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# Collaborating with the ‘more capable’ self: Achieving conceptual change in early science education through underlying knowledge structures

## Abstract

It is well-documented that children do not begin school as blank slates but that they bring with them extensive knowledge about how the world around them works. This conceptual knowledge, embedded within rich theoretical structures, is not always accurate and requires change through learning and instruction. Yet some ideas – such as object motion – appear to be particularly resistant to such change. So how can conceptual change be achieved or facilitated? Collaboration, for one, has long been recognised as a beneficial learning and teaching approach, including early science education. However, for deep-rooted ideas collaborating with others may not always have the desired impact. Instead, the notion of self-collaboration is considered in this review. The current state of research in the field of predictive and underlying knowledge in childhood is outlined and different models of how the knowledge systems relate to each other are discussed. While further work is still needed to establish a clearer picture of how self-collaboration might effect conceptual change, research to-date clearly identifies significant differences between predictive and underlying knowledge structures throughout childhood, how these structures can be related to traditional conceptual change theories, and how they may play a role in future learning and instructional approaches.

**Key words**: Early science education; object motion; conceptual change; underlying knowledge; self-collaboration

## Conceptions in the early science classroom

It is widely acknowledged that children are not blank slates when they begin school. On the contrary; they hold a wide range of well-developed theoretical conceptual structures, and many ideas – particularly in science – are based on their extensive experiences of and interactions with the everyday physical world around them (Klaassen, 2005). However, many of these ideas are erroneous or incomplete. Such inconsistencies have been widely noted, with currently over 8,000 studies having been collated to illustrate this point (see Duit, 2009, for a comprehensive list). One particular aspect of science is that of object motion – understanding how objects move under consideration of different variables such as gravitational force or friction. The importance of this area is due to the rather extensive opportunities for everyday world experiences, practically from birth (Planinic, Boone, Krsnik, & Beilfuss, 2006). As far as children’s predictions are concerned, we now know a good deal about what their theories are and how they relate to scientifically acceptable ideas, with children displaying notions largely incommensurate with accepted scientific views (see Howe, 1998, for a review).

Having such ideas in childhood may not seem critical, since they are perceived to be sufficient to navigate within the everyday world (Reif, 2008). Furthermore, the purpose of education should be to facilitate change in conceptions – to encourage the modification of personal knowledge or theories – and to instil correct views, so there should be opportunities for such change when necessary. Yet we also know that adults hold very similar views regarding object fall in particular (e.g. Cahyadi & Butler, 2004; Sequeira & Leite, 1991). Such ideas are highly resistant to change through instruction and interfere with further learning of related concepts (Bloom & Weisberg, 2007; Duit, Treagust, & Widodo, 2008). Given such resistance conceptual change needs to be addressed early. Looking at these concepts in childhood to see whether they can be changed at this stage – before ideas become too resistant to change – is crucial. Despite problems with conceptual change in the context of science education, all children are believed to hold the capacity for conceptual change (Carey, 2000). This raises the question as to why some conceptions do not change.

A key approach to conceptual change is outlined by Posner, Strike, Hewson and Gertzog (1982). According to this approach there are four conditions that need to be met before conceptual change can occur: 1) there must be dissatisfaction with the existing conception, 2) a new and intelligible conception must be available, 3) the new conception must appear plausible, and 4) the new conception should open up to new fruitful research. The final condition is not seen to be relevant for most primary school children. The main problem, however, seems to lie in the fact that the first two conditions are frequently not met effectively – students will, for example, conduct an experiment and find that their predictions are not met, but instead of reformulating their theories they may place blame on other factors such as the experimental setup (Howe, 2012). Importantly, Posner et al.’s theory is, to their own acknowledgement, merely epistemological, and the approach has shown little positive effect in its applications to classroom teaching (cf. Duit et al., 2008). However, what if the conditions of their theory can be met by using a different approach? Using object motion as a key example to highlight its potential application, an alternative of self-collaboration is explored next.

