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Drawing on a Sculpted Space of Actions: Educating for Expertise while Avoiding a Cognitive Monster

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INTRODUCTION: LEARNING, EXPERTISE AND A TRANSITION TO MULTIPLE WAYS OF COGNITIVE PROCESSING

Philosophers and scientists have across the ages been amazed about the fact that development and learning often lead to not just a merely incremental and gradual change in the learner but sometimes to a result that is strikingly different from the learner's original situation: amazed, but at times also worried. Aristotle, for example, notes that excellent and virtuous behaviour is considered by thinkers like Plato to require conscious and rational control in all persons and occasions, whereas Aristotle himself observed that sustained practice often leads to a form of habituation which renders such control of an agent unnecessary, yielding in fact a very different situation (*cf.* Aristotle, 1984: *Ethica Eudemia* 1216 b 6–10). More recently and from a completely different perspective, a seminal brain imaging study comparing brain activation patterns in novices and experts performing identical tasks showed that increased expertise correlated with drastic changes in functional brain anatomy. Indeed, the differences were so large that the authors concluded that novices seem to perform outright 'different tasks' from those that experts do: the functional anatomy of experts was both more efficient and task-relevant networks were more associated with other, potentially relevant, functional networks (Petersen *et al.*, 1998).

Such philosophical and empirical perspectives give some insight into what happens when a novice is transitioning to a stage of expertise. Generally, this implies that increased skill and expertise support better results and a more flexible performance, in part because these allow an agent to withdraw part of her attention and other cognitive resources from the tasks involved, enabling her to devote those resources to supporting, or completely different, tasks. This implication of expertise (which here includes also skill learning, even though the two are not identical in all respects) comes naturally in many cases after many hours of exposure and practising particular behavioural or cognitive tasks. In the case of humans, targeted training and education contribute in specific ways to the development of expertise as well.[1] We are apparently capable of accomplishing drastic changes

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in our behaviour and cognition and in the processes subserving these. As positive as this may sound, these changes have also raised concerns.

The main concern is whether gaining expertise is like raising a 'cognitive monster' which escapes the individual's conscious control and influences her actions with undesirable automatisms (Bargh, 1999). If so, we should ask ourselves whether experts are capable of taming this monster. The answer appears initially not to be positive. Indeed, it has been noted that since it is difficult for experts to withhold automatic responses this can lead to inflexibility and consequently that sometimes 'expertise is correlated negatively with performance' (Sternberg, 1996). Studies have indeed demonstrated that expert performance is optimal under certain conditions only, because it is limited to a specific domain, often context-dependent, biased and inflexible (see, for example, Chi, 2006). In situations that are relatively common, experts outperform novices, yet in more exceptional situations their performance is less optimal, demonstrating the 'brittleness' of their expertise (Lewandowsky and Thomas, 2009).

In what follows, I will consider this challenge of protecting expertise and harnessing this brittleness from philosophical and cognitive neuroscientific perspectives. Taking into account that action is in general determined by a multitude of factors, with learning and development affecting how these factors exert their influence, a philosophical question is how this complex and dynamic process can be explained and subsequently, how controlling it might be understood. First, though, I will present the issue at hand more closely: should we appreciate expertise if it is similar to growing a 'cognitive monster'? Second, I will introduce the framework of a Sculpted Space of Actions, which I developed in order to explain how the challenge of selecting an adequate option for action is facilitated by expertise as it helps to constrain the space of potential action options. Subsequently, the question is raised of how such a Sculpted Space of Actions influences an expert's engagement with specific situations, like teaching students in a classroom setting. It will be argued that a well prepared expert—teacher or otherwise—is not only able to rely upon her routines but will at the same time be more perceptive and attentive to unforeseen events and actions, according to the recent cognitive neuroscientific theory of Predictive Processing. Integrating the theory of Predictive Processing with the Sculpted Space of Actions framework, I conclude that expertise contributes to adaptive and flexible responses to specific contexts, yet only if it is associated with explicit planning and articulation of situation specific intentions—the latter effectively putting the cognitive monster at rest for a while.

CONCERNS ABOUT A COGNITIVE MONSTER

In education, expertise and automatisation play important roles: relying upon their own automatised skills and insights, which are dependent upon their own expertise, educators are able to navigate the complex and ever-changing environment of the class room. Automatisation may also be involved when the aim of the lesson is to help pupils automatise certain skills, musical ornamentation, grammatical rules, and the like. A reason to aim for their automatisation is that conscious cognitive control is no longer necessary for performing such tasks. Yet although we acknowledge the benefits of such routines and automatisms, they do at the same time raise the spectre of persons whose actions are largely determined by them. We might fear that as a consequence they would no longer consciously perceive nor pay attention to the individual needs of others, unexpected classroom situations, or surprises more generally nor would they be able to respond flexibly to all of this. Moreover, automatisms are also associated with stereotypical, prejudiced, discriminatory and racist responses, which have very negative effects on education and its outcomes.

