Chapter 9
Vygotsky and Science in Higher Education

9.1 Introduction

The teaching of science at third level in universities and colleges is very different from that of school, particularly regarding the practice of lecturing to large groups of students, routinely carried out in teaching first- and second-year science students. Traditional science education at third level is considered to be less appealing to science students, and accounts partially for increasing attrition rates, particularly in the physical sciences.

The aspirations of Project 2061, launched as long ago as 1986, by the American Association for the Advancement of Science (AAAS), aimed to improve general levels of scientific literacy by the year 2061. Its founder, F. James Rutherford, stated that:

> *The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics, and technology and to acquire scientific habits of mind; without a scientifically literate population, the outlook for a better world is not promising.* (Rutherford & Ahlgren, 1991, pp. v–vii)

Thirty years on, it is the undergraduate science students, not only the public, who have yet to acquire scientific habits of mind as part of their formal undergraduate education. Acquiring scientific habits of mind includes investigating phenomena in lab classes and applying explanations to solving realistic problems. Some examples of the scientific habits of mind include:

- Curiosity.
- Scepticism.
- Openness to new ideas.
- Creativity.
- Intellectual honesty.
- Ethical responsibility.

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Such habits are encouraged when Vygotskian ideas of social constructivism are integral to students' experiences of practical learning science, such as:

- Designing, modelling, and executing experiments that test hypotheses.
- Constructing knowledge from the outcomes of their experiments.

A few years ago, I worked with physics and mathematics colleagues to explore a model of problem-based cooperative learning (PBCL) in which one cohort of students was tasked in groups to determine experimentally a value for the acceleration due to gravity, whilst a second cohort followed a more traditional lab-manual approach, usually as individual or paired learners (Bergin et al., 2018). The students who followed the PBCL approach appeared more engaged, and their perceptions of the scientific process emphasised creativity and criticality. Students who followed the lab-manual approach thought the experiment was "easy".

This chapter focuses on three elements of Vygotskian theory which help towards providing a framework for pedagogic innovation in higher education science learning and teaching. They are social constructivism, the ZPD and concept development. The main focus is on undergraduate student science learning, but most of the ideas and examples can also be applied in master's and doctoral science programmes.

A key global problem is the relatively high attrition rates among science undergraduates and postgraduates from universities. There are many reasons for this, including student lack of engagement with a wide range of undergraduate science courses, the perception that much of the content is too difficult, and low performance in science examinations. Science educators have considered problems with the way undergraduate science is taught in universities and colleges for more than 100 years, decrying too much emphasis on didactic teaching via lectures and heavily structured laboratory manuals. In 1894, the physicist Thomas Preston suggested:

> *It cannot be too soon or too often impressed upon the beginner that an acquaintance with a number of facts does not constitute a scientific education … Knowledge is not the mere memory of facts, but the comprehension of their whole meaning in the story of nature.* (Preston, 1894, p. 25)

Forty years later, John Dewey asked:

> *Why is it, in spite of the fact that teaching by pouring in, learning by passive absorption, are universally condemned, that they are still so entrenched in practice?* (Dewey, 1916, p. 46)

Of course, there are factors relating to attrition which are external to universities that cannot be addressed by changes to science pedagogy, but there are ways in which pedagogy can be enhanced to develop students' science *habits of mind*, such as critical thinking and reflection, imagination and creativity, curiosity, scepticism, team-working, and problem-solving. Several interventions and innovations have been introduced and shown to improve science habits of mind, such as interactive response systems; for example: 'clickers'(wireless devices used to conduct student participation activities in the classroom), e-learning, the use of specific apps, wikis etc., inquiry-based learning, cooperative problem-based learning, and other forms of active learning.

9.2 Social Constructivism

Social constructivism is a term used frequently in this book. Basically, it draws on constructivism, emphasising the *collaborative* nature of learning. Vygotsky rejected the assumption that it was possible to separate learning from its social context, as his CHT suggests. He argued that all cognitive functions originate in, and are products of, social interactions. According to Vygotsky, language and culture play essential roles both in human intellectual development and in how humans perceive the world. Human language enables us to impose culturally defined sense and meaning on the world. Language and culture are the frameworks through which humans experience, communicate, and understand reality. One of Vygotsky's famous quotes states:

> *A special feature of human perception … is the perception of real objects … I do not see the world simply in colour and shape but also as a world with sense and meaning. I do not merely see something round and black with two hands; I see a clock and I can distinguish one hand from the other*. (Vygotsky, 1978, p. 39)

In science and other subjects that require specific terminology (e.g., music, social science) and conceptual schemes that are transmitted by means of language, are essentially social phenomena. Thus, Vygotsky maintained that concepts are socially constructed. Knowledge is not simply constructed: it is co-constructed.

