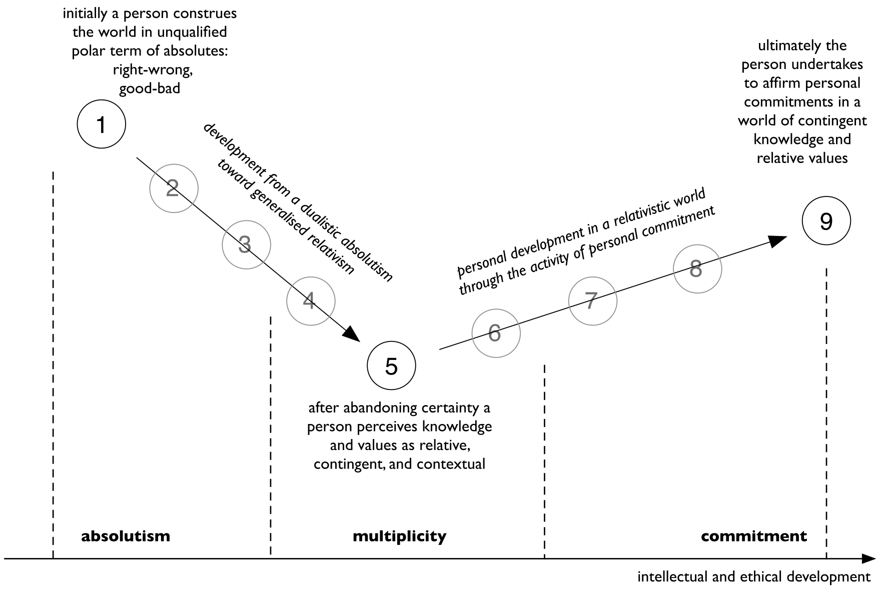

Fig. 15.1 A representation of Perry's developmental scheme (Adapted from Taber, 2013, Fig. 14.3, p. 265)

The Challenge of Becoming a Scholar

Perry found that even intelligent, highly motivated undergraduates struggled with the kinds of work they were set in some classes. These students expected their teachers to set out a particular perspective of a topic that needed to be understood, and which the student might later apply and be tested on. Yet, in many humanities classes, teachers did not offer this. When they were set alternative readings offering contrary viewpoints, these students assumed they were expected to identify with one of the approaches and they also expected their teachers to later confirm which was the superior position. Instead, they were often exposed to diverse perspectives, asked to appreciate them all, but not told which account they should believe or which standpoint they should adopt.

In simple terms, Perry found students were looking for a 'right' answer that could clearly be distinguished from the alternatives, and so often assumed their teachers were expecting them to work out which of the set readings they were meant to agree with. They were often then frustrated when their teachers refused to cooperate through indicating that a particular take on a topic was to be preferred. The teachers, however, recognised that there were multiple valid views supporting ongoing debates in many fields and saw their job as introducing perspectives and encouraging the students to think their way through to their own positions.

The realisation that they were not meant to find right answers could lead students to come to the view that there were not any right or wrong answers, because it was all a matter of personal opinion—so that anyone's take on a situation was as good as anyone else's. This still fell short of what was expected, which was that students could recognise the strengths and weaknesses of different positions; appreciate that judgements were informed by values and come to their own evaluations based on personal sets of values that could be articulated and so recruited to argue for a position. Over time, many students, but not all, would manage this.

For students studying a modular degree, these challenges to their developing thinking were not necessarily the same in all areas of the curriculum. History might offer alternative explanations of events; there might be different interpretations of texts in literature and different aesthetic judgments of the relative merits of different authors and their works; there might be different ideological political positions deriving from the perspectives of different interest groups: but in the natural sciences, these challenges were less extreme.

Science teaching tended to offer canonical understandings, and (at undergraduate level, at least) the basis for scientific knowledge was often presented in terms of clear-cut critical experiments. Science is not only written by the 'victors' (cf. history), but it is the 'victors' who come to be heavily cited, and then featured in the textbooks. Scientific reports deal with the context of justification and generally hide the messy aspects of the context of discovery (Medawar, 1963/1990): the cul-de-sacs, the human mistakes and the role of serendipity. Scientific accounts privilege the logical thinking underpinning the deductive nature of reaching conclusions in studies, rather than the creative thinking required to imagine those possibilities to be considered and tested (Taber, 2011).

