Developing expertise with objective knowledge: Motive generators and productive practice

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Abstract

The benefits which experts seek to derive from formal knowledge are manifold. Experts, viewed as progressive problem solvers (Bereiter & Scardamalia, 1993), face psychological and practical challenges to learning in depth, particularly given demands for breadth and a lack of cognitive productivity tools. What mental changes occur when one understands deeply and develops new skills, new attitudes, implicit knowledge, etc.? With a few scenarios, I propose that deep understanding of conceptual artifacts, in the sense of Bereiter (2002), establishes and configures many new motive generators which enable the valenced detection of gaps of understanding, cognitive infelicities and opportunities (cognitive itches). This proposal, derived from a designer-based approach to motivation (Sloman, 1987; Beaudoin & Sloman, 1993), is significantly different from how motivation is typically treated in psychology. It raises many questions about how motivational mechanisms develop and operate in the propensities of expertise. I suggest that experts facing great cognitive productivity demands can benefit from productive practice.

Keywords: cognitive itch; cognitive zest; expertise; motive generators; productive practice; progressive problem-solving; transfer of learning.

Preface

Flush with scholarships and graduate school opportunities in 1990, having researched the Commonwealth for the most fertile ground in cognitive science, I heeded Dr. Claude Lamontagne's advice to study with a brilliant scholar he had known at the School of Artificial Intelligence of the University of Edinburgh (1972-3). Lamontagne praised Aaron Sloman's penetrating mind, one which always offered insightful comments, criticisms and suggestions aimed at the heart of the matter. Lamontagne also knew that Sloman (and Sussex University) fully embraced theoretical, computational cognitive science. He was right. Sloman is—as

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all who know him well will attest—a productive thinker of the highest caliber and the wise steward of a beautiful mind.

This somewhat Escherian paper weaves five themes from cognitive science in my quest to understand and help enhance experts' cognitive productivity:

1. Productive learning and expertise (Bereiter & Scardamalia, 1993; Wertheimer, 1959). Sloman introduced me to the work of Wertheimer (e.g., Sloman, 1978), who seemed to capture the essence of productive thinking, though, ironically, Wertheimer's understanding, like Freud's, was stunted by concepts from physics.
2. Motive processing, from a designer stance (Sloman, 1993). The stance itself affords productive thinking.
3. Conceptual analysis (Sloman, 1978), which also are helpful thinking tools.
4. Potent psychological principles for productive learning (too many to list here).
5. Self-regulated learning with technology (Beaudoin & Winne, 2009; Winne, 2006).

The paper makes frequent reference to Sloman's work, which is both an indication of how he has shaped my thinking and an illustration of the variety of ways in which his ideas can be applied and extended.

In my quest, I seek to wrest the mechanisms underlying "testing effects" (Kuo & Hirshman, 1996) from Ebbinghaus's undying grasp on cognitive psychology, to polish them and to hand them over for theoretical and practical study to the scions of Immanuel Kant, Max Whertheimer, Frederic Bartlett and Warren McCulloch. I hope this paper will inspire others to address the difficult problems I have raised.

Introduction

> [We] must, so far as we can, make ourselves immortal, and strain every nerve to live in accordance with the best thing in us; for even if it be small in bulk, much more does it in power and worth surpass everything. [...] the best and the most pleasant life is the life of the intellect, since the intellect is in the fullest sense the man. So this life will also be the happiest.
> Aristotle (Nic. Ethics, Bk. X, Chapter 7)

This paper addresses factual and practical problems concerning expert multi-purpose (broadly transferred) learning from formal knowledge (whether factual, practical or normative (Sloman, 1978 ch. 2)). I describe purposes of and modern challenges to such productive learning. The factual problems concern the motive processing involved in productive learning. The practical problems are to enhance learning from knowledge resources. I focus on motive generators for the former problems. Based on some of the most potent applicable principles from cognitive science,[1] I propose productive practice for the latter. I raise a number of research challenges regarding these overlapping concerns.

I propose that when and after experts process documents[2] conveying formal knowledge in such a way that they can apply it much later—e.g., they develop a *lasting* understanding, acquire skills, develop new attitudes, etc.—they grow *new* motive generators. *Motive generator* is a concept proposed by Sloman (1987) and developed by his Cognition and Affect (CogAff) Project in response to the problems of understanding autonomous agency (Sloman, 1987, Sloman 2008, Beaudoin 1994). Motive generators are mechanisms which tend to produce evaluations, wishes, wants, goals, etc., that may be selected for consideration or physical action. To my knowledge, the concept of motive generator has not previously been explicitly applied to the problems of transfer of learning (Haskell, 2000); though I take its applicability to be implied by the CogAff schema Sloman (2008). The concept suggests a new, mechanistic[3] way to interpret, answer and spawn new problems from the question raised by Bereiter & Scardamalia (1993), "What motivates the process of expertise?"