9.2.1 Implications for Undergraduate Science Teaching

One of the key researchers in changing undergraduate teaching and learning is Eric Mazur. Mazur is Balkinski Professor of Physics and applied physics at Harvard University. He is also a passionate advocate for improving undergraduate science teaching that involves social constructivist approaches, including the use of digital technology resources. His own teaching experience was based on sharing information, including sharing his lecture notes at the end of the class, which made him question the value of transmissive teaching.

Mazur began to question his own teaching approaches after observing his students' relatively poor improvement on the Force Concept Inventory (FCI) test, despite a semester's teaching. The FCI is designed to assess student understanding of the Newtonian concepts of force and is widely held as the 'gold standard' conceptual inventory in the physical sciences. As a consequence of the lack of improvement after traditional teaching, Mazur began to think of his teaching as more than the transfer of information. He created opportunities for students to digest that information and apply it within the realm of their own experience – and in contexts beyond their own, working collaboratively (Fagen et al., 2002).

A key idea was that the learning distance between most of the students and the expert (Mazur, in this case) was too great – outside their zones of proximal development (ZPDs). So, in lectures, he invited the class to discuss the problem with each other and within minutes found they had figured it out. Sharing the ideas with a few other students who had just learned about the concept to solve, a problem which might sound simple enabled them to pool their knowledge and come up with a solution.

Mazur utilised the interactive response technology of 'clickers' to generate a plot of their individual answers initially and after the collaborative discussions, noting the significant change that showed few correct solutions the first time and mostly correct the second time. The shift in learning was characterised by making the lesson more active (not passive), and allowing for the personalisation of learning, thus enabling students able to engage with each other in ways that an individual teacher never could. The focus of the exercise moves from knowing a fact to generating curiosity, thus motivating students to share knowledge as a more effective way to problem-solve.

Another key idea in Vygotsky's *oeuvre* is that of providing time for brain processing in concept development – the more social interaction in the process, the higher chance that students will be able to grasp the concept more fully. Mazur, in a keynote speech (summarised in a blog by Tessa Gray, 2017) referred to Vygotskian theories when discussing that education as a social experience, not an isolated one.

Mazur also used evidence for active versus passive learning from research carried out by Poh et al. (2010), in which subjects were fitted with wrist sensors that measured skin conductance as an index of the "arousal associated with emotion, cognition and attention" (p. 1243). Mazur presented a figure from the Picard group's paper showing wrist-sensor readings for a single MIT student over the course of week (see Fig. 9.1). The sensor recorded regular, strong spikes during periods of study, lab work and homework, but the readout flatlined during two activities: attending lectures and watching TV.

A PDF of the Poh, Swenson and Picard paper, "A Wearable Sensor for Unobtrusive, Long-Term Assessment of Electrodermal Activity," is available online.[1] This research clearly showed that for the student under study, attending science lectures showed almost no activity that related to emotional engagement, which, according to Vygotsky and others, is an absolute requirement for learning to occur.

Mazur's focus on social constructivism has led to his role in developing technologies which facilitate social learning. One such is Perusall,[2] a social learning platform developed by him and his colleagues, providing powerful asynchronous learning experiences for students out of class. Such software provides a rubric-based assessment approach, which can be used as a powerful way of engaging students and enabling them to take ownership of their learning. This social interaction provides the intrinsic motivation for learners to learn. Vygotsky maintained that true learning is that which is learning for the sake of learning, as opposed to learning