The logical argument from evidence can be audited by the scientific community, whereas the creative insights that made a study possible are not open to any objective validation. That many scientific discoveries emerge from messy research programmes that only slowly lead to a consensus position is usually ignored in textbook accounts reduced to a rhetoric of conclusions (Niaz & Rodriguez, 2000). When science teaching follows this pattern, it may not seem to require students to have developed far along Perry's progression.

The Relevance of Perry's Scheme to Socio-Scientific Thinking

The science curriculum now often requires students to appreciate more of the nature of science and the complexities around actual scientific work. Moreover, increasingly school science encompasses socio-scientific issues (Zeidler, 2014), where science interacts with the wider society. There are many important matters of public policy, of global, international or just local concern, where scientific knowledge is needed to inform decision-making, but where, of itself, science is insufficient to reach a judgement. Often different groups in society take different views in debates about such matters: perhaps because they have different interests (perhaps the wider community will benefit from the new airport, power station or chemical refinery: but those living in the immediate vicinity may have good reason to oppose the development) or different ideological and value positions (there is no objective view on how to balance economic wealth against environmental protection) or different perceptions of risk (as when the best advice is that there is a possibility of a serious disaster, but with a very small chance of it occurring).

For students to engage in these areas of learning they have to not only understand the science but also appreciate and empathise with different standpoints and value positions, and then apply their own values to reach a recommendation. This requires schoolchildren to engage in just the kinds of thinking that Perry found many undergraduates at elite institutions were still developing. This potentially presents something of an enigma. In the 1980s, the school science curriculum was criticised because it expected students of around 14–16 years of age to master abstract scientific concepts when many were still in the process of fully acquiring the requisite formal operational thinking skills (Shayer & Adey, 1981). Yet in the twenty-first century, the school curriculum in many countries has been reformed to ask students to appreciate a more nuanced understanding of scientific enquiry that forms provisional knowledge from messy datasets, and to engage in debate over socio-scientific issues drawing upon diverse value-based standpoints, that is, activities requiring what has been characterised 'post-formal' thinking.

Perry's Model Informing Science Pedagogy

Perry's model can be seen as descriptive, rather than prescriptive. That is, Perry undertook detailed and careful enquiry at a particular time. His scheme describes what he found among undergraduate students who experienced a particular college curriculum, and more importantly had previously passed through a particular school curriculum. It might be argued that a school curriculum that largely presents canonical accounts to be understood, learnt and applied, does not give learners the necessary experiences to fully develop from expecting right and wrong answers, through a form of contextual relativism, towards a position of personal commitment based on a system of coherent values (i.e. the kind of value system Bloom and his colleagues saw as the highest level of their taxonomy of educational objectives in the affective domain).

If it is accepted that the forms of thinking developed depend upon the educative experiences provided in a culture (Luria, 1976), then the levels of intellectual development supported depend upon educational aims and their enactment in what learners are expected to do and achieve. After all, if IQ tests are considered to offer useful measures of human intelligence, then measured human intelligence increased substantially in many countries during the twentieth century (Flynn, 1987)—presumably reflecting greater levels and standards of education (as there was negligible physiological evolution over that period). Perry (1985) reported that "a study of examination questions given to freshman at Harvard at the turn of the [Twentieth] Century reveals them all to … ask for memorised facts and operations in a single assumed framework of Absolute Truth" (p. 5) and suggested that over a period of 25 years he had seen that the "position [on his scheme] of the modal entering freshman at Harvard has advanced from around Three to nearly Five" (p. 12).