Can expertise and automatisation produce a positive yield while avoiding the undesirable effects mentioned before? Unsurprisingly perhaps, automatisation has been compared to raising a 'cognitive monster' because of the habitual and stereotypical responses that might determine many actions and that are difficult to control once they have been formed (Bargh, 1999). Indeed, although being diagnosed in the context of social cognition, several lines of research have established in many other areas that we are generally prone to have in some sense 'two minds in one brain' (Evans, 2003). These two minds have been found to be at work not only in our social cognition but also in tasks as different as reasoning, perception and moral judgement. These can all be carried out via partly different cognitive and neural processes, recruiting also partly different neural areas or systems along the way: hence theories that focus on 'dual processing' (Barrouillet, 2011; Evans, 2011; Frankish and Evans, 2009; Smith and DeCoster, 2000) or rather on 'dual systems' (Cushman, 2013; Hofmann *et al.*, 2009; Lieberman, 2007).

Two minds in one brain might in itself not be a reason for concern. Yet research shows that those 'minds' sometimes produce contradicting results, thus causing a person at times to respond inconsistently with herself in a particular situation. For example, subjects were found to uphold controlled attitudes and automatic, implicit attitudes towards other individuals that were inconsistent with each other: when asked to explicitly and consciously rate a person's likability they would give responses that were at odds with their implicit attitude ratings (Rydell *et al.*, 2006). Follow-up research showed in addition that providing subjects with specific information meant to influence their attitudes did have a faster impact on the controlled than on the automatic attitude (Rydell *et al.*, 2007). Judgements on arguments, too, can be influenced simultaneously in conflicting ways by having an attractive person present weak arguments or vice versa: our two minds are steered into different directions without us really noticing it (Smith and DeCoster, 2000).

There are both moral and practical reasons for concern about such inconsistency in our cognition and behaviour which are also relevant for educational contexts. Philosopher Michael Bratman describes how humans as planning agents are able to perform complex and temporally extended intentional actions both individually and in co-ordination with others. Such intentional actions require that inconsistency is minimised. Inconsistency in our performances will inevitably lead to counterproductive results as many of our actions depend upon long-term planning with refined means-ends relationships, for example when carrying out a scientific study requires a lot of planning and preparation. Moreover, such actions often involve social interactions and distribution of tasks over several agents, which requires their consistent and reliable performances even more, if such a study is ever to be realised (Bratman, 2007). Reducing inconsistencies and enhancing the consistency in our cognitive and behavioural responses is therefore an important practical and moral challenge.

Now it may seem surprising to bring this phenomenon of the 'cognitive monster' and of having 'two minds in one brain' up in the context of expertise. For one of the main characteristics distinguishing experts from novices, is that experts 'reach a consistently superior level' in their performances (Ericsson, 1999, p. 332). Indeed, experts are usually found to perform better than novices in, among other things, generating better solutions to relevant problems, detecting and recognising relevant features of a situation, monitoring their own responses better and doing all this with less cognitive effort (Chi, 2006). These positive effects of expertise are to a large extent dependent upon the automatisation of component processes that are involved in expert task performance, allowing an expert to spend time and attention on other component processes (Feltovich *et al.*, 2006). However, as desirable as these results may seem, the importance of automatisation suggests that expertise may rely upon the same cognitive monster that was found to threaten our functioning as planning agents.

The question presents itself of whether it is possible in education to have the cake of expertise and automatisation as an educator and let the student eat it in a digestible manner too? Particularly in education, expertise and automatisation might have negative effects as education is not aimed at superior performance of an individual in her own particular domain but is aimed at aiding someone to improve her performance at whatever level she is and with an eye to the specific challenges she faces. As I will explain in the next section, educators are able to meet this demand as they can draw during their teaching on the Sculpted Space of Actions that facilitates the cognitive and brain process of choosing adequate action options in their domain of expertise. Yet at the same time educators and other experts must be sensitive to exceptional situations and surprises. Since their brains are constantly engaged in so-called Predictive Processing, I will argue that in order to adequately prepare for surprises, educators must articulate and make explicit—verbally or otherwise—the relevant features of an upcoming lesson and its aims.

EXPLAINING EXPERT PERFORMANCE: DRAWING ON A SCULPTED SPACE OF ACTIONS

Consider the situation when we are beginning any kind of action, like starting to make a sentence. Initially, there is an almost infinite set of available options: the language we will use, whether we will ask, state or command something, how we will start doing so which also depends upon the person we will be addressing, and so on. Indeed, we may consider such a beginning as a demand for selecting just one option in a 'world full of action choices' (Cisek and Kalaska, 2010).[2] Fortunately, though, there are several constraints at work that limit the range of options we are choosing from, facilitating the choice or decision we are about to make. For example, our own cognitive and behavioural capabilities seriously limit the number of options to begin with, and knowing the capabilities of those around us further constrains our choice. Furthermore, with regard to both action and speech the immediate context is likely to matter, that context consisting of both previous exchanges we just had and the situation in which we find ourselves. In many cases, our future-oriented or distal intentions will also influence our behaviour and speech by effectively excluding some options while lowering the threshold for execution of others (Bratman, 1992; Pacherie, 2008): words or actions that we find abhorrent and seek to avoid will usually be suppressed while options that we have practiced a lot because we found them elegant will have a much larger probability of being selected for their potential execution.