[1] https://affect.media.mit.edu/pdfs/10.Poh-etal-TBME-EDA-tests.pdf

[2] https://perusall.com/

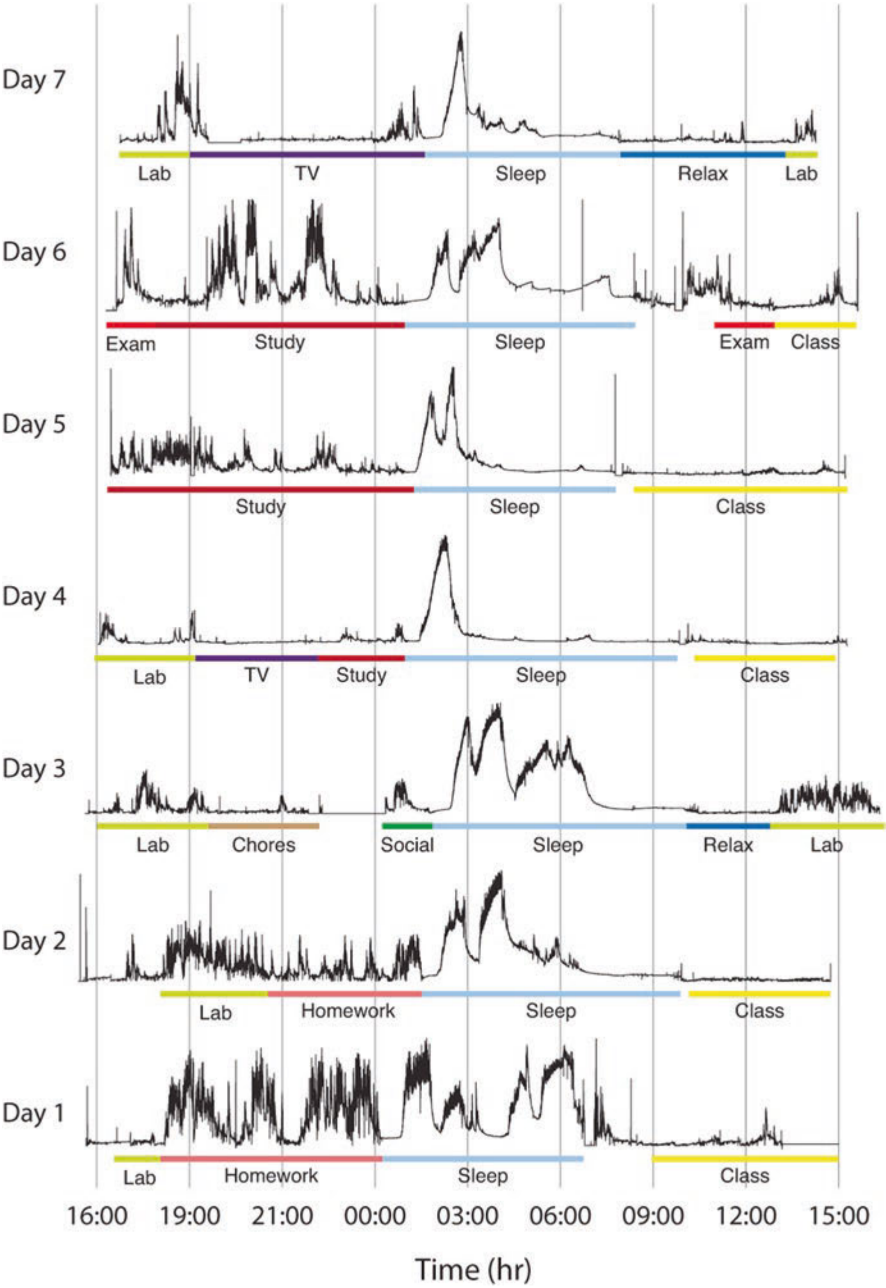

Fig. 9.1 Wrist-sensor readings for a single MIT student over the course of a week

for short-term gain, like studying for an examination. It is common for such learning to be transient and irretrievable not long after sitting an exam.

Collaborative learning methods require learners to develop teamwork skills. In group investigations, students may be split into groups that are then required to choose and research a topic from a limited area. They are held responsible for researching the topic and presenting their findings to the class. A good example of such learning is described later in this chapter (Bergin et al., 2018). Collaborative learning should be seen as a process of peer interaction that is mediated and structured by the teacher. Discussion can be promoted by the presentation of specific concepts, problems, or scenarios, and guided by means of effectively directed questions, introduction and clarification of concepts and information, and references to previously learned material.

9.3 Using the ZPD in Higher Education Science

Vygotsky (1997) argued:

> *That the school has been locked away and walled in as if by a tall fence from life itself has been its greatest failing. Education is just as meaningless outside the real world as is a fire without oxygen, or as is breathing in a vacuum.* (p. 345)

This quote could also relate to many undergraduate science courses that are still dissociated from real-world science and still lack the engagement factors which ‘hook’ students into a desire to extend their learning beyond the lecture. Fortunately, the pedagogy of teaching science courses in higher education is starting to move from the traditional *sage on the stage* towards a more *guide on the side* approach. The latter approach requires changing from a teaching paradigm towards a student-centred learning paradigm. Student-centred learning is more experienced-based. Examples abound, such as inquiry-based learning, flipped, problem-based, cooperative, digital, and project-based learning.

Vygotsky’s ZPD and his emphasis on social learning have been adopted widely as both theoretical frameworks and their applications in science teaching and learning in universities and colleges. The ZPD describes the process by which individuals learn from others. The ZPD represents the distance between a learner’s current developmental level and problem-solving ability, and their *potential* developmental level and problem-solving ability when assisted by others. Interactions between learners and others who are more skilled or knowledgeable in the task enable the learner to complete the task alone. Working within the ZPD is a two-way process and often leads to learning for all participants, particularly in their abilities to clarify and share meaning, which can lead to a deeper understanding of the topic or process. The combination of learning via discussions *with* practical activities are considered to contribute more towards cognitive development than by working alone.

9.3.1 Formation of the ZPD

Vygotsky suggested that an individual's actual level of development as determined by independent performance, such as an IQ test: "not only does not cover the whole picture of development, but very frequently encompasses only an insignificant part of it" (Vygotsky, 1998, p. 200).

He reported that responsiveness to mediation is required for understanding cognitive ability because it provides insight into the person's future development. Thus, what the individual can do one day with help, they can do tomorrow alone. Potential development varies independently of actual development, meaning that the latter cannot be used to predict the former. Vygotsky's work illustrated that test such as the IQ measure knowledge that is already known, but they give no indication of the learner's ability to build on or extend that knowledge.