The educational theorist Jerome Bruner (see Chap. 18) claimed that it was possible to teach any subject, in some intellectually honest manner, to a learner of any age (Bruner, 1960). This attitude suggests that it should be possible to teach school students richer accounts of the nature of science, and to engage them in debate over socio-scientific issues, as long as they are suitably supported by teachers structuring appropriately engaging and accessible learning activities (cf. Chap. 19). If the message to take from Perry's work is that higher levels of intellectual and ethical development do not occur automatically (that is, purely under biological control) but require suitable educational experiences (cf. Chap. 19), then appropriate pedagogy needs to be developed.

Kuhn on the Development of Critical Thinking

Deanna Kuhn is an educational psychologist who has taken great interest in the development of thinking skills, such as scientific reasoning. Her work explores a range of themes important to science teaching and indeed to education more widely. This includes aspects of informal reasoning and argumentation, and approaches to pedagogy. One particular theme in her work is critical thinking, and how this develops. She is also interested in metacognition, which she considers as strongly linked to critical thinking. The treatment here is necessarily limited to offering a flavour of some of her most important work.

Kuhn sees the origins of what might be called 'scientific thinking' in developing epistemological understanding—understandings relating to the nature and sources of knowledge (Kuhn & Pearsall, 2000). This links to the appearance of what is sometimes known as a theory of mind (Wellman, 2011). Usually by the age of 5 children recognise that statements people make about the world are actually statements about the claimants' beliefs about the world. So young children will come to appreciate that an actual state of affairs may not be the same as a person's construal of the state of affairs: people may have false beliefs. This is a starting point for developing the ability to coordinate theory and evidence, which Kuhn considers the essence of scientific thinking.

Metacognition is cognition about cognition—so could be considered to encompass judgement about others having false beliefs. However, usually the term refers to thinking about one's own cognition. Kuhn (1999, p. 18) argues that "thinking about one's thought—in contrast to simply engaging in it—opens up a whole new plane of cognitive operations that do not exist at a simple first-order level of cognition". Students may be said to show different levels of metacognitive awareness and can be encouraged to develop metacognitive skills. This links to themes such as being a reflective learner and developing what are sometimes called 'study skills'. An

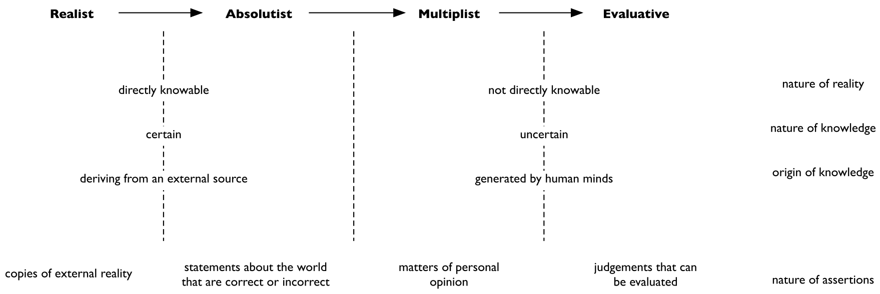

Fig. 15.2 Kuhn's model of levels of epistemological understanding

effective learner needs to have knowledge of their own current knowledge level (i.e. meta-knowledge), and whether it matches educational goals (that may either be set by the learner or provided by a teacher or other external agent); to appreciate which activities are likely to help them learn and to be able to monitor their own learning so that they can know when (and to what extent) they have been successful—and can judge when a learning activity is proving unproductive and some change in activity is indicated (a different approach, taking a break, seeking additional support). Metacognition is important to effective learning, in science as in other curriculum areas.

Kuhn (1999) proposed a four-stage model of levels of epistemological understanding (see Fig. 15.2). Young children consider reality to be directly knowable, so that assertions can be considered unmediated accounts of reality, but later they come to develop greater epistemological sophistication and appreciate that such direct access to the way things are is not possible. That is, they start to appreciate that knowledge is something generated within human minds, rather than taking the naïve view that reality imposes itself on mind. This can be considered as moving to a constructivist position (see the contributions in Sect. 4 of this volume), appreciating that knowledge takes the form of conjectures, ideas, theories and so forth—constructions put upon perceptions—rather than perfect impressions of an actual state of events. This reflects a contemporary understanding of the nature of science that sees science as a reliable—but not infallible—means of generating and evaluating theoretical knowledge.