Bereiter & Scardamalia (1993) coined a distinction between two senses of the word expertise. *Crystallized expertise* is the hard-earned ability to solve problems and perform at a superior level. *Crystallized expertise* is the result of abilities that are applied by people as they strive to become more competent. They refer to these abilities as *fluid* expertise. The terminology parallels the distinction between crystallized expertise and fluid intelligence. Following R. W. White (1959) I refer to the motivation to solve problems at the edge of one's competence and to push the boundaries of one's understanding of important (and increasingly complex) problems, solutions, formal knowledge, etc., as effectance. Effectance is the motivation for increased effectiveness. The concepts of effectance and fluid expertise help one to understand how some become and remain (crystallized) experts while others become non-expert specialists.

This paper is particularly addressed at expertise of knowledge workers and lifelong learners who increasingly use technology and knowledge in their pursuit of personal excellence. While this is not a precise demographic, targeting it allows one to study deep understanding and those who strive for it.

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[1] I include psychological (e.g., affect) theory in cognitive science if it can be expressed as information processing.

[2] I use the words "document" to stand for all kinds of information objects (e.g., podcasts, audiobooks, videos, designs, illustrations web pages, books, papers, etc.) that convey knowledge. I use "to process" documents to mean reading, viewing or listening to documents.

[3] "Mechanism" here does not refer to a physical or biological layer, but virtual machine layers (Sloman & Chrisley, 2010). It does not preclude but underpins teleology (Boden, 1972/1978).

Experts develop highly tuned abilities and tendencies to detect and repair gaps in their understanding, cognitive infelicities and cognitive opportunities. In the context of the CogAff schema (Sloman, 2008), it is natural to suppose that experts develop innumerable, finely tuned motive generators. These mechanisms are constantly responsive to important problems of understanding, which they perceive in a valenced way —meaning that the perception inherently disposes their host to engage in problem solving (Beaudoin, 1994). I elaborate this point in Section 0 below.

An irony of the expertise and education literatures is that experts are often placed on a pedestal whereas students are frequently seen as deficient. Yet expertise involves seeking situations that highlight one's ignorance and perceiving problems of understanding as *enticing opportunities* to better understand. With the concept of fluid expertise, Marvin Minsky's remark applies: "No matter what one's problem is, provided that it's hard enough, one always gains from learning better ways to learn" (Minsky, 1986). In this vein, the current paper, though largely conceptual, also aims to understand how to help experts extend their own excellence as they process objective knowledge (Popper, 1978), or conceptual artifacts (Bereiter, 2002).

The contributions that this paper makes to the latter, practical objective, are (1) to characterize the goals and challenges of expert learning, i.e., its requirements; and (2) to briefly specify how these objectives can be met with upcoming, new technological developments that expand and leverage concepts, principles and findings from cognitive science, namely annotation systems and *productive practice* systems.

Purposes of productive learning from formal knowledge

To understand the role of motive generators in expert learning and to enhance such learning, one must consider the manifold aims of learning. Bereiter (2002) criticized Bloom's (1956) taxonomy for leaving out understanding. Gagné, Briggs, & Wager's (1992) taxonomy is performance-oriented, simplifies understanding and reduces affect. This paper and its literature deal with some of these shortcomings.

A philosophical pre-amble is required. Bereiter (2002) argues compellingly that to understand understanding, it helps to divide the world into three (Popper & Eccles, 1977; Popper, 1979): World 1, the physical world; World 2, the psychological world; and World 3, the world of artifacts, of which only conceptual artifacts and the documents that describe them are central to my paper. Here, I refer to conceptual artifacts, i.e., designs, theories, models, prescriptions, etc. as "formal knowledge" and to their descriptions as documents. Understanding lies not in *one* world. Rather, it consists of a relation between a knower (World 2) and formal knowledge (World 3). This relational concept of understanding has many benefits; e.g., it allows one to improve the already potent concept, *knowledge gap* (Vanlehn, Arbor & Jones, 1993).

Here follow some overlapping categories of purposes that experts may have when processing documents. The list glosses over superficial and transient purposes of learning from documents as well as the practical (psycho-, socio-, and economic) consequences of learning. I focus instead on goals of understanding and of personal enhancement, which are not all easily researched experimentally.