Vygotsky considered performance on summative tests as an indication of the already known 'past' knowledge and argued that "instruction must be orientated towards the future, not the past" (Vygotsky, 1962, p. 104).

Applying this research to higher education science indicates that ways of assessing students need to be developed, such that low levels of recall (the bottom level of Bloom's taxonomy of knowledge) are not the key measure of attainment. There needs to be a move towards assessing higher and different forms of science knowledge and expertise at undergraduate level, particularly in the early years of study. And more use of continuous assessment which includes teamwork, giving presentations, developing position papers and other activities which allow for assessment of learners' potential, will help learners to navigate through the ZPD.

9.3.2 Key Elements of the ZPD for Developing Teaching

Learners' behaviour, as it affects learning, is the realisation that learning can be difficult, and that it does not always assume a smooth upward trajectory. Regression and recursion are key to deep learning. A most useful illustration of regression and recursion was developed by Tharp and Gallimore (1988), illustrated in Fig. 9.2.

An example of de-automatisation in science learning could be observed in relation to learning genetics. Students can be taught all the requisite terminology and the way to perform genetic crosses successfully, but after time and without repeated practice, the ability to perform such crosses needs to be developed anew. Further learning by an individual is made up of these same regulated ZPD sequences, from other- to self-assistance, recurring repeatedly for the development of current and new capacities.

There is a mix of other-regulation, self-regulation, and automatised processes for each learner at any one time. Therefore, even the expert can benefit from regulation for enhancement and maintenance of performance (e.g., teachers undergoing CPD). Gallimore and Tharp (1990, p. 187) further suggest that de-automatisation and

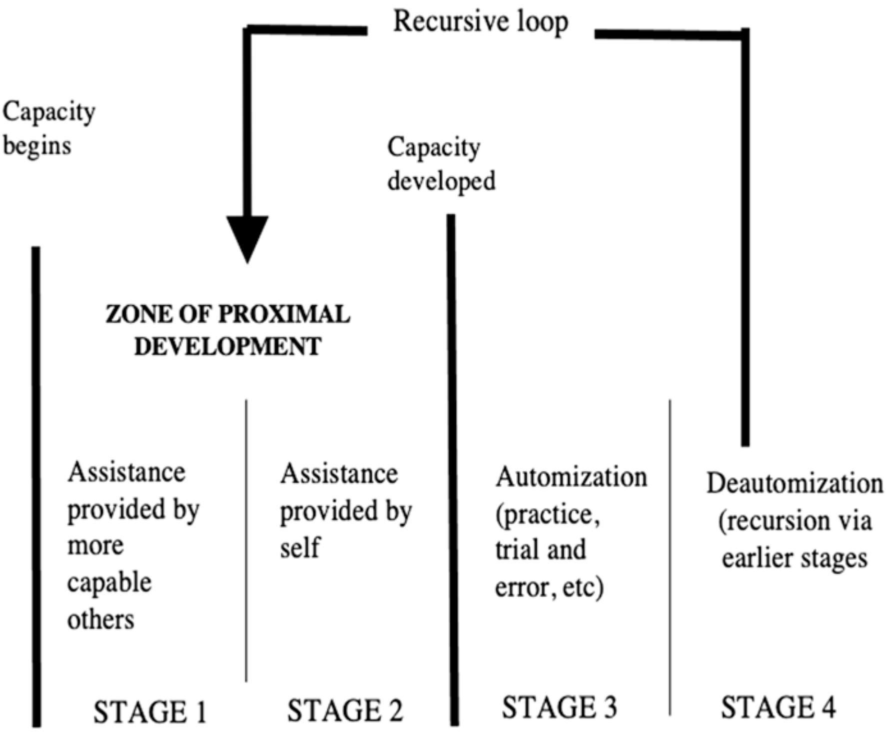

Fig. 9.2 My adaptation of the ZPD by Tharp and Gallimore (1991)

recursion occur regularly: "What one formerly could do, one can no longer do". It often happens that self-regulation is not sufficient to restore performance capacity after de-automatisation and thus other assistance is again required.

Some reasons for de-automatisation, suggested by Dunphy and Dunphy (2003) in the context of surgical training, could be "environmental change, stress, major upheaval and trauma" (p. 50). In the case of school learning, one major reason for de-automatisation could be he variety of different experiences the student has undergone between successive learning situations. De-automatisation as a concept is most helpful in designing ZPDs which allow for cycles of assisted and non-assisted task completion in the development of scientific concepts.