## Collaborating with the ‘more capable’ self

Collaboration plays a key role in several traditional approaches to education. Piaget (1985), Vygotsky (1978) and Bruner (1996) all emphasise the importance of interaction in learning – though they may differ in their views as to how exactly interaction benefits the learner. It is unquestionable, though, that regardless of the exact mechanisms, collaboration among peers or with more knowledgeable adults can be a useful approach to effecting conceptual change in early science education in general (Howe, 2009, 2010; Howe, McWilliam, & Cross, 2005). However, such approaches may not always be most effective. Certainly where ideas are deeply entrenched due to experiences with the everyday world practically from the first day of our lives – as is the case for object motion – even collaboration with more capable peers or adults may not suffice in meeting the conditions set out by Posner et al. (1982). This may be because the plausibility of new or alternative conceptions is not given, or because the collaborator’s views are not ‘trusted’ enough (Howe, 2013). As a result conflicting ideas are rarely resolved; particularly in younger children’s science classroom interactions (cf. Howe & McWilliam, 2006). However, collaboration in a different manner could still be seen as a potential solution to the conceptual change problem – that is, by seeking collaboration with the underlying self.

Over the past thirty years a significant body of work has built up that demonstrates infants do not live in a world of “blooming buzzing confusion” (James, 1890, p. 488), but that they are in fact, among many other things, capable intuitive physicists who are able to interpret the world around them according to how they expect it to behave. Many studies have demonstrated that babies understand principles related to object motion, such as what kind of trajectories objects should follow (e.g. Friedman, 2002; Kannass, Oakes, & Wiese, 1999; Kim & Spelke, 1992). By relying on some form of internal reasoning system that monitors events, infants respond to scenarios that violate their expectations of how an event *should* have occurred, in accordance to physical laws, by spending more time looking at and scrutinising these incorrect events (Baillargeon, 2004). The assumption is that humans are born with what is termed core knowledge (e.g. Kinzler & Spelke, 2007) and these core beliefs represent an initial theory of the physical world.

According to the core knowledge view, these beliefs should also stand at the centre of adults' understanding, and while they can be enhanced through additional or new knowledge, the core itself cannot be altered (Carey, 2009). Indeed, research with professional ball players shows that while they are successful on a playing field, knowing where to be to catch a ball and what kind of trajectory that ball will follow, they cannot *explain* this knowledge and they perform poorly on related pencil-and-paper tasks (Reed, McLeod, & Dienes, 2010). Similarly, there are studies showing adults are able to recognise dynamic trajectories correctly, even if their predictions are incorrect (Kaiser & Proffitt, 1984; Kaiser, Profitt, Whelan, & Hecht, 1992; Shanon, 1976). Importantly, this ability to 'do' or 'see' not only differs from the ability to explicitly know, but it also seems to be decidedly different from guessing, for which performance success rates should be much lower (cf. Fu, Dienes, & Fu, 2010).

If underlying knowledge exists in childhood and it needs to become available to children so that conceptual change can occur, what is the best approach? The method traditionally used to evaluate what babies know about physical laws does not work very well beyond around the first year of age (Rosenberg & Carey, 2009). Instead, judgement tasks can be used, by enforcing decisions as to whether an event appears to be correct or incorrect (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). Particularly helpful in this respect are computer simulations, as in addition to demonstrating events that should elicit feelings of familiarity they also allow the creation of dynamic events that cannot exist and therefore would not be observable in the everyday world because physical laws would have to be violated (Hennessy, 2006; Hennessy et al., 2007). Moreover, the role of digital technologies has become more and more important in educational contexts, including in the primary classroom (e.g. Livingstone, 2012; Porter, 2013). As such it offers an excellent opportunity to approach conceptual change from a new perspective and to evaluate new techniques.

Research with children in this area is still limited, but relevant studies are beginning to emerge. Howe, Taylor Tavares and Devine (2012) conducted a computer-based study with primary school aged children, assessing their predictions and recognition of the trajectories of objects being dropped from a moving hot air balloon. Predictions mainly fell into the category of straight-down or backward parabolic motion trajectories and only rarely into the correct forward parabolic trajectory category. In contrast, when required to decide whether a shown trajectory was correct or incorrect these children were quite able to recognise that the forward parabolic motion trajectory was correct, rejecting the remaining two. Taylor Tavares, Howe and Devine (2009) showed similar effects with the same age groups, though focusing on motion direction along a horizontal.