This description of the situation we are facing at the start of an action or sentence has been elegantly demonstrated in a cognitive neuroscientific study on speech. Searching for a word turns out to be a task that in part relies upon the activation of specific prefrontal brain areas. This task can be made easier if the space of options is somehow limited. For example, as soon as we have begun a sentence, preceding words put constraints on the options available for continuing it in a correct and understandable way, making the selection task easier for subjects: instead of having to consider a huge number of options, there are only a few words that make sense in a particular spot halfway through that sentence. The number of options for finishing the ambiguous sentence 'When I arrived at the ball, I searched . . . ' is diminished as soon as it continues with either 'amidst the fashionable crowd' or 'on the field'—the subject's target being either a dance partner or a striker. In other words, the more constraints limiting the number of options for continuing a sentence are available, the faster and more appropriate subjects' speech will be, demanding less of their cognitive and neural efforts: these constraints have effectively constrained or 'sculpted the response space' (Frith, 2000).

The role of such a sculpted response space implies that over time language users develop knowledge structures or representations of information that facilitate their process of determining an appropriate word or action. Leaving aside here how these representations are precisely implemented in our brains, it should be noted that generally expertise in a particular domain implies the development and memorisation of a large set of representations containing information that is relevant in a particular situation and also information pertaining to options for the next step to be performed. This has first been shown by De Groot's seminal studies of chess masters (de Groot, 1946), followed up by Simon and others (Chase and Simon, 1973; Gobet and Simon, 1996; Simon and Chase, 1973) that have inspired many subsequent studies about expertise. These have provided much evidence about how expertise rests in part upon the development of knowledge representations that are different from the representations that novices use. When sizing up a particular chess position, for example, an absolute beginner might have difficulty in recognising the different chess pieces and not realise that the left bottom position should be black, making it a daunting task to recall the position of just three pieces. In contrast, a chess master at a glance recognises that the particular position largely resembles a famous 1935 board played by Max Euwe yet with two pieces in a different position. With both experts and novices being required to cognitively represent the necessary information in order to decide what piece should be moved on the board, experts' representations turn out to be much richer: they contain much more information, with the information also being more hierarchically organised (Freyhof *et al.*, 1992).

Yet it is not only in their perceptual and recognition capabilities that experts are showing better results than novices. Indeed, experts can employ ever larger and more complex representations that enable them to weigh multiple deep chess strategies against each other, carrying out the preferred strategy in a flexible way. Studies in humans and animals show how action performance relies upon hierarchically structured sequences of actions that are composed and recomposed from the representations underlying previously learnt actions. The representations of such complex actions have also been referred to as 'scripts': for example the script of how to make breakfast which in turn consists of boiling tea and preparing bread, each of which can be further broken down into subcomponent actions.[3] Such hierarchical and temporally extended action representations are being stored in memory and employed in understanding or preparing for new experiences (Schank, 1980; Schank and Abelson, 1975). Moreover, the action representations that are contained in scripts can be recomposed in manifold ways and employed in different kinds of cognitive processes, ranging from the immediate performance of an action to imagination of potential future actions or understanding the actions by other agents (Cooper and Shallice, 2006; Norman and Shallice, 1986).[4]

In other words, even if we don't know the specific cognitive and brain processes underlying their performance, we can still study and observe how novices and experts are employing representations of actions that are different in several ways. Gaining expertise can be understood as the process that yields for an agent a Sculpted Space of Actions, I am claiming.[5] Let me explain this with the help of the figure below.

Take again the example of a novice and expert, both having to perform an action in a specific situation, which implies having to determine and select an appropriate option from a wide set of options. Of the many potentially relevant dimensions, the figure above represents three dimensions that have been found to largely determine human actions—particularly those actions that are related to long-term intentions.[6] Obviously, the situation itself will constrain the potential set of action options as there may be objects available that afford certain actions, with other actions being impossible to perform (Gibson, 1977): a chair to sit on or another person to speak to is available, yet no kite to fly or bread to eat. An expert faster and better perceives and recognises relevant options for action pertaining to her domain of expertise,

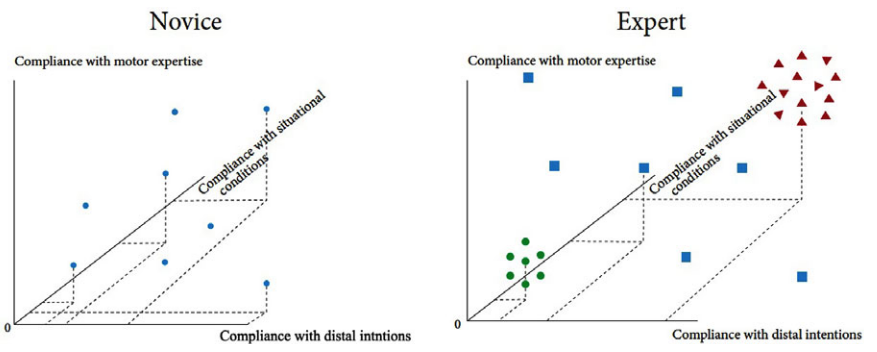

Figure 1: Spaces of Actions of a Novice and an Expert.
[Colour figure can be viewed at wileyonlinelibrary.com]
The expert's space of options for action is sculpted along (at least) three dimensions which represent the compliance of these action options with situational conditions (z-axis), with motor expertise (y-axis), and with distal intentions (x-axis) respectively. This sculpting process entails that an expert's action options are no longer randomly distributed across the space—as is the case in the novice's space that is filled by action options that are neither preferred nor suppressed. Instead, the expert's sculpted space of actions is filled with more action options, some of which occupy sub-spaces as a function of having become strongly preferred (red triangles in Expert panel), or strongly suppressed (green dots in Expert panel), depending upon their degree of compliance with three important action characteristics, with some indifferent (blue squares) options scattered through the space. (Figure adapted from Keestra, 2014, p. 375 with permission.)