- To understand and work formal (statable) knowledge. To characterize understanding as a relation between knower and an object of knowledge, one needs to take stock of the different types of formal knowledge. Sloman (1978) provides a taxonomy of scientific knowledge (implicit in science's aims). It includes many of the following types of *formal* knowledge: problems, concepts, symbolisms, languages, methods, designs, vocabulary, etc.; real possibilities; correlations, contingencies, explanations of (known) possibilities; limitations (laws, strict principles); explanations of limitations; analyses, criticisms, assessments, etc. Understanding (recursively)[4] requires an understanding of the problem that the formal knowledge is meant to solve. Some formal knowledge has a design. As such, to understand it requires knowing its structure, whether and how the design solves the problem, and how well it solves it (Wertheimer, 1959; Perkins, 1986). Understanding is neither an all-or-none nor a scalar concept.[5] A thorough understanding involves understanding the space of possible requirements, other designs, and implementations and the relations between these levels.[6] There are other types of knowledge, e.g., regarding the *content* of the world.
- To develop implicit understanding. This involves an ability to work with knowledge, to make predictions and counterfactual statements without necessarily being able to formulate it explicitly or verbalize it to others. (See Karmiloff-Smith (1995) and Sloman (1985) for additional representational subtleties.)
- To develop skills and mastery. This entails abilities to solve problems and achieve goals (cognitive and other).

[4] Space does not allow me to demonstrate that the circularity in this concept of understanding is virtuous.

[5] Sloman admonishes readers and listeners to beware of the tendency to falsely assume that they are dealing with continuity as opposed to richly structured discontinuous spaces (e.g., Sloman, 1984; .)

[6] Thus, the designer-stance (Sloman, 1993) to the mind can be applied to other objects of understanding. This is consistent with the elaborate concept of understanding in (Bereiter, 2002). Problem-centred knowledge becomes requirements-driven knowledge.

- To develop episodic, historical and narrative knowledge and abilities to utilize it (e.g., knowing which stories are pertinent to which situations and being able to tell them appropriately).
- To understand norms (standards, processes, etc.) (Ortony, Clore, & Collins, 1988), to assess, them, to select them and to regulate one's behaviour according to them.
- To develop attitudes towards objects (tastes, likes, dislikes, etc.) (Ortony, Clore, & Collins, 1988). E.g., one might want to like one's neighbour or dislike salty food.
- To develop habits and propensities. High-caliber knowledge is wasted unless one tends to think and act in accordance with it when it is applicable.
- To develop more abstract cognitive-behavioural dispositions that combine the above. E.g., one might want to become more *resourceful* after listening to it (Robbins, 2010); or acquire thinking dispositions, such as to think broadly, rigorously and systematically with the knowledge.

This taxonomy is not complete. It shows that there is a variety of top level goals and types of learning, not to mention the innumerable instrumental ones. Affect is doubly involved in the foregoing list. Learning from objective knowledge is not just a matter of developing 'declarative' and 'procedural' knowledge[7]. First, affective change is an abstract class of specific learning outcomes one may strive for. Second, each of these types of knowledge inherently involves affective change, e.g., developing new motives.

Now here is a major challenge for cognitive science. How can one help experts respond to information such that they can achieve these manifold learning objectives? Transiently comprehending knowledge as one processes a document— e.g., about conceptual analysis, emotions, attitudes, resourcefulness— is not a significant problem for the expert. But achieving lasting benefits from it—e.g., to develop the skills of conceptual analysis, to apply potent theories of emotion when solving problems (i.e., achieving broad transfer), to develop desired attitudes towards one's partner, or to actually become a more resourceful person — poses a collection of problems for the individual and cognitive science, particularly in the light of the challenges described in the next section.

Productivity concepts are required in order to improve or supersede the hoary concepts of *active learning* and *deep learning*. Productive learning from objective knowledge involves the kind of productive thinking expounded by Max Wertheimer — it entails understanding. It involves the production of manifold psychological dispositions, abilities and underlying mechanisms, as opposed to merely the development of content in long-term memory (if there is such a thing) or merely skills and abilities to perform. Cognitive productivity is an optimization of effectiveness and efficiency that involves dispositions to think in a manner that

[7] Sloman (1975, 1996, 2011) undermines the distinction between declarative and procedural information.

is deep, open-minded, aware, systematic, broad, rigorous, creative, curious, strategic, understanding-driven and sensitive to unfolding opportunities and context (e.g., Baron (2008), Perkins (1995)). The *internal* products of productive learning are new mechanisms (such as new motive generators) and configurations of these and existing mechanisms.

These cognitive productivity concepts are aimed at addressing theoretical and practical problems of transfer and satisfaction of personal as well as extrinsic criteria. Theoretically, they are to be developed to address problems of understanding for cognitive scientists (understanding transfer). What must happen during and after processing a document in order for the mechanisms to be grown so that one can surpass one's former self? Practically, they are tools to focus expert learning, to ensure that more of what is temporarily comprehended is understood, remembered and applied in the long run.

