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Scientific concept development in early childhood through the lens of "over-development"

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Abstract

Conceptual development in the scientific domain begins early. This typically brings with it an "overthinking" in form of mis- and alternative conceptions. This contribution examines more closely the emergence of scientific misconceptions by drawing on three other areas of early rule-based learning where overapplication of rules can be observed in early child development, namely overextension, overregularisation, and overimitation. Key similarities across the different domains of development showcase similar U-shaped trajectories but which are seen as sophistication in children's thought processes, evident through the extrapolation of rules. Age-related differences in when these trajectories emerge are considered, exploring how these developments do not necessarily occur in parallel but as a potential result of each other. Implications for educational practice are considered, given the observed interaction between linguistic and non-linguistic forms of overdevelopment. These focus particularly on the role of talk in formal and informal settings.

Keywords: Overconceptualisation; overextension; overregularisation; overimitation.

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1. Introduction

During my doctoral research (Hast, 2011) I interviewed children on their beliefs about how everyday objects behave when in motion. For example, they were asked whether a tennis ball or a billiard ball would roll faster down a slope when released from the same height at the same time. Moira, aged 5 years, predicted that the tennis ball would roll down faster. When asked to explain she said, "I saw my daddy play tennis and he hit the ball and it went really far. That's how I know tennis balls can go really fast." Some of the other children shared similar explanations based on examples from events they had witnessed in the real world – even if their use did not lead to scientifically accurate responses.

Moira's approach is just one illustration of how children's – and adults' – thinking frequently results in conceptions that are incommensurate with scientific positions on the same matters. Typically, conceptual development in childhood is therefore seen with some caution from a classroom perspective. Children hold a very wide range of ideas about how the world functions (Hast, 2020; Hast & Howe, 2012). These ideas seem to emerge early on in the developmental trajectory, seemingly making their first appearances somewhere between 2½ and 3 years (Hast, 2018, 2019). It is widely observed that changing such conceptions continues to be challenging, including for teachers (Hast, 2017).

The question thus posed is whether the fostering of scientific knowledge formation can be approached from another position, which this research referred to as "overconceptualisation", to aid in the development of appropriate conceptual change approaches. The objective of this paper is to examine whether, and if so, we can learn from other forms of over-development in early childhood that may help us better understand conceptual development. Specifically, the evaluation draws on overextension, overregularisation, and overimitation.

2. Overextension

One of the earliest and most notable forms of over-development is overextension, commonly seen during the early language acquisition phases when vocabulary has only begun to be accumulated (Naigles & Gelman, 1995). Here, young children frequently use words in contexts where adults would typically not. For instance, where an adult might have various names for different animals that share certain characteristics (e.g., dog, wolf, hyena, coyote) a child may initially only hold the lexical concept "dog" and will readily apply this to any animal for which a specific name may not be known but that could feasibly be considered to be "dog" based on conceptual and perceptual similarities (such as the wolf, hyena or coyote). This can be further illustrated through the specific example of "dog" versus "wolf" (wordbank.stanford.edu; see Frank et al., 2017). By 16 months of age, around two-thirds of children are reported to have "dog" in their productive vocabulary repertoire, but close to none have "wolf". At 30 months, "wolf" exists in a little over half of the reported vocabularies, so even among many 2½-year-olds "dog" would still be the most suitable option to use when labelling what is a wolf.

Overextensions are relatively frequent, occurring with around a third of word types in a 1-year-old's repertoire (Naigles & Gelman, 1995). Thanks to a rapid vocabulary build-up, by around 2½ years of age overextensions, begin to decline, as is also clear from the "dog-wolf" example. However, overextensions occasionally reappear even in adulthood – usually a result of a slip of tongue. This is not unlike observations with scientific thinking. Adults may have learned scientifically appropriate concepts through instruction in the classroom, yet these do not actually supplant or override prior naïve ideas. Instead, the naïve ideas may re-emerge under certain conditions, such as performing under timed constraints (Shtulman & Young, 2020), just as overextensions may do.

The overall developmental process of overextension, however, signals sophistication in thought based on the ability to extrapolate rules and to apply existing labels as the "next best thing" in the absence of more specific knowledge. Conceptual learning in science is frequently language-based, and specific observations, like Moira watching her father, provide children with opportunities to generate rules to contribute to the language-based construction of their mental worlds. This may help us also understand, for example, the differences in verbal and non-verbal performance on tasks about predicting and evaluating events based on the violation or non-violation of physical laws (Hast & Howe, 2015; 2017).