9.3.3 Practical Examples of Using the ZPD in Undergraduate Physics Teaching

A useful summary of the ZPD comes from Wass and Golding (2014, p. 671), which suggests that the basic idea is that "…we should pitch what we teach so that it is slightly too hard for students to do on their own, but simple enough for them to do with assistance". However, this idea could be contested on the grounds that it might assume a one-way relationship between 'learner' and 'teacher'. A social constructivist approach to science education research and practice positions learners and teachers *both* contributing to ZPD development and promotes for collaborative and active learning approaches.

The core idea is that students can operate at a higher and more independent level than they could on their own if they were provided with more capable peer or teacher assistance. The two key 'scaffolds' to facilitate development through the ZPD are *structuring the task* and *problematising* (Wass & Golding, 2014).

These ideas about the ZPD in science learning in higher education were useful in developing a pilot study to improve the learning experience of engineering students in their studies of a freshman year physics course (Bergin et al., 2018). They adopted a learner-centred instructional approach, PBCL, in which students, working as collaborators, took responsibility for their own learning as problem-solvers in their practical lab classes. Two cohorts of students (each comprising approximately 100 students) carried out an investigation on finding a value for acceleration due to gravity, one using the traditional lab-manual-led approach (control group), whilst the others (PBCL group) worked in small teams and were encouraged to create, construct and critique their own approaches.

The lab-manual-led cohort was asked to find a value for acceleration due to gravity using a pendulum, an equation, and an explicit step-by-step procedure given in the lab-manual. Students worked in pairs and, at the end of the three-hour laboratory session, reported on their findings in a pre-designed template. A student's work was assessed against their ability to follow procedure and arrive at a pre-determined solution.

For the PBCL approach, students worked in teams of three or four. They were posed with an experimental problem, and encouraged to construct and critique their own approaches, using any equipment or technology available to them in the lab or on-line. They were introduced to the lab (in groups of approximately 20 students) before starting, in small teams, to develop their strategies for solving the problem. A demonstrator was on hand for advice when required. After an hour, student teams presented their initial ideas, strategies, and findings to one another. They were encouraged to peer-review each other's strategies, suggest modifications to one another's strategies, and use ideas from the review session in their own team's experiments. Approaches employed to determine acceleration due to gravity varied greatly from those covered in standard university physics textbooks to more creative methodologies. PBCL students recorded their experimental findings in a 'free' format and were encouraged to record all of their ideas and thinking in attempting to find a value for acceleration due to gravity. Their reports were assessed in terms of their creativity, as well as the reliability and validity of findings. A similar completion rate of the submitted lab report was seen in both cohorts.

In terms of the ZPD, it was observed that members of the PBCL group were facilitated to develop their ideas in a much-expanded ZPD, which comprised peers for discussion, freedom to access information and potential strategies from a much broader source, including internet, videos, on-line communication, choice of materials where possible, excitement, teamwork, curiosity, thinking 'outside the box', freedom and challenge.

In Vygotskian terms, the difference in breadth of conceptualisation of the scientific process between the two groups could be explained by the narrow ZPD (development of skill manipulation) within which the traditional group of students were learning. The more expanded ZPD provided by the PBCL approach encouraging students to use and interrogate scientific principles in their design method and data interpretation using dialogue, discussion, experimentation with ideas, to fail, try again, persevere, trust, critique, create and discover, could be key to promoting bigger-picture thinking about science.

Analysis of the student perspectives indicated that responses from PBCL students indicated more engaged and broader thinking than those in the control group. Students who participated in a PBCL approach to labs reflected on enjoying the challenge of designing their own experiments and demonstrated a better understanding of the scientific process in devising and verifying their own experimental work via practices associated with constructing their knowledge of physics and scientific endeavour. Students' responses from the PBCL cohort contrasted with those of students in the control cohort, who showed an alternative understanding of the scientific process from their learning experiences in the lab (e.g., following procedure) and were not as positively engaged in their learning.

These findings are in line with advice from a recent report from the American Association of Physics Teachers (AAPT) on undergraduate laboratory curricula that emphasised 'sensemaking' strategies over excessively procedural approaches (Kozminski et al., 2014). Sense-making comes from the learner struggling, usually with others directly via collaboration, or more indirectly via books, computers, etc. – all of which have been written or programmed by others. Vygotsky referred to sense-making as the learner becoming the source of their own learning. Most traditional approaches, by which teachers structure the content and guide students through it, represent that in which *teachers are the source of learning*. Creating conditions which encourage students to ask questions, try out strategies, etc. as in PBCL is spontaneous learning, in which the *students are the source of their own learning*.