Kuhn's model comprised of four stages labelled as realist, absolutist, multiplist and evaluative—a model that has strong parallels with Perry's scheme for intellectual and ethical development:

> The absolutist sees knowledge in largely objective terms, as located in the external world and knowable with certainty. The multiplist becomes aware of the subjective component of knowing, but to such an extent that it overpowers and obliterates any objective standard that would provide a basis for comparison or evaluation of opinions. Only the evaluativist is successful in integrating and coordinating the two, by acknowledging uncertainty without forsaking evaluation. (Kuhn, 1999, pp. 22–23).

In the realist stage, the child simply accepts that assertions made by others report the world as it is, but when they come to appreciate there can be false beliefs they shift to an absolutist position that some assertions are indeed statements reflecting reality, and others are not. This allows a role for critical thinking in making judgements about which assertions are true, and which are false. This absolutism is similar to the starting point of Perry's scheme (see Fig. 15.1)—Perry had not included children in his study and did not find any undergraduates holding a realist position.

However, the child later moves to a multiplist position where it comes to appreciate that absolute and certain knowledge of the world is not possible, as knowledge is generated within minds, which admits scope for subjectivity in all human knowledge. (Science may be seen as a system to minimise the subjective aspect of human knowledge.) Given that assertions cannot simply be considered true or false—as how things seem often depends upon one's viewpoint, or the perspective adopted—there is then considered to be no sense in seeking to apply critical thinking to evaluate various assertions. This position may be more productive in some contexts than others. We live in pluralist societies, where democracy requires respecting and valuing the views of those we disagree with. However, science depends upon critical evaluation of ideas and is not generally considered consistent with a multiplist position. While some philosophers of science have argued that some degree of pluralism within science is valuable when exploring complex phenomena (Mitchell, 2003), this would generally be considered an epistemological stance rather than an ontological commitment. That is, reality is seen as having a unitary nature, but when our models and conceptions are imperfect accounts of that nature, then working with several complementary partial accounts can sometimes be valuable. Pluralism is then adopted pragmatically (see Chap. 16), rather than on principle as a commitment to the nature of reality.

School science, and arguably especially chemistry, commonly presents students with pluralism in terms of the models and representations used in teaching. So electrons may be located in shells or in orbitals—or even outside those orbitals when they are understood as probability envelopes—or as being diffuse clouds; solids may be hard and incompressible because they are composed of particles in contact—but those same solids may be subject to thermal expansion and contraction due to the variable amount of space between the particles from which they are composed. It is assumed that students will have the sophistication to appreciate that this pluralism of models and representations sometimes reflects limitations of knowledge, and more often the challenges of expressing nature in ways we can easily comprehend and visualise, rather than being a realistic account of nature itself. Yet, this is something that needs to be taught and is unlikely to simply be intuited (Taber, 2010).

A young person who moves beyond multiplism comes to appreciate that even if there cannot be absolute certainty, it is still possible to critically evaluate ideas and make choices between alternatives. Good scientific practice includes being self-critical, always looking for alternative explanations, never prejudging results, identifying weaknesses in positions adopted, being open to revisit conclusions in the light of new evidence or conceptualisations, and so forth: but also, ultimately, in making judgements about the extent to which the best available interpretation of the evidence supports mooted hypotheses. This allows the positing of provisional knowledge that is seen as the best currently available way of making sense of some aspect of nature—and evaluating how robust and refined it seems to be.

If school-age students are working at different levels of epistemological understanding then this has consequences for how they make sense of the science they are taught. One interview study of 13–14-year olds suggested most of those participating had a naive view of the epistemic basis of scientific knowledge—often little more than someone having a hunch that could be tested and shown to either be true or false (i.e. an absolutist stance). So, theories were not considered substantially different in nature from hypotheses and were seen as uncertain simply because the necessary determination had not yet been made:

> there was limited evidence that these students saw scientific knowledge as existing on a continuum that allowed continuous variation (and change) in the extent to which ideas might be considered as reliable scientific knowledge as, over time, different evidence is collected, critiqued, checked, compared etc. Rather, these secondary students tended to think scientists carried out experiments that prove a theory to be correct…or obviously wrong…The general impression was that theories were largely seen as yet-to-be-supported products of imagination, and that testing them was largely straightforward. (Taber, Billingsley, Riga, & Newdick, 2015, p. 390).

