FaSMEd Position Paper

Developing Conceptual understanding through Cognitive Conflict and Discussion in Mathematics and Science Education

Malcolm Swan, Geoff Wake and Marie Joubert

Centre for Research in Mathematics Education

University of Nottingham

Definition

Cognitive conflict is a term used to describe the psychological tension or perturbation that is created when an individual's expectations about a phenomenon do not accord with his or her observations or pre-conceived ideas. Individuals may seek to account for and reduce this tension by reviewing and reformulating their beliefs or by reinterpreting their observations. This may in turn lead to a reorganisation of the conceptual framework.

In lesson design, cognitive conflict may be engineered by the careful juxtaposition of experiences. Coherent sequences that are designed to promote conceptual reorganisation typically have a three-part sequence: an exposing event in which students are encouraged to describe their pre-existing conceptions and expectations; a discrepant event in which an anomaly serves to generate cognitive conflict; and a resolution event in which students modify their conceptual understanding, through internal individual reflection or through discussion and debate with others.

This process may form part of a formative assessment process in which teachers deliberately seek to uncover pre-existing conceptual understandings and then respond adaptively toward them.

The origin and concept of cognitive conflict

> "Just as a scientific theory remains unchallenged until conceptual or empirical anomalies become apparent, students operating at the frontiers of their conceptual knowledge have no reason to build new conceptual structures unless their current knowledge results in obstacles, contradictions or surprises." (Cobb 1988)

The notion of cognitive conflict was formulated by Piaget (1896-1980), a developmental psychologist. Piaget's ideas have their roots in an evolutionary biological metaphor, according to which the organism adapts to its environment in order to survive. For Piaget, the learner constructs personal theories and adapts these through the twin processes of 'assimilation' and 'accommodation' in order to reconcile observation with experience. 'Assimilation' refers to the absorption of new ideas while 'accommodation' refers to the modifications that the learner subsequently makes in order to 'fit' new ideas into his or her pre-existing conceptual framework (von Glasersfeld 1995).

The theory suggests that these processes work as follows. Students mentally compare new situations with prior experiences. They construct expectations of what may happen when they act in these new situations. They comfortably assimilate observations when these are consistent with expectations, but where there are inconsistencies and contradictions, there is a perturbation, or 'cognitive conflict'(Piaget 1975a). This may produce an emotional response of disappointment, surprise, or anxiety. The need to reduce such 'dis-equilibration' is a basic, powerful human motivator that may lead the student to revisit and review characteristics of the situation to analyse the cause of the inconsistencies. The initial situation is thus observed in a new way and there is a change in the ‘recognition pattern’ (von Glasersfeld 1995). This in itself is an act of learning and ‘accommodating’ results. Piaget’s term ‘equilibration’ is a generic term for the elimination of perturbations. Cognitive development is characterised by ‘expanding equilibration’, a term by which Piaget means an increase in the range of perturbations that the learner is able to eliminate.

There is a considerable amount of literature supporting the value of cognitive conflict in promoting learning, while others are more cautious, pointing out that the state of ‘dis-equilibration’ is insufficient on its own (Posner, Strike et al. 1982; Schoenfeld 1983; Bell, Swan et al. 1985; Bell 1993; Bell 1993; Adey and Shayer 1994; Duit and Treagust 2003; Burkhardt and Bell 2007). Students may be brought to awareness that their own conceptual structure is inadequate to explain a phenomenon, but that they may also need help from their teacher or their peers to resolve this state of affairs.

The role of discussion in learning

> “The only way to avoid the formation of entrenched misconceptions is through discussion and interaction. A trouble shared, in mathematical discourse, may become a problem solved.” (Wood 1988)

Piaget viewed the child as the active constructor of his or her own understanding. For Piaget, the most effective form of social interaction is cooperation between equals in which each tries to understand and modify the other’s point of view. He felt that if pupils were unequal partners, then one might resign their position too readily and accept an opposing view without verification. Piaget thus believed that learning through cognitive conflict comes about through the logical evaluation of differences of perspective or opinion. This may be inter-personal or intra-personal, but contradictions coming from two opposing points of view may be more easily perceived than inconsistencies perceived by an individual. Students working collaboratively are committed to overcoming conflict:

> “When attempting to solve a contradiction, they may manage to coordinate the two points of view into a third one overcoming both initial points of view and corresponding to a higher level of knowledge.”(Laborde 1994).