The manifold purposes of learning call for a conceptual understanding of affect and its role in cognition and transfer. Researchers might turn to practical psychological literature on developing affective states (see Section 6.3). But psychologists must also revisit information-processing theories and conceptual analysis. More research is required to understand affective processes in expert learning and to develop better practical suggestions for experts. In Section 0 below I begin to specify a form of practice, which I call productive practice, aimed at supporting productive learning.

Understanding how to facilitate productive learning is of great significance to society. It may allow (groups of) experts to better exploit the opportunities (and face the challenges) posed by the knowledge age.

Challenges to productive learning

In order to support the processes of expertise one must understand the modern challenges to productive learning from documents. Expertise does not make one invulnerable to learning challenges; moreover, it does present problems that are distinct from those faced by most students (e.g., cognitive aging) and specialist non-experts. In this section, I discuss some of these technical and psychological challenges. The technical ones could be alleviated by cognitive productivity software such as an annotation system and a productive practice system. The psychological challenges could be addressed by cognitive productivity workflows and concepts.

The knowledge economy is extremely competitive. Jobs are often scarce. The amount of information that one must process is soaring. Many IT workers, for example "never feel they have enough knowledge for their jobs" (Westar, 2009). Yet reading is not enough. Expertise demands productive learning that can be used for progressive problem solving. Determining what to learn is challenging—

distractors abound and the future is uncertain. Cognitive aging (Craik & Salthouse, 2008), parenting and commuting bring problems and opportunities.

It is no wonder that "productivity software" sells well. However, the category *cognitive productivity* software had not previously been adequately articulated. Cognitive productivity software would be designed specifically to help users achieve the types of objectives listed above while achieving other, extrinsic goals. Some applications could be adapted for this (e.g., outlining and diagramming tools). However, two important categories of cognitive productivity software are not available commercially.[8] One has to do with annotating; the other with practicing. Ultimately, one's computers, tablets, smartphones, etc., need to be an integrated productive learning ecosystem including these two types of applications.

Information processing

Here I describe information processing challenges faced by experts.

Technology serves objective knowledge in various formats: PDF files, e-books, web pages, emails, videos, audiobooks, podcasts, etc. Meanwhile, paper has not gone away. Internet-enabled applications connect experts to each other.

Each expert must develop his own cognitive workflows using a hodge-podge of software. Even for one type of information (ebooks) users may rely on several different applications (e.g., Kindle® and iBooks®.) An expert needs to annotate, organize and link information together in a systematic, powerful and coherent way to rapidly re-access and use it. Each application has its own interface and limited set of capabilities. One cannot yet even uniformly highlight or precisely link arbitrary text (let alone audio and video) from the various formats listed above. Tagging text is not possible in most applications. Neither is annotating in a general fashion.[9] Such links would need to be robust under document changes. Furthermore, experts must either create their own glossary management tools or manage glossaries spread across numerous servers and documents.

Even today, publishers and major software vendors have not adopted schemas (Vlist, 2002) or implemented software that would allow users (and software) to

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[8] Existing annotation, practice and "cognitive fitness" software applications address narrow requirements (e.g., types of document and types of learning outcomes) Beaudoin (2010, 2010a, 2013).

[9] By general annotation, I mean to link any information item accessible from the local host to any existing or self-authored one (e.g., a new note). An example of general annotation is to link a paragraph in an iBooks document to a snip in an email message. My colleagues and I have created several personal learning environments with extensive annotation capabilities, e.g. Winne (2007); Beaudoin & Winne (2009).

query a schema-compliant document for information, such as its table of contents (which ought not to be limited to the few levels that typical books provide but should include all headings), index and bibliography. Knowledge workers must process each document to obtain this information. This is unnecessarily tedious. They should be able to issue a command to have the information presented to them— in the style sheet of *their* choice.[10] This information could be extracted and form a starting point for *their* detailed meta-documents, i.e., documents about the resources they are reading,[11] with powerful outlining,[12] editing, tagging, search, referencing, and productive practice integration.

Adding to the expert's woes, previously studied documents are distributed across multiple platforms: e.g., a computer, ebook reader, tablet and smartphone. The expert must devise a scalable way to sync his documents, meta-documents, etc. Of the exabytes of content available to the expert, of the subset one 'reads', what matters most is that which one has read carefully and one's thoughts about it. Yet due to technical issues, even the expert likely does not properly annotate most of the noteworthy electronic documents he reads.