However, whilst these students were best understood as at the 'absolutist' stage, often the same students would adopt a multiplist position when asked about what they were taught in religious studies lessons—where different positions were seen as a matter of personal opinion or choice, and it was considered as inappropriate to critique someone else's convictions about religious or ethical issues. This suggests that individual learners may appear to be at different positions on schemes such as those of Perry (see Fig. 15.1) and Kuhn (see Fig. 15.2) when asked about different domains of knowledge.

Conclusion

Models necessarily simplify reality, but the general pattern identified by Perry, and reinforced in the work of Kuhn and others, seems to be robust. Perry acknowledged that individuals can regress, and (as Piaget found in his work on cognitive development) setting tasks in different domains of experience may lead to individuals appearing to operate at different levels. It is important to acknowledge that Perry's work has been subject to critique, in particular, that females were underrepresented in his sample—an issue later explored in the programme to elicit women's ways of knowing (Finster, 1989)—although later work at Wellesley College (an elite U.S. institution educating women) supported Perry's general findings (Ashton-Jones & Thomas, 1990).

Regardless of such caveats, this chapter has discussed a general pattern in the development of thinking that has great significance for science education. That is, there is a form of intellectual maturation which allows individuals to move from assuming statements can unproblematically be shown to be right or wrong, to accepting that the evaluation of an assertion may differ according to perspective—but where all arguable positions are considered of similar merit—to appreciating that, although knowledge is a human construction with a subjective element, it is often still possible to identify criteria that allow one to evaluate alternatives and make a rational and justifiable (if potentially fallible) choice between them.

At one level, this assertion about the development of intellectual sophistication could be seen as a potential restriction on science education, highlighting aspects of the curriculum that students may struggle to engage with. Alternatively, such a scheme may be seen as the basis for organising educational experiences (e.g. Finster, 1991) to support—and perhaps even accelerate—progression. For example, from a sociocultural perspective (e.g. see Chap. 19), awareness of this pattern of progression may suggest an important dimension for diagnostic assessment, which can then inform the extent to which teachers need to offer mediation to support learners in appreciating and adopting, and so slowly internalising, more mature epistemological stances.

Further Reading

Perry, W. G. (1970). *Forms of intellectual and ethical development in the college years: A scheme*. New York: Holt, Rinehart & Winston.

Taber, K. S. (2017). Beliefs and science education. In K. S. Taber & B. Akpan (Eds.), *Science education: An international course companion* (pp. 53–67). Rotterdam: Sense Publishers.

References

Arlin, P. K. (1975). Cognitive development in adulthood: A fifth stage? *Developmental Psychology, 11*(5), 602–606.

Ashton-Jones, E., & Thomas, D. K. (1990). Composition, collaboration, and women's ways of knowing: A conversation with Mary Belen. *Journal of Advanced Composition, 10*(2), 275–292.

Bloom, B. S. (1968). The cognitive domain. In L. H. Clark (Ed.), *Strategies and tactics in secondary school teaching: A book of readings* (pp. 49–55). London: MacMillan.

Bruner, J. S. (1960). *The process of education*. New York: Vintage Books.

Finster, D. C. (1989). Developmental instruction: Part 1. Perry's model of intellectual development. *Journal of Chemical Education*, *66*(8), 659–661.

Finster, D. C. (1991). Developmental instruction: Part 2. Application of Perry's model to general chemistry. *Journal of Chemical Education*, *68*(9), 752–756.

Flynn, J. R. (1987). Massive IQ gains in 14 nations: What IQ tests really measure. *Psychological Bulletin, 101*(2), 171.

Kohlberg, L. (1973). Stages and aging in moral development—Some speculations. *The Gerontologist, 13*(4), 497–502. https://doi.org/10.1093/geront/13.4.497.