It is not always realised that both Piaget (1977) and Vygotsky (1987) stressed the role of social interaction in cognitive development. Vygotsky is the one that is best remembered for this, claiming that ideas appear first in the social plane and then later become internalised by individuals. Piaget acknowledged that it may be possible for a teacher to develop a relationship with pupils which allows for the free examination and discussion of ideas, but pointed out that this would involve the teacher in taking the role of an equal - unlikely in an authoritative, constraining classroom atmosphere. Some ways in which teachers might do this are suggested by Wood (1988) who showed that pupils can become more active in verbal participation when teachers replace controlling commands and closed questions with open questions and when they allow increased time for responses. The gap in status is also reduced when teachers reveal their own uncertainties.

Mercer (1995; 2000) has described in some depth the types of interaction that promote effective and ineffective learning. In particular he demonstrates the superiority of *exploratory* talk over *disputational* and *cumulative* talk. Exploratory talk consists of critical and constructive exchanges, where challenges are justified and alternative ideas are offered. Disputational talk consists of disagreement, argumentation and individualized decision making. This is characterised by short exchanges consisting of assertions and counter-assertions. (This is sometimes confused with ‘cognitive conflict’, but it should be emphasised here that ‘cognitive conflict’ does not mean argumentation of this type). In cumulative talk speakers build positively, but uncritically, on what each other has said. This is typically characterised by repetitions, confirmations and elaborations. In short, the most helpful talk appears to be that where the participants work on and elaborate each other's reasoning in a collaborative, rather than competitive, atmosphere. Exploratory talk enables reasoning to become audible and knowledge becomes publicly accountable (Alexander (2006; Alexander 2008)

Examples of lesson design based on cognitive conflict and discussion.

During the 1980s Bell, Swan and others (Bell, Swan et al. 1985; Swan 2006) designed sequences of classroom studies that showed that a "diagnostic teaching" pedagogy for mathematics (that incorporated cognitive conflict) was more effective for long term learning than expository or guided discovery methods. The pedagogical sequence is described in table 1 below. It was found that explicitly addressing misconceptions during teaching improved achievement and long-term retention. Avoiding conflict by giving explanations before problems was found to be less effective than beginning with problems that exposed existing ways of thinking, then holding small group and whole class discussions to resolve the emerging difficulties and misconceptions. In addition, the intensity of student engagement in small group discussions was found to be more important than the amount of time overall spent on the task. Thus, the resolution of cognitive conflict through discussion was central to this approach.

Table 1: The 'diagnostic teaching' methodology.

• **Before teaching, explore pre-existing conceptual frameworks through assessment.**

• **Make existing concepts and methods explicit in the classroom.** An initial activity is designed with the purpose of making students aware of their own intuitive interpretations and methods. At the beginning of a lesson, for example, students are asked to attempt a task individually, with no help from the teacher. No attempt is made, at this stage, to 'teach' anything new or even make students aware that errors have been made. The purpose here is expose pre-existing ways of thinking.

• **Provoke and share 'cognitive conflicts'.** Feedback to the students is given in one of three ways:

- by asking students to compare their responses with those made by other students;
- by asking students to repeat the task using alternative methods;
- by using tasks which contain some form of inbuilt check.

This feedback produces 'cognitive conflict' when students begin to realise and confront the inconsistencies in their own interpretations and methods. Time is spent reflecting on and discussing the nature of this conflict. Students are asked to write down the inconsistencies and possible causes of error. This typically involves both small group and whole class discussion.

• **Resolve conflict through discussion and formulate new concepts and methods.** A whole class discussion is held in order to assist in 'resolving' a conflict. Students are encouraged to articulate conflicting points of view and reformulate their own ideas. At this point, the teacher suggests, with reasons, a 'mathematicians' viewpoint.

• **Consolidate learning by using the new concepts and methods on further problems.** New learning is utilised and consolidated by

- offering further problems for discussion;
- inviting students to create and solve their own problems within given constraints;
- asking students to analyse the work of others and to diagnose causes of errors for themselves.

In a similar way, Adey and Shayer (1994) developed programmes called 'cognitive acceleration through science education' (CASE) and 'cognitive acceleration through mathematics education' (CAME). CASE and CAME were designed to replace regular science and mathematics lessons (every two weeks for two years) by lessons that focused on ten of Piaget's formal operations (such as the notion of controlling variables systematically). The suggestion is that addressing higher order thinking skills improves students' "general intellectual ability across the board". Three central principles were involved: *cognitive conflict*; *social construction* (emphasising the discussion of scientific ideas in small groups) and *metacognition* (or reflective abstraction). (There are clearly close parallels between 'diagnostic teaching' and 'cognitive acceleration' approaches. Both place a similar emphasis on the importance of cognitive conflict and discussion. Metacognitive aspects (that is students reflecting on their own understanding) was articulated fully in the follow-up to the diagnostic teaching studies (Bell, Swan et al. 1993b).)