I conjecture that even most technically savvy experts have not yet developed optimal solutions to these problems. Moreover, many fail to use powerful cognitive productivity software that does exist (e.g., outliners and diagramming tools). Having worked on cognitive productivity problems for 10 years, I believe these issues are tractable. With well-articulated requirements, expertise in cognitive science and an engineering approach, adequate solutions (software and workflows) can be specified and implemented. The shallow, defeatist meme that the Internet has "rewired our brains" and that one is doomed to light learning is easily refuted (Pinker, 2010) and will hopefully become extinct as better solutions are developed and disseminated.

A landmark literature review showed what one would expect, namely that as experts read important paper documents they (often zestfully) seek overall meaning, make and adjust predictions about the problems and content, categorize, and assess—while leveraging their prior knowledge (Pressley & Afflerbach, 1995). This they do flexibly, often writing as they read. Well before the Internet, knowl-

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[10] A simple example of this would for readers to be able to choose for any scholarly document whether to view it in MLA, APA or some other format. This entails the separation of data from its presentation, as is commonly done with XML and cascading style sheets (CSS).

[11] Reading is just a special case. This applies to processing knowledge resources in general. Beaudoin (2013) explicitly deals with knowledge processing in general.

[12] Why should the annotator need to switch to a limited editor in a special-purpose annotation tool? An annotation system could easily leverage the user's preferred word processor, outliner and diagramming tools. This is in the spirit of Poplog Ved, emacs and OpenDoc.

edge workers developed reading and annotating schemes to deal with overflowing information (Selye, 1964).

Annotation software should allow experts not merely to highlight text but to categorize and extend information in their terms. Examples of fine-grained annotation tags an expert might use to categorize text, images, audio and video segments include: purpose, thesis, major proposition, ancillary proposition, term, concept, definition, criteria, question, author, hypothesis, premise, conjecture, methods, results, data, findings section, key argument, warrant, "I disagree", interesting, "I do not understand" (i.e., knowledge gaps), to do (follow up on, reread, etc.), irrelevant, comment, learning questions. A configurable color scheme could enhance this deeper coding.

Users should be able to quickly (within 2 seconds) locate any document they have annotated. Given such a document, one should be able to rapidly list or locate one's annotations (e.g., to find the thesis, extract the technical terms, or their points of disagreements). Navigation between comments, the annotated document, one's personal glossary and related meams (as defined below) should be very rapid.

The absence of this functionality, workflows and skills, hinders cognitive productivity in ways that experts may not explicitly realize but would easily understand if the tools were made available to them. Even these tools would not be enough for experts to meet current demands—something more transformational is required.

Productive learning

In this section, I describe psychological and technical challenges to deriving deep benefits from information. Whereas the empirical study-strategy literature has focused mainly on formal paper/pencil education with normal-range students (as opposed to expert self-education with technology) (Mulcahy-Ernt & Caverly, 2009), some of the educational psychology findings are relevant to our interests here, e.g., about meta-cognition, self-regulated learning and self-testing.

Many students are quite susceptible to the following types of "illusions of competence" (Karpicke, Butler, & Roediger, 2009) as they process documents. They

- fail to recognize that they have not properly comprehended what they have read (their knowledge gaps) (Karpicke, Butler, & Roediger, 2009.) (The illusion of understanding.)
- overestimate the likelihood that they will remember what they have read (McDaniel, Callender & Byrne (2008)). (The illusion of remembering.)
- fail to predict that they will not be able to solve diverse problems with the objective knowledge they have processed because they will not do what it takes

to ensure transfer —and to adapt their processing accordingly. (The illusion of transfer.)

Whereas the illusion of understanding is much less a problem for experts, I suspect that experts are not immune to the latter two illusions. Further, while if prompted, experts might make better judgments of learning than college students, they might not be prompting themselves sufficiently (e.g., skimming too much). Given the availability of information, the demands to process large amounts of it, and the state of technology described above, perhaps many experts are not spending enough time ensuring they can utilize the most potent information they 'consume' (see also Schopenhauer 1841 ch. 3 and Lamontagne, 2002).

Students tend to overestimate the effectiveness, for both understanding and remembering, of re-reading documents or applying ideas (e.g., in open book exams and assignments); conversely, they under-estimate the effectiveness of being tested (closed book) (Karpicke & Blunt, 2011). I suspect that experts are also susceptible to this error. If they were properly informed about the implications of these findings and how to leverage them with software, they might adapt their learning strategies and improve their cognitive productivity (i.e., they might more deeply understand, recall and apply what they learn, while consuming less time overall.)

The market has yet to produce a second important class of cognitive productivity software. Experts likely have answers to questions such as: "What applications do you use for: writing email? Developing a spreadsheet? Composing a document? Browsing the web? Reading PDF files? Drawing a diagram?" But if you ask: "What software do you use when you want to not only read but learn something (i.e., turn information into your own knowledge and personal excellence)?" an answer is likely less forthcoming. If you were to further explain that the software should help to achieve the manifold purposes of learning described above, there may still be no answer. This calls for productive practice system with document annotation capabilities. There are many principles of cognitive science that could inform the development of cognitive productivity software and workflows which would have significant impact on knowledge workers—particularly if, like many other applications, they shipped with operating systems.