3. Overregularisation

A second notable form of early over-development in language acquisition is overregularisation. Here, children consistently apply language-based rules even when the rules do not apply to specific cases. In the English language, for instance, a common example to illustrate is the use of the past tense (the effect is also evident in other languages). Frequently, this involves adding the suffix -ed to the present tense stem – so "I walk" becomes "I walked". But there are many exceptions to this rule. Yet as a result of over regularisation, a child that has extrapolated the "stem + -ed" rule but is still having to acquire the exceptions to that rule will readily use this approach even in cases where it is not applicable – "I go" may become "I goed" instead of "I went".

These errors make their first appearance roughly between two and three years of age and typically seem to become evident at around 2½ years of age for most children (Marcus, 1995; Pinker, 1995). Once again, children are consistently applying language-based rules even when these rules do not apply to specific cases. As with overextension, sophistication in thought is evident. More critically, the observation that overregularisations tend to emerge at around 2½ years corresponds well with the suggestion that children's "overthinking" in science domains becomes evident from around the age of 2½ to 3 years (Hast, 2018; 2019). However, even 16-month-olds already have a preference for listening to incorrect -ed versions of correct past tense forms that are irregular (Figueroa & Gerken, 2019), suggesting the rule extrapolation process precedes actual production.

In overregularisation, we may also find further insight into why conceptual change is challenging. In the particular case of the past tense, over-regularisation has been noted to be a result of a lack of blocking. Irregulars have to be stored through rote memorisation, and progressively more frequent exposure to these irregulars increases their usage. But this requires time. Meanwhile, the "mental concatenation operation" (Marcus et al., 1992, p. 129) – attaching the -ed suffix to the stem – is more readily available as a rule. Because children will not have come across irregulars too frequently in their early language use, the -ed rule cannot yet be successfully blocked where it would need to be. In the context of science concept development, this may help understand why certain rules – such as "heavy objects fall faster because they are heavier" (Hast, 2016) – are consistently applied in predictions of dynamic events because everyday experiences such as that by Moira cannot be blocked.

4. Overimitation

To reflect that overdevelopment is not uniquely related to language, the third example to be considered here is overimitation. Like language, imitation is an important early skill for human interaction and learning. Imitation, too, appears early in development, and is possibly even already present at birth (e.g., Meltzoff & Moore, 1989; but also see Oostenbroek et al., 2013, for a more critical review of this argument). Infants seem to be largely rational in their copying behaviours, differentiating between goals and actions, and demonstrating the understanding that some actions are not necessary to achieve certain outcomes (e.g., Schwier et al., 2006).

However, this imitative behaviour seems to then progress towards a concept of over imitation (Hoehl et al., 2019): From around 3 years of age, children begin to copy actions modelled for them even if these specific actions are not necessary for reaching a particular goal. This behaviour pattern appears even more marked among 5-year-olds – 3-year-olds, on the other hand, are still more likely to leave out irrelevant actions. This behaviour appears to show high consistency across different cultures (Stengelin et al., 2020). Eventually, this overimitation behaviour reduces again to more rational goal-oriented copying.

The reasons for this behaviour are not fully understood; or rather, different possible explanations are on offer (Hoehl et al., 2019). One of these is that children at this age are learning to apply social norms; the observed actions of others are considered part of the convention, regardless of whether they are functionally necessary or not. It is the subsequently more frequent experience of such activities as well as interaction with others who are performing these activities that may help a child learn whether there is a need – social or functional – for specific actions. As a result, we can consider over imitation in similar ways as overextension and over regularisation. Basic rules of social behaviour and convention have been extrapolated, but rather than applying these rules selectively or considering whether they need to be applied, children will do so consistently.

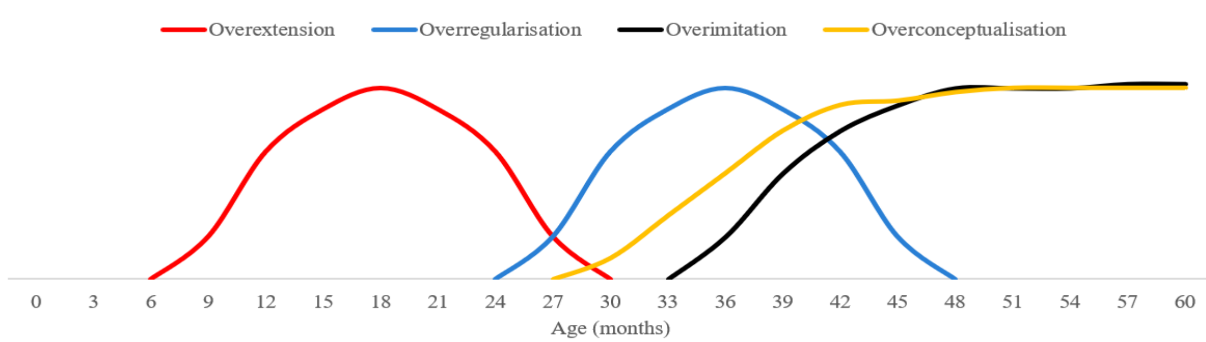
In addition to the social norm argument, which can be viewed from a cultural perspective of wishing to demonstrate affiliation, the process of communication seems to be a critical factor as well. Gergely and Csibra (2006) have argued that because tasks where children overimitate are frequently underpinned by communication from adults, children may copy because they anticipate that the adult's communication would surely serve the purpose of conveying culturally relevant information. This may also help explain why in the overall developmental trajectory overimitation occurs after overextension and overregularisation so that communication in form of language can be mastered first. It also again enables us to understand why overconceptualisation begins at roughly the same time as conceptual development patterns in the science domain – emphasising the importance of language mastery.