as studies of chess masters to which we referred above have shown and which have by now been generalised to many other domains of expertise. As a result, experts are quickly and unconsciously detecting and grouping options lower or higher along the dimension of 'Compliance with situational conditions', whereas a novice does not perceive and recognise how some moves are likely to bring loss instead of checkmate closer than others: options are more randomly grouped and differentiated less in the novice's un-sculpted space of actions.[7]

The dimension 'Compliance with motor expertise' applies particularly to forms of expertise that involve motor movements, as in sports or music: for the Sculpted Space of Actions for other domains of expertise this dimension might be less relevant in which case another dimension—or dimensions—might be added in order to represent their spaces of actions more adequately. In many cases, however, experts must not only be able to recognise action affordances in a given situation, they also must be able to estimate the feasibility of the afforded action options for themselves. Research on expert athletes shows consistently how they score better on 'perceptual, cognitive and strategic aspects of behaviour' (Swann *et al.*, 2015). In a given situation a soccer player can either pass a ball or make a goal attempt herself with her motor expertise partly determining which of those options has higher probability of succeeding and will therefore be—implicitly—ranked higher along the dimension of 'Compliance with motor expertise'. Obviously, it is the interaction between perceived situational conditions and motor expertise that really matters: which of the affordances in a given situation fits best with the expert's motor expertise?[8] In other words, expertise in sports will yield very rich representations that contain the necessary components both for perception and recognition of the affordances as well as for the flexible performance of appropriate motor movements (Travassos *et al.*, 2013). Indeed, interdependence between motor skill and action decision-making has been found more in experts than in lesser skilled sport players (Bruce *et al.*, 2012). For beginners, lacking the experience with and practice of sport-specific movements, there are hardly any action options that score particularly high on this dimension of compliance with their motor expertise.

The third dimension of the sculpted spaces of actions in the figure—on the x-axis—represents the future-directed or distal intentions of the person whose sculpted space it is. Such future-directed intentions can be defined as decisions or plans for options for action somewhere in the future, which constrain subsequent options for action by 'providing a filter of admissibility for options' (Bratman, 1987, p. 33). Providing such a filter holds also for the scripts that we mentioned above, like the script of making breakfast: pouring a beer or brushing one's teeth is considered inadequate at that time. The result of this filtering or constraining is a greater consistency in the overall actions of the agent as potential counterproductive actions are avoided while supportive ones are being promoted. (A bribed soccer player has probably to cope with conflicting distal intentions, negatively affecting his sculpted space of actions and consequently his fast and smooth performance.) Although Bratman refers primarily to deliberative processes, both philosophical arguments and empirical evidence provide reasons to extend this influence of distal intentions not just on deliberation but—often indirectly—on other processes as well (Keestra, 2014; Pacherie, 2008).[9] Bratman emphasises that the coordinating role of these intentions is facilitated by their having a more elaborate hierarchical structure, including many means-ends relationships: such a structure allows the agent to plan his actions both individually and to coordinate them with others (Bratman, 1981).[10]

Distal intentions of various kinds contribute to expertise and the increasing coherence in the selection of action options that is characteristic of experts focused on performance in the near or more distant future. Distal intentions without which expertise cannot emerge are obviously the long-term commitments that filter future action options as Bratman emphasises. Experts, for example, typically have composed their planned actions such that they devote over a period of at least ten years circa thousand hours per year to practicing in their field, distinguishing themselves from non-experts (Ericsson *et al.*, 1993).[11]

Besides these more general commitments, distal intentions are implemented more specifically in so-called 'deliberate practice', that is found to be valuable for growing expertise. This deliberate practice contributes to further sculpting the expert's space of actions in specific ways. Experts' characteristic skills and knowledge require not just exercise but many hours of well defined practice with specific properties: it requires determination and timing of specifically relevant activities and providing adequate feedback and monitoring of the results (Ericsson *et al.*, 1993; Ericsson *et al.*, 2007). With specific targets in mind, (aspiring) experts focus their attention and time upon improving particular movements, positions or other tasks, which has been demonstrated to be effective in many domains such as sport and music (Ward *et al.*, 2004). In other words, relevant knowledge structures or representations are developed and further refined in their practices. For this, experts are leaning heavily upon specialised educators and trainers at the beginning of their development to shape their deliberate practice, tending to still consult them even after the have themselves reached high levels of proficiency.

With this brief presentation of the Sculpted Space of Actions it has been argued that gaining expertise can be understood in part as the development of a continuously updated space of adequate knowledge structures or representations that can be defined along different dimensions. The question to be asked next is how this multidimensional space of representations is employed, what role it might play in the relevant cognitive and brain processes that underpin the extraordinary cognitive and behavioural responses that experts show. Reminding us of the 'cognitive monster' mentioned earlier, the question is also to what extent experts are automatically confined to employ the preferred representations from this sculpted space? Will experts have perhaps more difficulty in responding to unexpected situations than beginners? Or is the reverse true and are experts potentially better in preparing themselves for surprises, perceiving and recognising these better as well?