The role of motive generators in productive learning

> Cognitive psychologists are often accused of ignoring motivation. A more generous appraisal would be that they honour the principle if you don't have something worthwhile to contribute on a topic you should refrain from speaking. Most of what psychologists of any sort have to say about motivation is warmed-over common sense. The part that is not common sense involves the brain, but it is at such a basic level that we

> cannot expect it to be helpful in distinguishing experts from experienced nonexperts. (Bereiter & Scardamalia, 1993) p.101

There is truth to Bereiter and Scardamalia's view. However, I take issue with the idea that motivation theory must either be folk psychology or biology. Moreover, folk psychology ought not to be ignored—let us not forget that Einstein's theory of relativity involved his analysis of ordinary concepts. Psychology, when its research methods are divorced from conceptual analysis, does not do justice to the rich English affective lexicon (Ortony, Clore, & Foss, 1987). Alas, conceptual analysis sometimes goes astray. A major problem with the influential book, *The Intentional Stance* (Dennett, 1987), is its coarse reduction of affective states to the concepts of belief and desire. That book is not unique in over-emphasizing prediction and neglecting the importance of understanding; for understanding is a relation that almost always requires dealing with the object's inner structure (in the tradition of Kant, Wertheimer, Bartlett and design-based AI). One of the problems with Psychology's approach to motivation is that it is too focused on explaining why individuals do things, rather than how the mind enables them to generate, process and pursue their goals. It tends to reduce motivation to scalars (mainly intensity), thereby ignoring rich structures and information processing underlying motivation. There is an over-emphasis on data collection and an apparent failure to recognize the key insight of (design-based) cognitive science: One can only discover the *actual* mechanisms of mind by specifying what the mechanisms, architecture and control sub-states (Sloman, 1993b) might *potentially* be in relation to the requirements that they must satisfy. I do not claim that the designer stance guarantees rapid success.

The CogAff project's approach couples the designer stance (McCarthy, 2008; Sloman, 1993) with conceptual analysis (Sloman, 1978). The designer stance encourages one to develop conjectures about information processing mechanisms that are layered on the brain and other physical devices.

The CogAff theory assumes that the mind is perpetually generating (and not merely deriving through means-ends analysis) motivational states (motives). We assume a human mind contains a multitude of motive generators. These mechanisms perpetually monitor internal processes, events and states and respond by creating motivational states (motives), which are control states that incline one towards affecting the (internal or external) world in some way. Humans may have fewer than ten physical perceptual modalities, but they have countless internal monitors. Motives underlie our wishes, wants, desires, whims, preferences, etc. The fact that the mind is inhabited by these mechanisms has never ceased to fascinate me, ever since I first read about them in (Sloman, 1978). In my opinion, understanding motive generators and how they develop is as fundamental to cognitive science, writ large, as understanding force and energy is to physics.

This section addresses one aspect of the following question: In what way does your mind need to change in order to be able to apply what you have previously learned? In other words, what must happen in your mind such that you transfer this information 'far' from its original context? In this section, I propose that an important part of the change is that one's mind creates and configures new motive generators. These mechanisms produce motivational states to respond to *future* applicable situations. An important goal of (self) education must implicitly be to fine-tune these motive generators such that they create the right motivational states at the right moment. Another goal is for management and meta-management processes to properly process these motives when they surface.

I will provide examples of three types of transfer targets: skills, understanding and attitudes. My answer makes use of concepts developed by Sloman (1987) and other members of the CogAff project which were based on Simon (1967) as were (Frijda, 1986; Oatley & Johnson-Laird, 1987). The CogAff project sought to understand, amongst other things, motive processing requirements, architectures, mechanisms and representations. Productive learning impacts on each of the latter. In particular, it must affect motive generators and management processes (Beaudoin, 1994).

My conjecture is that as one learns productively, one's mind creates and fine tunes a potentially large collection of motive generators. These mechanisms become tuned to respond to specific opportunities and problems that pertain to the information in question, at various levels of abstractions. Many of these monitors are looking for problems in the solutions that other mechanisms in the mind are generating, or that other people have generated, or that are explicit or implicit in conceptual artifacts.