9.4 Concept Development in Higher Education Science

Davydov (1930–1998) was a prominent educationalist in the Vygotskian tradition, famous for his significant work on generalisation and the practice of inquiry-based teaching. This section introduces Vasily Davydov's (2008) conception of theoretical thinking in terms of concepts which illustrates the complexity of scientific concepts and their existence only in relation to other concepts:

> *…the basis of theoretical thinking, which operates not with conceptions but rather with proper concepts… a concept is the form of thinking activity that reproduces an idealized object together with its system of links. In their unity, these links reflect the universality or*

> *essence of the movement of the material object. The concept is simultaneously* ***both a form of reflection of the material object and the means for psychologically reproducing or constructing it****. That is, the concept is a special thinking action*. (pp. 90–91, emphasis added)

Concepts in science learning and teaching are often used as singularities, which exist on their own. Such practice leads students to develop a lower form of concept, described by Vygotsky as a "pseudo concept", which can be confused with true concepts because the learner might be using the right words to describe the concept, but lacking the logical connections between its parts. The learner can use the pseudoconcept in communication and activities, such as exams, as if it were a true concept. For example, the learner may use the definition of an electron transport chain in the context of photosynthesis metabolism but cannot relate it to other contexts.

The special *thinking action* of concepts, as noted by Davydov (2008), has its genesis in the development of scientific or abstract concepts in childhood as discussed by Vygotsky. Everyday and scientific concepts differ in terms of their history of development (Vygotsky, 1987). Everyday concepts are learned and developed through experiences. Scientific concepts are those that are taught and often experienced, at least initially, as abstractions. The richness of everyday concepts provides the basis for development of scientific concepts or abstracted forms of a concept. Current research highlights the rather common issue of holding potentially contradictory concepts; as one example, an everyday concept of 'fish' that contradicts the scientific concept of 'fish' (Karpov, 2003). A central concern for educators, then, is how to integrate everyday concepts and scientific concepts into a dialectically logical system (Howe, 1996).

In contrast to what is promoted in many learning contexts, Vygotsky (1987) argued that the process of concept formation is not just an act of generalisation on the part of the learner, but it considers both the everyday conception of a phenomenon and an abstracted reading of the same experience. Whilst everyday and scientific conceptions develop differently, they are always related to each other, and always united in a single, albeit at times contradictory, system of conceptual knowledge construction that is culturally formed communities or as part of professional and scientific knowledge construction. The emphasis here is not on the solitary learner, but on interacting, sharing, and negotiating meaning to integrate everyday concepts into a system of related concepts.

The complexity of integrating everyday and scientific concepts is a contributing factor in student engagement/disengagement in science subjects. Indeed, Howe (1996, p. 48) raised some important research questions based on a Vygotskian approach to science learning:

> *What problem solving strategies do children use in everyday life that have been ignored in school and can be used as a basis for science teaching? What are the differences between the everyday science concepts of children from different socioeconomic, ethnic and regional backgrounds and how does this affect what is learned?* (p. 48)

Scholars have long highlighted the potential incongruity between learning in and out of schools (Resnick, 1987; Sefton-Green, 2012), in addition to the differences in how everyday and scientific concepts develop, the role of teaching and learning in this development, and the often inauthentic and abstract ways in which the structure of undergraduate science courses prioritises curriculum delivery over deep and relevant study.

The vast literature on gender and science and mathematics related fields contributed initial momentum and a vision for science education that engages both females and males in preparation for science and mathematics careers as a method for overcoming the bias and male dominance in these fields. Democratisation of scientific institutions is an ideal, but many concerns remain (e.g., Bottia et al., 2015) and have been extended to the ways in which socioeconomic, ethnic, and language differences intersect to steer students away from science subjects.

The profound sociality of concepts, as well as teaching and learning, further emphasises the importance of authentic engagement in problems that matter to participants. As noted by Wells (2008), scientific concepts are not possessed by individuals; rather they are historical, social, and cultural resources that are used for a variety of purposes. Scientific concepts are ‘cultural tools’ developed by scientists, to help describe and explain the world around us. Mastering their use, Wells (2008) suggested, is best developed when students are engaged in scientific problem solving that requires these ‘tools’. The concepts that develop emerge when the relationships between teachers, students, and curricula are brought together to attend and inquire into academic questions that are relevant to those involved.

The issue of relevance to learners is central for this discussion because it highlights *how* educators engage students in inquiry. Like the scholars and scientists before them, students arrive at school from multiple locations with different experiences and cultural expectations, along with their own needs, interests, and motives (Hedegaard & Chaiklin, 2005). Human development occurs in relation to access to shared collective memories, or knowledge, that have been recorded and passed on through writing. This shared knowledge was more permanent and, thus, independent of those who produced it, becoming a written ‘objects’ for education in different cultures (Wells, 2008).

Knowledge was passed on via collaborative activity using cultural tools, such as pictures, diagrams and writing. As science developed, concepts were created, based on empirical observation and thorough scientific investigation, to help explain phenomena. Yet, and consistent with Vygotsky’s and Davidov’s emphasis on teaching the history of ideas, the focus on teaching the ‘complete’ concept in schools often erases the complexity of knowledge construction: the history of ideas, the disagreements, the misunderstandings, and the power inherent in which and whose knowledge is valued.