Hast and Howe (2010) also investigated 5 to 11-year-olds’ underlying recognition of various dynamic events by specifically focussing on the role of object mass, since this element seems to play such a crucial role in predictive theories. At the same time, it should bear no effect on the ability to recognise dynamic events since speed, even taking into account air resistance or friction, has little effect on the speeds of two balls identical in size and differing only in their mass. Indeed, while predictions of speed of a heavy and a light ball were largely erroneous, as in other research (Baker, Murray, & Hood, 2009; Chinn & Malhotra, 2002; Hast & Howe, 2012, 2013a, b; Inhelder & Piaget, 1958; Nachtigall, 1982; van Hise, 1988), most children were able to correctly identify dynamic events as correct when they showed natural same-speed object motion and to reject events where one ball was simulated to be faster than the other.

Interestingly, the children in Hast and Howe (2010) were much more accurate in their *rejections* when the simulation events did not match their predictions. That is to say, while overall they were able to select the correct events as correct they also often judged the – incorrect – event to be correct that matched their predictions, but rarely the event that was neither correct nor matched predictions. Howe et al. (2012) found similarly that while the correct forward parabolic motion was recognised as being correct children frequently accepted incorrect trajectories as being correct in a manner that reflected their predictions but not so for trajectories that neither were correct nor had been predicted.

## An explanatory model of underlying knowledge

Prediction tasks seem to necessitate deliberation, reflection, and a conscious understanding of rules or decisions involved, that is, an explicit engagement with knowledge structures (cf. Plessner & Czenna, 2008). At the same time, we have seen that primary school aged children are able to recognise dynamic trajectories that are physically correct and to reject trajectories that appear unnatural to them, even if they are more likely to predict the unnatural events beforehand. It has been hypothesised that such recognition tasks may need merely to engage *underlying* knowledge structures (Collins, 2010; Polanyi, 1967) – structures set to provide quick responses without conscious awareness but eliciting feelings of familiarity (Scott & Dienes, 2010).

There are currently at least three different views on the relationship between expressed and underlying knowledge models. The first view posits that explicit knowledge is merely underlying knowledge elevated to a new level, and inaccuracies in expressed knowledge are explained as a result of omission of knowledge elements during the process of elevation (Kim & Spelke, 1999; Spelke & Hespos, 2001). The second view holds that there are two coexisting systems, each unaffected by the other, and depending on the task requirements, only one system is accessed (Hogarth, 2001; Plessner & Czenna, 2008). The third view, in contrast, rejects both omission and separation, and proposes a hybrid model in which there are two, partially associated knowledge systems wherein explicitly expressed knowledge is, at least in part, an embellishment of underlying knowledge (Carey, 2009; Hast & Howe, 2010; Howe et al., 2012). The question that remains is, then, how the two knowledge representations are linked. Which of the three theories is most likely to account for the differences?

The research with children outlined earlier would suggest that the omission theory cannot be upheld. For if the disparity observed by Hast and Howe (2010) were due to omission of conceptual elements then deliberation should call upon underlying knowledge and leave elements out. However, given that in actuality object mass plays a very minor role in relevant dynamic events correct recognition would not need to depend on any understanding of mass. Yet children clearly specifically call upon mass in their largely erroneous predictions – *adding* conceptual information rather than omitting any.

Arguing between separate systems and the hybrid model is a more formidable task at this stage. Mathematical research, for one, can help reject the notion of separate systems. Explicit mathematical computations are carried out on the basis of several underlying processes, such as approximate representations of numerical magnitudes (cf. Stanescu-Cosson et al., 2000). When such underlying processes are damaged, mental arithmetic suffers as a result (Lemer, Dehaene, Spelke, & Cohen, 2003), suggesting the underlying and the explicit representations must be linked in some manner. As a result the research on motion recognition (Hast & Howe, 2010; Howe et al., 2012) suggests an overlap of systems, but merely through partial association. In both studies recognition performance was generally accurate, but not always – and where it was incorrect it was far more likely to reflect predictive knowledge of dynamics rather than any alternative view.