A key design problem for transfer is to decide how the insistence of these motives is to be determined. In previous work we characterized insistence as heuristically related to the importance and urgency of motives (Beaudoin, 1994; Sloman, 1987). I have previously analyzed the components of goals (Beaudoin, 1994). Another factor that contributes to determining the insistence of motives that are derived from mastering objective knowledge is the perceived potency of the particular objective knowledge for a range of problems.[13] This is akin to the usefulness of any tool (conceptual artifacts are tools). An important part of the development of expertise is being able to recognize the potency of knowledge for problems that one might encounter. This should influence the effort that one expends on mastering the knowledge. Repeated, elaborate use of knowledge in varied real or imagined situations depends on and influences judgments of its potency. Using knowledge creates motive generators that monitor for situations in which it might be of future use. An expert mind must do what it can to ensure that the motive generators related to potent tools develop adequately. This will often initially lead to situations in which the resultant (potent-tool related) motives have too high insistence. Compare when one considers using a new kitchen instrument when a different one applies.

[13] This is related to *promisingness* in Bereiter & Scardamalia (1993) and *potential* in Sinclair (2006).

The heuristic nature of asynchronous motive generators (Sloman, 1987) has a dark side. For example, knowledge workers are exposed to red herrings — alluring, impotent information that may trigger motives to read. Motives don't necessarily distract attention; nor do they necessarily lead to external action. For instance, higher level processes can reject a motive until the next time it surfaces. But cognitive processing is an action of sorts, which must be monitored to detect distractions (an example of what we have called meta-management (Beaudoin, 1994)).

The importance to productive thinking of detecting what are now commonly called knowledge gaps cannot reasonably be disputed. Like many scientific propositions, that experts have a keen ability to detect and repair knowledge gaps is not merely a contingent, empirical truth; it is analytical. Experts continue to develop new motive generators to detect new types of knowledge gaps; they create motives to repair the gaps. Frequently, if one can detect a problem of understanding in a valenced way, one is most of the way to solving it; one merely has to "dare to think". A challenge is to detect the knowledge gap on the basis of the applicability of the objective knowledge with which one is already sufficiently familiar.

Max Wertheimer discussed the perception of knowledge gaps in his own terms. He emphasized that productive problem solvers become keenly aware of discrepancies between the "requirements of the problem they face" and their current "view" when it lacks adequate "penetration" or "clarity". Of course, experts do not always recognize their lacunas. Still, it is important to keep knowledge gaps in mind when thinking about learning. In this paper I focus on situations in which the expert already has acquired much of the information that he needs to address a problem. This enables one, subsequently, to somehow detect gaps in one and others' knowledge, which can lead to more progress.

One can ask numerous questions from the foregoing, such as what motivational mechanisms develop, enabling one to detect increasingly sophisticated knowledge gaps. What are the possible internal differences between the case when (a) one has understanding of some objective knowledge and yet when one tends to fail to apply (transfer) it and (b) when one does apply it? One possibility is that a motive generator actually fires in response to a knowledge gap in (b), but the motive is not sufficiently insistent to attract attention. What are the different ways in which this can happen? In answering these questions, we should not limit our attention to a simple layered architecture, in which a layer of motive generators is connected to one interrupt filter layer, connected to one management layer and a meta-management layer. Motive generators (i.e., monitors) are spread throughout a human-like mental architecture. There are monitors of monitors (meta-monitors). Failure to transfer could be due to failures in meta-monitoring.

The English lexicon contains a much larger number of words denoting negative affective states than positive ones (Fredrickson, 1998). This may be pertinent to the problems of transfer. In the much prized state of "flow", the expert proceeds smoothly, solving one problem after another, and gracefully deals with setbacks.

Progress is a rougher ride; expertise involves pushing the boundaries of one's competence, which means that one must face what are potentially annoyances or worse. Experts require cognitive zest, to put a positive spin on the difficulties they encounter. A setback, a difficulty, a bug in a computer program, a relationship that is not quite right — these are often opportunities to improve one's knowledge. But for many experts — perhaps for most — negative affect is present in otherwise optimistic states before the hurdles are overcome on the road to further excellence. Perhaps this fact about the English affective lexicon reflects the human condition and entails that learning produces more motive generators to detect impasses than to detect (and enjoy) progress. (How could this be determined?)

In the following sub-sections, I will provide examples of the role of motive generators for three types of knowledge: skills, dealing with a theoretical problem of understanding, and attitudes. The examples are somewhat Escherian in that they directly involve matter developed by Sloman and leveraged in the writing of this paper. These are not explanations but loglines, scenarios and allusions for further elaboration, requirements analysis and design exploration.

A cognitive skill set: Conceptual analysis

In this section, I will provide an example of the role of motive generators in someone who is skilled at conceptual analysis. I could have chosen any other cognitive skill. However, this one is particularly apposite to this symposium — given the emphasis Sloman has placed on conceptual analysis — and to this paper, given that conceptual analysis demands and promotes deep understanding. Moreover, as one masters conceptual analysis, motive generators are created that ought to be active in a wide variety of verbal problem solving situations.