In CASE and CAME, each unit was structured in four phases:

- **concrete preparation;** concrete activities were used to introduce the terminology and the context in which a problem is presented, linking this to prior knowledge;
- **cognitive conflict;** problems were presented at a level of challenge set just above the current level of secure knowledge. In a science lesson this would take the form of a demonstration with an unexpected effect;
- **metacognition;** students were encouraged to explain what they were thinking, what they found difficult, what they had learned, what mistakes they had made and how they corrected them;
- **bridging;** explicit activities were introduced to help transfer the thinking strategies to novel situations.

The results of this approach have been reported as very effective for learning scientific concepts. For example, when properly implemented, a CASE intervention led to, in comparison with matched control groups: "(a), at the end of the two year intervention, greater gains in cognitive development; (b), one year later, greater achievement in science tests; and (c), two years later again, significantly higher grades in nationally set and marked measures of achievement – not only in Science, but also in Mathematics and English." (Schoenfeld 1987; Shayer and Adey 1993; Adey and Shayer 1994).

References

Adey, P. S. and M. Shayer (1994). Really raising standards. London, Routledge.

Alexander, R. (2006). Towards Dialogic Teaching: Rethinking Classroom Talk. Thirsk, Dialogos.

Alexander, R. (2008). How can we be sure that the classroom encourages talk for learning? Here is what research shows. Cambridge, Dialogos.

Bell, A. (1993). "Principles for the Design of Teaching." Educational Studies in Mathematics **24**(1): 5-34.

Bell, A. (1993). "Some experiments in diagnostic teaching." Educational Studies in Mathematics **24**(1).

Bell, A., M. Swan, et al. (1993b). Awareness of Learning, Reflection and Transfer in School Mathematics; Report of ESRC Project R000-23-2329, Shell Centre for Mathematical Education, University of Nottingham.

Bell, A., M. Swan, et al. (1985). Diagnostic Teaching for Long Term Learning. Report of ESRC Project HR8491/1, Shell Centre for Mathematical Education, University of Nottingham.

Burkhardt, H. and A. Bell (2007). "Problem Solving in the United Kingdom." ZDM Mathematics Education **39**: 395-403.

Cobb, P. (1988). "The tension between theories of learning and instruction in Mathematics Education." Educational Psychologist **23**(2): 87-103.

Duit, R. and D. F. Treagust (2003). "Conceptual change: A powerful framework for improving science teaching and learning. ." International Journal of Science Education **25**(6): 671-688.

Laborde, C. (1994). Working in Small Groups: A Learning Situation? Didactics of Mathematics as a Scientific Discipline. R. Beiler. Dordrecht, Kluwer**:** 147-157.

Mercer, N. (1995). The guided construction of knowledge. Clevedon, Philadelphia, Adelaide.

Mercer, N. (2000). Words and Minds. London, Routledge.

Piaget, J. (1975a). The equilibration of cognitive structures: the central problem of intellectual development. Chicago, University of Chicago Press.

Piaget, J. (1977). Logique genetique et sociologie. Geneva, Librairie Droz.

Posner, G. J., K. A. Strike, et al. (1982). "Accommodation of a scientific conception: Toward a theory of conceptual change." Science Education **66**: 211-227.

Schoenfeld, A. (1983). Episodes and executive decisions in mathematical problem-solving Acquisition of mathematics concepts and processes. R. Lesh and M. Landau. New York, Academic Press**:** 345-395.

Schoenfeld, A. (1987). What's all the fuss about metacognition? . Cognitive Science and Mathematics Education. A. Schoenfeld. Hillsdale, NJ, Laurence Erlbaum**:** 189-215.

Shayer, M. and P. Adey (1993). "Accelerating the development of formal operational thinking in high school pupils, IV: Three years on after a two-year intervention. ." Journal of Research in Science Teaching **30**(4): 351-366.

Swan, M. (2006). Collaborative Learning in Mathematics: A Challenge to our Beliefs and Practices. London, National Institute for Advanced and Continuing Education (NIACE) for the National Research and Development Centre for Adult Literacy and Numeracy (NRDC).

von Glasersfeld, E. (1995). Radical constructivism: A way of knowing and learning. London, The Falmer Press.

Vygotsky, L. S. (1987). Thinking and Speech. The Collected Works of L.S. Vygotsky. R.W.Rieber and A. S. Carton. New York, Plenum Press.

Wood, D. (1988). How Children Think and Learn. Oxford and Cambridge, MA, Blackwell.