Hast (2011) details a model that explores the possible relationship between predictive and underlying knowledge (see Fig. 1). Earlier the notion was introduced that humans are endowed with a set of core knowledge principles and systems (cf. Kinzler & Spelke, 2007).

According to the model these principles and systems are, in appropriate combinations, loosely connected to form prototypical representations of, for instance, dynamic events. In recognition tasks we may merely need to map witnessed events onto the relevant model and depending on the goodness of fit between actual event and prototype we then either accept or reject that event’s correctness. The models relied on in predictive reasoning, on the other hand, require some incorporation of symbolic representations (e.g. language, mathematics or maps), and this incorporation may be interfering with the process of fully accessing the underlying structures at an explicit level.

[Insert figure 1 about here]

## Applications to education and future directions

More interesting for educationalists might now be whether this knowledge differentiation – in whatever form it manifests itself – has any applicability to the classroom in effecting conceptual change. The short-term answer is in the affirmative and is demonstrated by a recently published study by Howe, Devine and Taylor Tavares (2013). Between them, 8- to 12-year-olds generally demonstrated similar levels of predictive knowledge about fall events in a pre-test. Some of these children then worked with an intervention program developed on the basis of Howe et al. (2012) where the children worked with recognition tasks; the remainder did not follow the intervention. A post-test on predictions given several weeks later showed that those children who had worked with the program were now much more successful in their predictions, whereas the control group’s results mostly remained static.

What seems to be the case is that the computer program elicited personal dissatisfaction with concepts already held, evident by the rejection of incorrect scenarios. In addition, a new conception was available, and it was a plausible conception because it was recognised to be correct by the 'more competent' self. All crucial conditions laid out by Posner et al. (1982) can be met here. There has been some discussion about interventions and timing, raising the question of how much time is needed to effect conceptual change. Frequently, change can still occur several weeks after intervention (e.g. Howe et al., 2005), and *long*-term evaluations may be needed to provide a more accurate picture. So as such the findings provided by Howe et al. (2013) may need to be treated with some caution but they certainly provide an optimistic outlook.

A further point that has been addressed in the past is that many primary school teachers show low levels of confidence when it comes to teaching physical science topics (Murphy & Beggs, 2005). Integrating underlying knowledge assessment can provide at least two benefits here. Firstly, teachers can work on their own conceptions – an unpublished follow-up study based on Howe et al. (2013)[1] showed that adults, too, are able to address a change in conceptions using such programs. Doing so could, as a result, help develop confidence in teaching science topics. Secondly, teachers can avoid unsuccessful superimposition of ideas by letting children access their personal underlying knowledge systems. In either case teacher willingness to engage with such technologies is needed in order for benefits to be applied (Ifenthaler & Schweinbenz, 2013). Working together with teachers in future research undertakings is therefore crucial to understand how they incorporate such assessment possibilities into their classroom activities.

[1] See http://www.educ.cam.ac.uk/research/projects/objectmotion/classroomuse-download/ where the software used during the intervention phase of Howe et al. (2013) is also available.

So while there may currently not be any clear indication whether approaching conceptual change in this fashion may have long-term benefits or what these benefits may be – simply because the research is too recent to be able to reach any such conclusions – there is already a call for continued work. It has been proposed that future research could particularly expand into other areas showing similar conceptual issues as found with object motion, such as floating and sinking, or heating and cooling (Hast, 2012; Howe et al., 2013). Moreover, the usefulness of this knowledge distinction may also provide applications in other educational fields where underlying rules play some role, such as learning of mathematics or grammar. Especially given the notion of underlying knowledge appearing to exist in both of these particular areas – innate numerical understanding (see Dehaene, 2011, for an extensive review) or the slightly more debated notion of innate grammar (e.g. Chomsky, 2007) – one might expect similar dichotomies between predictive and underlying knowledge, which could serve as opportunity for conceptual change programmes.