Kramer, D. A. (1983). Post-formal operations? A need for further conceptualization. *Human Development, 26,* 91–105.

Krathwohl, D. R., Bloom, B. S., & Masia, B. B. (1968). The affective domain. In L. H. Clark (Ed.), *Strategies and tactics in secondary school teaching: A book of readings* (pp. 41–49). New York: The Macmillan Company.

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*(2), 16–46.

Kuhn, D., & Pearsall, S. (2000). Developmental origins of scientific thinking. *Journal of Cognition and Development, 1*(1), 113–129. https://doi.org/10.1207/S15327647JCD0101N_11.

Luria, A. R. (1976). *Cognitive development: Its cultural and social foundations*. Cambridge, MA: Harvard University Press.

Medawar, P. B. (1963/1990). Is the scientific paper a fraud? In P. B. Medawar (Ed.), *The threat and the glory* (pp. 228–233). New York: Harper Collins, 1990 (Reprinted from: The Listener, Volume 70: 12th September, 1963).

Mitchell, S. D. (2003). *Biological complexity and integrative pluralism*. Cambridge: Cambridge University Press.

Niaz, M., & Rodriguez, M. A. (2000). Teaching chemistry as a rhetoric of conclusions or heuristic principles—A history and philosophy of science perspective. *Chemistry Education: Research and Practice in Europe, 1*(3), 315–322.

Perry, W. G. (1970). *Forms of intellectual and ethical development in the college years: A scheme*. New York: Holt, Rinehart & Winston.

Perry, W. G. (1985). Different worlds in the same classroom: Students' evolution in their vision of knowledge and their expectations of teachers. *On Teaching and Learning, 1*(1), 1–17.

Piaget, J. (1970/1972). *The principles of genetic epistemology* (W. Mays, Trans.). London: Routledge & Kegan Paul.

Riga, F., Winterbottom, M., Harris, E., & Newby, L. (2017). Inquiry-based science education. In K. S. Taber & B. Akpan (Eds.), *Science education: An international course companion* (pp. 247–261). Springer.

Shayer, M., & Adey, P. (1981). *Towards a science of science teaching: Cognitive development and curriculum demand*. Oxford: Heinemann Educational Books.

Taber, K. S. (2010). Straw men and false dichotomies: Overcoming philosophical confusion in chemical education. *Journal of Chemical Education, 87*(5), 552–558.

Taber, K. S. (2011). The natures of scientific thinking: Creativity as the handmaiden to logic in the development of public and personal knowledge. In M. S. Khine (Ed.), *Advances in the nature of science research—Concepts and methodologies* (pp. 51–74). Dordrecht: Springer.

Taber, K. S. (2013). *Modelling learners and learning in science education: Developing representations of concepts, conceptual structure and conceptual change to inform teaching and research*. Dordrecht: Springer.

Taber, K. S. (2015). Affect and meeting the needs of the gifted chemistry learner: Providing intellectual challenge to engage students in enjoyable learning. In M. Kahveci & M. Orgill (Eds.), *Affective dimensions in chemistry education* (pp. 133–158). Berlin Heidelberg: Springer.

Taber, K. S. (2017). Reflecting the nature of science in science education. In K. S. Taber & B. Akpan (Eds.), *Science education: An international course companion* (pp. 23–37). Rotterdam: Sense Publishers.

Taber, K. S., Billingsley, B., Riga, F., & Newdick, H. (2015). English secondary students' thinking about the status of scientific theories: Consistent, comprehensive, coherent and extensively evidenced explanations of aspects of the natural world—or just 'an idea someone has'. *The Curriculum Journal, 26*(3), 370–403. https://doi.org/10.1080/09585176.2015.1043926.

Wellman, H. M. (2011). Developing a theory of mind. In U. Goswami (Ed.), *The Wiley-Blackwell handbook of childhood cognitive development* (2nd ed., pp. 258–284). Chichester, West Sussex: Wiley-Blackwell.

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research, and practice. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 697–726). New York: Routledge.

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