PREDICTIVE PROCESSING IN EXPERTS, FACILITATED BY A SCULPTED SPACE OF ACTIONS

Tying an individual agent's motor expertise and long-term intentions together with the conditions of her current environment, offers a picture of her 'carrying around' a Sculpted Space of Actions that is continuously responding to ongoing changes pertaining to one or more of its many dimensions. Obviously, as situational conditions are changing continuously as she moves around, this has the most impact on what her Sculpted Space of Actions looks like at any given moment. If an expert musician with a love for cooking and with no experience of ice-skating first sits at the piano while playing music, then cooks herself a meal and later goes to her second ice-skating class, her cognitive and brain processes will be facilitated by a Sculpted Space of Actions representing different sets of action options in accordance with the changing situational conditions. Sitting behind the piano, certain actions pertaining to reading and playing music are facilitating her rapid and correct playing of a memorised virtuoso score with the suppression of mistakes that she initially made while deliberatively practicing it. In the kitchen, some recipes have been made repeatedly and the associated knowledge structures are well memorised, allowing her to perform the required action sequences while having a phone conversation, which a new recipe would not. There are many fewer action options present and activated in her Sculpted Space of Actions when she enters the skating hall, with those present being less hierarchically structured and differentially preferred than the action options activated in her Sculpted Space of Actions in the two situations before. Compared to an expert skater, she has not only performed less deliberate practice than he and consequently has less motor experience with skates and movements on ice, yet she also does not perceive and recognise as good the affordances and risks that her particular skates and the skating rink with its many cracks offer to her. Over time, though, the space of actions activated during skating will become much more filled and sculpted, facilitating her brain and cognitive processes and as a result also her behaviour.

This picture of a continuously adapting and changing Sculpted Space of Actions may seem implausible as it contradicts the traditional idea that the brain is the stable seat of a collection of stored memories and preferences, waiting for incoming or self-generated information to process and then preparing behavioural or cognitive responses partly by retrieving and employing relevant memories. Yet it does sit nicely with a framework that is gaining more traction in recent years and which offers an alternative to this view of brain and cognitive processes as merely responding to specific input without a specific disposition. This novel framework instead proposes taking our 'predictive brains' as being continuously involved in 'action-oriented predictive processing' which involves environmental information as well as the agent's specific experience and dispositions (Clark, 2013, p. 186). A prime underlying aim of the predictive processing in which the brain is continuously engaged is that it strives for the minimisation of errors in the predictions it continuously makes, minimisation of the associated surprises. Such errors and surprises would negatively affect the adequacy of the agent's engagement with its environment, making it lose time and energy (Friston, 2012, 2014). Several pressures therefore continuously contribute to the development of predictive processing, integrating the agent's previous perceptual, cognitive and motor experiences: 'Perception is here tangled up with possibilities for action and is continuously influenced by cognitive, contextual, and motor factors' with the brain being 'an organ for the environmentally situated control of action' (Clark, 2015, p. 14).

In order to minimise prediction errors and surprises—and consequently to avoid costly time and energy loss—the agent employs for its ongoing predictive work the 'mental models' or representations that she has developed over time and that capture in a hierarchically structured way her previously acquired and situated expertise. These representations help to efficiently generate predictions of ongoing events, predictions that integrate the likely outcomes of the agent's own actions and interventions in her environment. Naturally, such models and the predictions based upon them are shaped by her relevant and situated experiences: '[e]ach organism's generative model is unique in that it has been formed and continuously revised according to the particular trajectory of that organism's cycle of action and perception' (Madary, 2015, p. 3).

This emphasis of action-perception cycles as the main source of the generative models that are being exploited in Predictive Processing may suggest that it allows no role for the explicit articulated intentions that were found to be an important dimension of the Sculpted Space of Actions presented above. If this were the case, it would also make the Predictive Processing account at odds with the notion of deliberate practice and would make it accordingly difficult to connect it with approaches to education that build upon that notion of deliberate practice. Fortunately, though, explicitly formulated intentions and even narrative are found to play a role in Predictive Processing, making it a convincingly hybrid model that integrates both 'bottom-up' probabilistic processing with 'top-down' narrative models or intentional inputs on such processing. Trumping the slow development of experience-based expectations, language enables agents to augment such predictive processing by developing and activating specific generative models because it offers cues for features that require closer attention and processing, for example (Lupyan, 2012). In other words, language can help to shape—whether only short-term or even long-term—structured representations that are then engaged in predictive processing, even in the absence of a particular situation or another agent to interact with. Indeed, language is usually involved in forms of 'mental agency' that have an impact on predictive processing, for example by formulating intentions that in several ways constrain the probable outcomes of these processes (Pliushch and Wiese, 2014). A language user is therefore in his predictive processing not fully determined by the accumulated motor experience and familiarity with a range of environmental conditions as his intentions add another dimension that bears on the space of predictable action options.