## Conclusion

With high resistance to conceptual change being an issue to overcome in early science education, new approaches need to be taken into consideration. What has been shown in this review is that we do not need to move away from traditional theoretical approaches per se. Looking particularly at the emphasis on collaboration to advance knowledge and skills (Bruner, 1996; Piaget, 1985; Vygotsky, 1978), it seems we can draw parallels to these ideas although no interaction with *others* needs to take place. Instead we have seen that self-collaboration by addressing underlying knowledge structures could provide a suitable solution as all relevant conditions outlined by Posner et al. (1982) can be met. It appears that humans may be endowed with a core repertoire of knowledge and skills from a very early age on, and that humans maintain this core throughout their lifespan. Being aware of this provides a take-home message for teachers in particular, but also for researchers interested in science education (or indeed other areas of education) – the knowledge expressed by children may not necessarily demonstrate the actual limits of what they already know.

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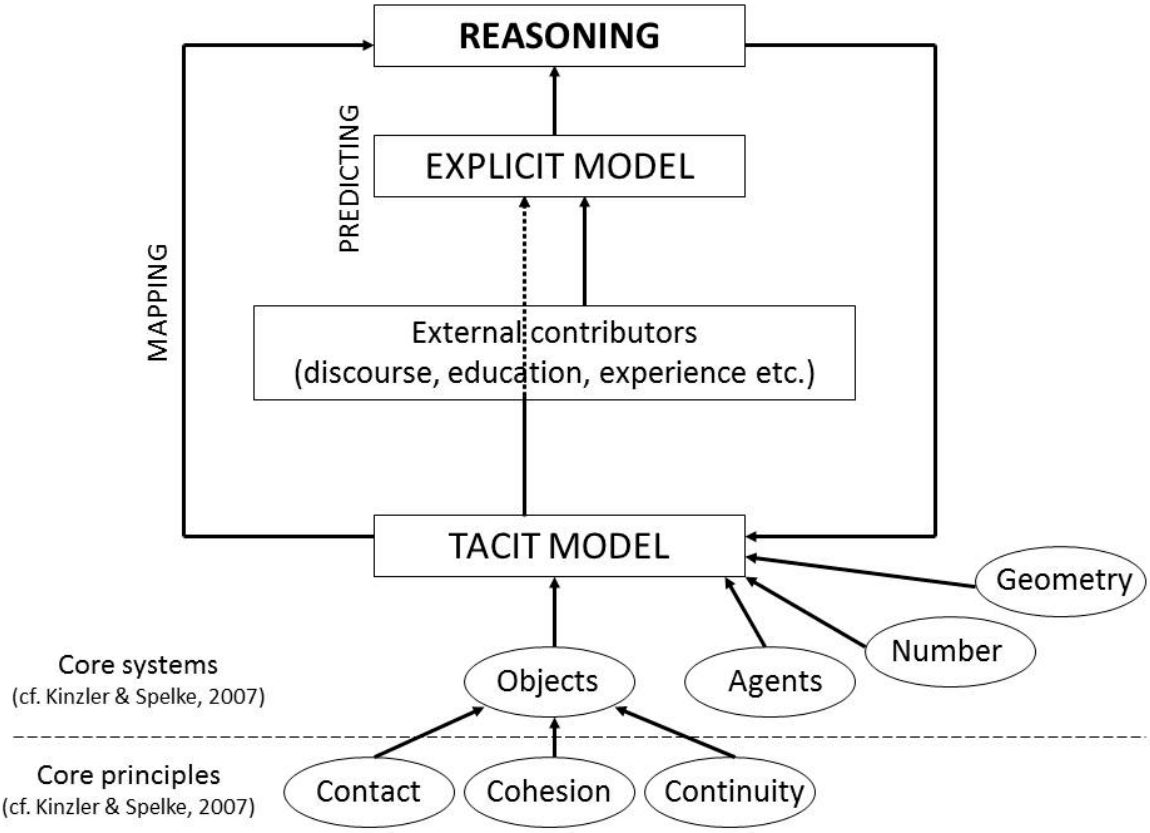


*Figure 1*. A dual-pathway model of reasoning (Hast, 2011).