From the narrative of Galileo’s letter to the Grand Duchess Christina, to Thomas Kuhn’s notion of ‘popular science’, to the complicated history of the theory of continental drift, scholars have argued for learners to become connoisseurs of science, which includes increased attention to discussions of how, where and when various scientific concepts came about, especially the associated difficulties, political and technological barriers and enablers, as well as other human factors, to engender a deeper appreciation of the scientific endeavour.

In his theoretical consideration of concepts, Vygotsky used a model from classical mathematics to suggests that, ultimately, concepts are all subsumed into one dialectical system that he referred to as a system of equivalences:

> *The higher levels in the development of word meaning are governed by the law of equivalence of concepts, according to which* ***any concept can be formulated in terms of other concepts in a countless number of ways***. (Vygotsky, 1986, p. 199, emphasis in original)

His broad grid for concepts is based on the surface of a globe, onto which every concept can be placed using a system of coordinates, corresponding to latitude and longitude in geography. A concept's 'longitude' relates to its degree of abstraction, and thus characteristic of thought processes, whilst its 'latitude' represents its objective reference, for example: plant or animal (Vygotsky, 1986, pp. 199–200).

However, the geographic analogy is only useful at a surface level. Vygotsky himself emphasised the limitation of the geographic analogy as being neither complete nor accurate, although it has been used since, particularly in philosophical considerations of concepts, such as in the work of the 'ordinary language' philosopher, Gilbert Ryle. Vygotsky contended that in a *true scientific concept*, the bonds between the parts of an idea and between different ideas are dialectically related; thus, the ideas form part of a socially constructed and accepted system of hierarchical knowledge (Roth & Lee, 2007). What was also obvious to Vygotsky was the necessity of change over time – change in concepts and knowledges in relation to changing conditions – as well as both the recognition of developments in science leading to new knowledge and the ease with which this knowledge can become coopted by political and economic interests and motives. It was for these reasons that he argued that freedom is the ability to break from current conditions, to imagine beyond what exists to what could exist (Vygotsky et al., 1994).

In teaching, Vygotsky proposed that teachers create a ZPD between the scientific and everyday concepts by illustrating and emphasising the *relationships* between them and showing how the scientific concept can be utilised to explain the everyday concept, whilst simultaneously raising the everyday concept towards its scientific conceptualisation (see Chap. 3, Fig. 3.1). For instance, a child may have a rich understanding of the everyday concept *brother* but not be able to define it in the more logical, conceptual way as *male sibling* (Panofsky et al., 1990). The task of the teacher, for Vygotsky, is not to evaluate individual conceptions as correct or as 'misconceptions', but rather to help the child, through instruction with respect to the *relationship* between concepts within a system of concepts, and to develop conscious awareness and voluntary control of their own thinking (Wells, 2008).

Vygotsky (1987) argued that a "concept must be seen as part of the entire system of the relationships … just as a stitch must be seen as part of the fibres that tie it to the common fabric" (p. 193). This underpins theoretical knowledge and thinking (Davydov, 2008). The system is captured through the relations between everyday concepts and scientific concepts embedded in meaningful practices of a particular community that a child is oriented towards motive orientation (Hedegaard & Chaiklin, 2005). When communities foreground the learning of scientific concepts in support of a motive orientation leads to more democratic and equitable outcomes for diverse students.

Vygotsky's fascination with teaching and learning, integrating everyday and scientific concepts, and contributing to social change was key to his idea that society needs to provide tools to engage learners with different characteristics and abilities. While engaging diverse learners and enabling them to access knowledge was a significant intergenerational responsibility and achievement, the purpose of doing this was to support the development of cultural tools that could be taken up, used, and transformed in their application to current and future concerns. It was expected that human action would transform the tools with which they think, create, and transform their worlds. Science continually puts to the test ways of thinking and acting and, throughout this process, opportunities arise to ensure that the direction of change in science and science education is towards becoming more equitable and inclusive. Vygotsky's equity orientation drives this process.

9.5 Summary and Conclusion

This chapter has considered a variety of sources of evidence for the recent increase in popularity of Vygotsky's research on the ZPD and concept development, together with the overall adoption of more social constructivist approached to teaching and learning in higher education.

The challenges of science teaching in large lecture theatres, despite the support of digital learning resources which are designed to promote more collaboration, are being addressed by scholars who are disappointed in student exam performance. It has also discussed the increasing rates of student attrition. Eric Mazur's work has been highlighted, since it stems from his own experiences in the areas just mentioned. His work has contributed to the recent development of teaching in many universities to promote twenty-first-century learning. The key Vygotskian concepts used in this regard are social constructivism, the ZPD and concept development. Change is slow, but it has started. Examples of successful integration of Vygotskian constructs in higher education described in this chapter should provide some inspiration and practical guidance for science educators in third-level institutions.

The next chapter features a Vygotskian perspective of science teacher education, both in pre-service science teacher education, and CPD for in-service teachers. In addition, those who work with students in informal science contexts may also be interested in considering Vygotskian approaches to science teacher development in the next chapter.