In addition, language contributes to other forms of imagination that influence how we process ongoing action–perception cycles. For example, an agent can practice or exercise particular actions without actually engaging in overt behaviour and still benefit from such exercise. Such practice would amount to a process of 'running imaginary actions that produce a sequence of fictive actions and of predictions relative to future (rather than present) situations' (Pezzulo, 2012, p. 1). Verbally formulated intentions thus feed into an agent's predictive processing, offering in that way an additional dimension to those of motor expertise and environmental conditions: '[w]ords, we might say, are (for us language users) a metabolically cheap and flexible source of "artificial contexts"' (Clark, 2016, p. 284). If imaginary, artificial or otherwise, these words will have a lasting impact on the predictive processing and the outcomes it generates that are visible in an agent's cognition and behaviour. This holds even for the narratives that agents use to sculpt their own rather stable spaces of action. Indeed, it has been suggested regarding 'narrative models of the world [as] occupying the highest levels of an individual's predictive hierarchy' (Hirsh *et al.*, 2013, p. 216) and functioning as an important 'prior' for the predictive processing that influences the perception–action cycles of an individual agent. The more coherent and tried the agent's narrative is, the more it will correctly prepare the agent for appropriate and flexible interaction with her environment. The reason for this is that narrative offers an important medium for facing the coordination and organisation challenges mentioned above.[12]

In sum, whereas predictive processing might function generally in a 'model-free' fashion, at other times 'model-based' processing might obtain with verbally articulated intentions or narratives influencing it. These figure in such cases as 'high-level elements in the models that structure our own self-predictions, and thus inform our own future actions and choices', effectively working as 'communal uncertainty-reducing device[s]' (Clark, 2016, p. 286). In describing 'The Predictive Mind', Hohwy confirms this description by contending that 'part of our communicative efforts also goes towards establishing common ground, that is ensuring we have the same model about the world in mind' (Hohwy, 2013, p. 253).[13]

One might fear, though, that when an expert or agent has narratively 'modelled' the upcoming self-predictions, she has in fact raised the cognitive monster that we discussed earlier. Perhaps surprisingly, neither the Predictive Processing account nor empirical studies confirm this fear that after such preparation an agent is set to merely perceive and respond as if being put on automatic pilot. On the contrary, the account instead predicts that her attention will be provoked by a situation or response that deviates from the self-generated expectations, as such an unexpected situation generates a strong prediction error (Winkler and Czigler, 2012). Such adaptive responses have been shown, for example, in studies with subjects carrying out long-term planning tasks—like the Travelling Salesperson Task, which entails finding the shortest route connecting many cities for only a single visit—who would notice relevant deviations from their expectations and respond flexibly to those by changing their planning strategies (Basso, 2013). In other words, when an expert or educator prepares herself adequately for an upcoming situation, she is preparing herself not to just rigidly apply a strict routine but also to flexibly respond to unforeseen situations.[14] Indeed, the Predictive Processing account suggests that, congruous with the specificity and complexity of the 'prior beliefs' or expectations that an experienced agent can employ, her attention will also be drawn more adequately to relevant deviations or surprises (Hohwy, 2012). Activating the more differentiated and hierarchically structured representations from the expert's Sculpted Space of Actions yields accordingly more helpful results than the less differentiated and structured ones that beginners have formed.

In the next section I will look more closely at whether this integrative cognitive neuroscientific account concurs with what we know about expertise in education. Is the integration of an account that explains how expertise is constituted in part by an organised 'collection' of relevant knowledge structures and explains how cognitive and brain processes more specifically employ these structures plausible in this domain? Responding to these questions we will observe that this understanding is partly at odds with an influential account that grounds expertise predominantly in intuition, rendering it consequently hard to articulate in an explicit, verbal mode (Dreyfus and Dreyfus, 1986). Applying this intuition-centred model of expertise to education, it has been doubted whether experts can be teachers, as experts are categorised 'as often arational. They have both an intuitive grasp of the situation and a non-analytic and non-deliberative sense of the appropriate response to be made' (Berliner, 1988, p. 43). In contrast, I will argue that experts in education, too, are developing a context-sensitive and intention-dependent Sculpted Space of Actions, contributing to an effective educational practice as their preparation influences the ongoing Predictive Processing that is required for the flexible interaction with pupils in a particular education context.

EDUCATORS' PLANFUL AGENCY AND EXPERTISE HELP TO MASTER THE COGNITIVE MONSTER

The previous section closed with a quote from an early and influential comparison of the stages involved in acquiring expertise with the specific development of educational expertise (Berliner, 1988). From the quote it may appear as if an expert teacher does not comply with my account of expertise which implies that experts profit from their having developed a Sculpted Space of Actions of which one dimension refers to articulated distal intentions and another dimension to compliance with situational conditions (Keestra, 2014). However, notwithstanding the possible support by an 'intuitive grasp' and a 'non-analythic and non-deliberative sense of the appropriate response', expertise in teaching is associated with important differences regarding the ability of explicitly recognising and articulating relevant classroom phenomena and of preparing with appropriately structured options for responding to those. Based upon observations and simulation studies, the authors found experts more likely than novice teachers to make assumptions, hypotheses and predictions with regard to classroom situations (Berliner, 1988). Such explicit articulation of future situations and focus on relevant features of specific situations—like individual students, contents or performances—feeds the upcoming Predictive Processing that prepares perceptual, cognitive and behavioural processes for engagement with those contents.