5. Summary and Implication

In sum, the comparison of the different forms of over-development allows us to draw a few conclusions. First, it is worth noting the similarities in developmental trajectories and asking whether it is time to add "overconceptualisation" to the table. As illustrated in Figure 1 below, all four show a similar inverted U-shape in their progression. The initial application of behaviour in each domain is largely appropriate, then enters a period of "over"-ing with increased errors, only to return to the correct application. Similarly, we see how the linguistic over-developments precede overimitation and overconceptualisation, which in turn to some extent depend on the mastery of communication skills.

Figure 1

A comparison of the trajectories of the different forms of "over"-development



Such inverted U-shapes can also be seen in different examples of conceptual development in science. In a study on children's understanding of the concept "animal", for instance, 4-year-olds showed a high level of correct recognition of what was an animal and what was not, as did 10-year-olds. Between this, the 7-year-olds showed recognition levels that seemed to be based on a more restricted definition of what qualified as "animal" and what did not (Hast, 2022). In the physics domain, children also increase in their incorrect predictions of dynamic motion events during this time (Hast & Howe, 2015, 2017).

It would also be reasonable to argue that another key commonality is a preverbal basis for over-development. In the language context, we can consider the argument that young infants take statistics of the language around them to help them become native listeners (Kuhl, 2014). With imitation, we have studies that demonstrate newborns being able to copy facial expressions (Meltzoff & Moore, 1989). And in the science domain, we also find a myriad of studies exploring preverbal infants' awareness of scientific principles (Carey, 2009). Collectively, this supports the notion that children construct models of the world around them that are used for mapping events to judge them as well as for making verbal predictions, where different task demands lead to different processing pathways (Hast, 2014). I argued here that the quality of everyday talk may be important in understanding why children's verbal predictions may be so different from their strong recognition skills.

The connections between conceptual development and language are hardly surprising as such. Concepts can exist without linguistic representation, as is likely in preverbal infants (Carey, 2009), but an explicit demonstration of such knowledge requires symbolic representation for sharing of that knowledge. Children are more likely to predict outcomes based on one object being heavier than the other, only rarely making the inference that inverse outcomes would occur because one object is lighter than the other (Hast, 2016; Hast & Howe, 2012). Unmarked concepts like "big" are learned before marked counterparts like "small", and this affects relevant task performances even at ages 3 and 4 (Marschark, 1977).

What remains of concern then is the subsequent persistence of key ideas that are based on the everyday world, even into adulthood. As a result, conceptual change programs should be geared towards supporting the completion of the inverted U-shape. In light of the parallels highlighted in this paper, two key recommendations can be made. First, the role of dialogue needs to continue playing a central role. This is hardly a new revelation, as dialogue is already seen as critical to early science learning in the formal classroom (France, 2021). Similarly, the fact that parent-child dialogue has a significant impact on the formation of scientific knowledge is also known (Eberbach & Crowley, 2017). The role of modelling should not be underestimated either. Together with language development, this highlights a key relevance of structured and scaffolded procedures (Bruner, 1978) to support conceptual change programs.

6. Final Thoughts

What the evaluation in this paper has certainly also been able to show so far is that the commonalities in the developmental trajectories allow us to consider overconceptualisation in a positive light. Retrospectively, despite having given a scientifically incorrect response, the fact that 5-year-old Moira was able to draw on her real-world experience to make a prediction about tennis balls versus billiard balls signalises sophistication in her thought process. It is an example of children being able to extrapolate rules from everyday events, just as they are in the contexts of language and imitation, and applying them until they have learned specific exceptions to those rules and can overcome any inhibition or blocking.

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