References

Bergin, S. D., Murphy, C., & Shuilleabhain, A. N. (2018). Exploring problem-based cooperative learning in undergraduate physics labs: Student perspectives. *European Journal of Physics, 39*(2), 025703.

Bottia, M. C., Stearns, E., Mickelson, R. A., Moller, S., & Valentino, L. (2015). Growing the roots of STEM majors: Female math and science high school faculty and the participation of students in STEM. *Economics of Education Review, 45*, 14–27.

Davydov, V. V. (2008). *Problems of developmental instruction. A theoretical and experimental psychological study*. Nova Science Publishers, Inc.

Dewey, J. (1916). *Democracy and education*. Macmillan.

Dunphy, B. C., & Dunphy, S. L. (2003). Assisted performance and the zone of proximal development. *Journal of Educational and Developmental Psychology, 3*, 48–58.

Fagen, A. P., Crouch, C. H., & Mazur, E. (2002). Peer instruction: Results from a range of classrooms. *The physics Teacher, 40*(4), 206–209.

Gallimore, R., & Tharp, R. (1990). *Teaching mind in society: Teaching, schooling, and literate discourse*. Vygotsky and education. Instructional implications and applications of sociohistorical psychology. In L. Moll (Ed.), *Vygotsky and education* (pp.175–205). Cambridge University Press.

Gray, T. (2017). *Eric Mazur Keynote: Innovating education to educate innovators*. Retrieved from https://www.youtube.com/watch?v=DoibiRIDZdw

Hedegaard, M., & Chaiklin, S. (2005). *Radical-local teaching and learning. A cultural-historical approach*. Aarhus University Press.

Howe, A. (1996). Development on science concepts with a Vygotskian framework. *Science Education, 80*(1), 35–51.

Karpov, Y. V. (2003). Vygotsky's doctrine of scientific concepts: Its role for contemporary education. In A. Kozulin, B. Gindis, V. S. Ageyev, & S. M. Miller (Eds.), *Vygotsky's educational theory in cultural context* (pp. 65–82). Cambridge University Press.

Kozminski, J., Beverly, N., & Lewandowski, H. (2014). *Recommendations for the undergraduate physics laboratory curriculum*. American Association of Physics Teachers (AAPT).

Panofsky, C., John-Steiner, V., & Blackwell, P. (1990). The development of scientific concepts and discourse. In L. C. Moll (Ed.), *Vygotsky and education: Instructional applications of sociohistorical psychology* (pp. 251–268). Cambridge University Press.

Poh, M. Z., Swenson, N. C., & Picard, R. W. (2010). A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. *IEEE Transactions on Biomedical Engineering, 57*(5), 1243–1252.

Preston, T. (1894). *The theory of heat* (4th ed.). Macmillan.

Resnick, L. B. (1987). The 1987 presidential address: Learning in school and out. *Educational Researcher, 16*(9), 13–20+54.

Roth, W.-M., & Lee, Y.-J. (2007). "Vygotsky's neglected legacy": Cultural-historical activity theory. *Review of Educational Research, 77*(2), 186–232.

Rutherford, F. J., & Ahlgren, A. (1991). *Science for all Americans*. Oxford University Press.

Sefton-Green, J. (2012). *Learning at not-school: A review of study, theory, and advocacy for education in non-formal settings*. MIT Press.

Tharp, R. G., & Gallimore, R. (1988). *Rousing minds to life: Teaching, learning, and schooling in social context*. Cambridge University Press.

Tharp, R. G., & Gallimore, R. (1991). *Rousing minds to life: Teaching, learning, and schooling in social context*. Cambridge University Press.

Vygotsky, L. S. (1962). *Thought and language*. MIT.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John- Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press.
Vygotsky, L. S. (1986). *Thought and language*. MIT Press.
Vygotsky, L. S. (1987). Problems of general psychology. In *The collected works of L.S. Vygotsky, vol. 1*. (pp. 243–285) (R. W. Rieber & A. S. Carton, Eds.; N. Minick, Trans.). Plenum Press.
Vygotsky, L. S. (1997). *The collected works of L. S. Vygotsky, vol. 4. The history of the development of higher mental functions* (R. W. Reiber, Ed.; M. J. Hall, Trans.). Plenum.
Vygotsky, L. S. (1998). The crisis at age seven. In *The collected works of L. S. Vygotsky, vol. 5* (pp. 289–296) (R. W. Reiber, Ed.; M. J. Hall, Trans.). Plenum.
Vygotsky, L. S., van der Veer, R. E., Valsiner, J. E., & Prout, T. T. (1994). *The Vygotsky reader*. Basil Blackwell.
Wass, R., & Golding, C. (2014). Sharpening a tool for teaching: The zone pf proximal development. *Teaching in Higher Education, 19*(6), 671–684.
Wells, G. (2008). Learning to use science concepts. *Cultural Studies of Science Education, 3*(2), 329–350.