Other studies confirm that teaching cannot just rely upon intuitively applying the expertise that an educator has acquired but that effective teaching requires many activities that contribute to careful planning, preparation and evaluation of teaching, like preparing written materials, mentally planning teaching strategies and activities, evaluating student progress with assignments and informally through observations (Dunn and Shriner, 1999). Such explicit articulation of teaching goals and means offers a response to what has been termed the 'problem of enactment' or the question of how education should employ in educational practice their knowledge about what and how to teach. Not only for student teachers but also for more seasoned teachers, this problem of enactment remains, given that educational contexts and practices tend to be often subject to change and '[s]uccessful enactment requires the formulation of intentions' (Bronkhorst *et al.*, 2011, p. 1120). From their analysis of expert teachers' interviews on their teaching, the authors learnt that these intentions stem from both retrospective and anticipatory reflection which then inform the deliberations about subsequent teaching practices (Bronkhorst *et al.*, 2011).

To the extent that teachers are formulating intentions, they are also making themselves responsible, ascribing agency to themselves in their educational practice. Again, differences can be found between expert and novice teachers with regard to their situating themselves as educators personally at several levels of specificity in the educational context. In a comparison of novice and more competent—not yet expert—teachers, it was found that novices tend to focus largely upon the teaching's subject matter while competent teachers make themselves responsible and develop an accordingly contextualised and personalised view of teaching (Schempp *et al.*, 1998). In doing so, competent teachers are further sculpting their space of actions, we can now contend. This has further ramifications as without formulating such personalised and contextualised intentions, 'undirected teachers' have difficulty with innovation, changing educational practices, and learning about their teaching (Vermunt and Endedijk, 2011).

In line with both frameworks articulated above, expert teachers are found to employ during all these educational reflections and preparations more and more hierarchically structured representations than beginners do. Such complex representations allow expert teachers to better recognise the affordances of specific class contexts and the needs of individual pupils, to interpret these and respond to them effectively, for example by scaffolding an individual student's learning demand (Ropo, 2004). Importantly, these representations concern not just the immediate goals and means of teaching particular classes, but also more abstract and general goals of education that can figure in a personal narrative. This emerged from analyses of pre-class and post-class interviews as well as class videos showing that expert teachers not only carefully plan their teaching in terms of the teaching goals related to real-world problems yet implemented in specific class contexts. More comprehensively still, their hierarchically structured representation of relevant knowledge and relevant aims for teaching are in fact connecting a tactical level of specific class planning via an intermediate strategic level with an overarching personal system of more general beliefs and values (McAlpine *et al.*, 2006).

Obviously, expert educators as well as other experts realise that they cannot always rely upon their assembled expertise as to what should guide them through an oftentimes unpredictable or intransparent environment. On the contrary, part of the development of expertise is precisely knowing not only how to keep on improving one's expertise but also knowing how to employ it under different conditions and to prepare oneself optimally for those. This is not just dependent upon cognitive and brain processes. Indeed, part of that practice concerns organising and timing of the use of materials, tools, interactions with colleagues and the like: experts learn as part of their training to scaffold and facilitate their performance also with many different resources outside of their individual skulls. As educators, experts not only rely upon their own but also train their students in such 'extended expertise' (Menary and Kirchhoff, 2014).

In sum, the studies mentioned in this section confirm that expert educators cannot merely be working from their implicit intuitions but that part of their expert performance requires carefully preparing their teaching, for example, by explicitly articulating their plans and intentions for upcoming lessons.[15] Updating and activating in a situation relevant fashion their Sculpted Space of Actions, these experts can aim to prepare ongoing cognitive and brain processes to draw their attention to unexpected, surprising situations and responses from others.

EDUCATION AND LESSONS FROM THE COGNITIVE NEUROSCIENTIFIC ACCOUNT OF EXPERTISE

After having raised the concern about the 'cognitive monster' that is lingering to determine our cognition and behaviour as a result of experience (Bargh, 1999), an empirical study showed Bargh and others that the situation might not be as bleak as thought before as there are ways to regulate and control the automatised and unconscious processes involved (Hassin *et al.*, 2009). However, the warning against monstrous behaviour is still partly justified and should encourage paying attention to the processes involved in developing and employing expertise. The explanatory framework presented above suggests how expertise involves not just the intentional establishment of an organised space of structured and coherent representations, but also awareness and control about how to regulate the processes that draw on this space in such a way as to avoid the downside of it. Both elements have implications for what education should accomplish.

In contrast to accounts of expertise that merely underline the role of implicit and automatised processing, my arguments point towards the fact that experts are employing a Sculpted Space of Actions as a coherent set of complex structured representations of action options that is partly determined by distal intentions to suggest how those intentions do play an important role during the process of sculpting that space of action options. Intentionally preparing for, attending to, and reflecting upon the structure of actions—including focus on undesirable action features—contributes to the formation of a coherent space of actions and as such facilitates flexible and cost-effective expert cognition and behaviour. In addition, expertise requires skills for monitoring and guiding relevant cognitive—and thus indirectly: brain—processes in such a way that potentially undesirable implications of having established a Sculpted Space of Actions are mitigated as much as possible.[16] Such monitoring and guiding involves not just an expert's relevant cognitive and affective processes but also the behaviours stemming from those and relevant situational conditions, including influential social interactions (Zimmerman, 2006).

Obviously, educating novices should equally entail these two faces of expertise: establishing both the specific resources that experts rely upon for their specific cognitive and behavioural performances as well as the metacognitive and practical skills to employ those resources in a regulated way or to intentionally modify situational or pragmatic conditions such that standards or goals are met. It is thus a whole suite of organised and stored action representations and multiple processes that together enable what often looks like installing a second mind in a single brain—surprising not just pupils themselves but also their educators again and again.

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NOTES

1. Indeed, it has been argued on the basis of comparative evidence that 'natural pedagogy' is specifically a human adaptation (Csibra and Gergely, 2011).
2. Experts often report that in a given situation they immediately feel, almost emotionally, that a particular option stands out against the rest, which they then perform with confidence. This holds for chess masters (Gobet and Chassy, 2009) but also for firefighters (Klein *et al.*, 1986), for example.
3. A similar concept is 'schemas', which is sometime used slightly different, for example when it is taken to include less explicitly the socio-cultural rules that are relevant for action 'scripts', with schemas being composed rather of a 'vocabulary' of motor movements (Jeannerod *et al.*, 1995).
4. According to the neuroconstructivist account of learning and development, the representations involved in learning are undergoing a process of Representational Redescription, which entails 'redescribing its representations or, more precisely, by iteratively re-representing in different representational formats what its internal representations represent' (Karmiloff-Smith, 1992, p. 15). Due to this process, the knowledge structures or representations become available for different cognitive and brain processes and allow an agent to perform a task under different conditions and with different properties. It is this process that also enables implicit learning during which sometimes very complex tasks that initially require conscious control and explicit instruction become automatised and performed more fluently (Cleeremans, 1997).
5. The description and explanation of cognitive processes by way of such multidimensional 'geometrical' accounts is not uncommon in cognitive neuroscience, robotics and elsewhere. Indeed, several authors have applied such accounts to wide ranges of cognitive processes, for example to perception or moral decision-making (Churchland, 1995) or to linguistic and computational functions (Gärdenfors, 2004).
6. In her review of philosophical and cognitive neuroscientific literature on intentional action, Pacherie presents a 'cascade of intentional action' consisting of motor intentions, proximal intentions and distal intentions (Pacherie, 2008). I have applied this framework more specifically to expertise, developing the notion of a sculpted space of actions with the three levels of intentions being transformed into the dimensions represented in the figure (Keestra, 2014).
7. Apart from motor and distal intentions, one could also distinguish 'proximal intentions' which are responsible for anchoring an intention in a particular situation (Pacherie, 2008). Since such anchoring in the case of experts depends largely upon the many relevant perception-action links that expertise has yielded, it is preferred here to include a dimension of 'compliance with situational conditions'.
8. Experts in a particular sports appear to perform better in perceptual and cognitive tasks in other sport domains than non-experts in sport. This confirms that an expert's Sculpted Space of Actions is to some extent transferable to other domains, not strictly limited to one domain (Abernethy *et al.*, 2005). Given the hierarchical structure of the representations involved (Weigelt *et al.*, 2011), this partial transferability is not surprising.

9. Indeed, Bratman has also argued that once a practical situation happens for which a relevant future-directed intention has been made earlier, it retains the coordinating role even though in that situation here it is not involved in a process of deliberation from which it initially stems (Bratman, 1999). In other words, a particular kind of intention may remain effective by being adjusted to another kind of intention formation.
10. Although animals are perhaps not capable of planning of complex actions like humans do, there is sufficient evidence that simple means-ends planning is prevalent in several other species and some are even 'using anticipatory planning in their social strategizing' (Byrne and Bates, 2007, p. 721).
11. There is still debate about the '10,000 hours' that experts typically devoted to their field, as other research suggests that far fewer hours can still lead to expert level performance (Baker *et al.*, 2003)—yet experts still devote much more time than non-experts to their field.
12. Conversely, difficulties in narrative simulation have been associated with issues in health and wellbeing: they can be observed in patients who have difficulties in other domains, too, like in employing complex representations of actions and performing those actions (Cannizzaro and Coelho, 2012; de Oliveira *et al.*, 2009).
13. Since narrative functions in part as a 'communal' or communicative instrument, it also invites co-construction with other agents. Indeed, as personal as narratives can be, they also employ (re-configurations of) representations that are rendered by tradition or in education (Keestra, 2008, 2014; Ricoeur, 1992).
14. Indeed, Predictive Processing is said to drive development and learning at different time-scales, from the millisecond scale of neural processing to the processes that figure at an evolutionary scale (Friston, 2011).
15. Working with expert musicians, it has also been noted that an intuition-based account like Dreyfus's falls short in that it does not provide room for top-down influences. The 'applying intelligence to the reflexes' model that the authors present seeks to remedy this, yet by focusing on the narrow process of memory recall the model fails to explain some forms of intentional preparations mentioned here (Geeves *et al.*, 2014).
16. Such monitoring and guiding require specific metacognitive capabilities and training, which have received little attention in the literature on expertise (Didierjean and Gobet, 2008).

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