Briefly, conceptual analysis allows one to improve one's understanding of concepts that are intuitively understood by many intelligent speakers of a natural language. English, having the largest lexicon of all natural languages, is a particularly fertile language for this activity. Sloman (1978, 2010a) has provided detailed descriptions and suggestions about how to perform conceptual analysis. Here I describe the kind of mind that has studied these readings in depth, thought about them and applied them.

Many university students—who may be strong in other areas—find it difficult despite instruction to understand and perform conceptual analysis. (What distinguishes those who get it from those who don't?) Yet it involves cognitive skills that are essential to day-to-day knowledge building, academic pursuits, and scientific knowledge building (Wilson, 1963). Although conceptual analysis normally takes informal knowledge as a starting point, its inputs can include objective knowledge and it can develop new concepts. It bears repeating that Einstein's theory of relativity involves a conceptual analysis of space and time. My own thesis contains a conceptual analysis of goals and motives. Conversely, scientific progress, particularly in the social sciences and psychobiology, is often held back by lacunas in conceptual analysis.

Reading conceptual analyses, reading about conceptual analysis, performing conceptual analyses and receiving feedback on one's analyses modifies one's mind in important ways. In particular, one grows new motive generators. One thus monitors what one reads, thinks and says, detecting conceptual infelicities, opportunities and noteworthy facts, such as the following. ("One" might be oneself or another. The citations below are mainly to documents that comment on the respective issue.)

- This concept is (potentially) very (im)potent (for some set of problems).
- This term, concept or distinction is new (to some or to all).
- This concept fills an important knowledge gap (of mine, of the community).
- This is a polymorphic (Sloman, 1978, 2010a) (cluster or suitcase, Minsky (2006)) concept. What meaning is one using? What are the different meanings? What words should we use for the differences?
- One is switching (explicitly, equivocating or havering) between meanings of a term.
- One has failed to make important distinctions. Reality is not being "cut at its joints" (Stanovich, 2009). The same term is being used for different concepts. See (Lakatos, 1980) 's elegant progression of distinctions.
- One doesn't understand something important about this concept (knowledge gap).
- A category mistake has been made (Ryle, 1949).
- This definition is circular (viciously, acceptably, inevitably (Sloman, 2011)).
- This definition is misleading (e.g., because it rules out (or in) cases that it ought to include (or exclude) or it has some other infelicitous implications).
- This concept has been vitiated by this definition.
- This is a false dichotomy.
- A structural concept is being inappropriately reduced to a scalar one Beaudoin (1994).
- This concept has self-defeating semantics (Sloman, 2010c).
- This concept is emblematic of a degenerating research programme (Lakatos, 1980).
- This concept lacks explanatory or generative power.
- The logical geography of this theory is a particularly small part of the relevant logical topography (Sloman, 2010a).
- The term is being used differently from its accepted, expected or referenced meaning.
- This high-level concept is being treated as a basic-level one — in a referent-centred rather than problem-centred way Bereiter (2002).

- The document's lexicon (e.g., based on the text, index, or glossary) is not sufficiently rich to address its objectives (an example is the index in (Gladwell, 2000)).
- The limits, boundaries or conditions of applicability of this concept are unclear or troubling.
- The author of a computer program errs in failing to apply a powerful structuring concept. E.g., Leach (2011) showed that Beck's (2002) use of incremental design Beck to overlook the concept, *bag*.
- This distinction adds no value (principle of parsimony has been violated.)
- It is (not) worth arguing whether the definition is right in this case.
- A new concept, taxonomy or language is required to address these problems.

As these examples and White (1964) suggest, the types and time courses of realizing are varied. As an expert processes a document, reference to a check-list is not typical. A large collection of special purpose monitors are at work, in parallel, observing records of high-level mental processes (related to the document and objective knowledge). They generate motives of varying insistence, which may (or may not) influence the reader's information processing. The motives are not necessarily goals or intentions; they are often merely valenced descriptions that may lead to the formation of specific goals. These motives involve a cognitive itch[14], e.g., that something is wrong. They will normally require attention. What representations are useful for these motives? Karmiloff-Smith (1995) points out that there are many different representational types, not just "explicit", "implicit" (see also Sloman, 1985). How do these mechanisms interact with management processes?

Conjecture: The expert-like novice in a domain must somehow grow these motive generators with respect to whatever skill being developed from objective knowledge. To develop, these motive generators must frequently drive cognition. That is, their motives need to be sufficiently insistent to surface and periodically spur problem solving. Otherwise, they will lie fallow and the result will be inert knowledge —skills will not develop. Once the motive generators have been sufficiently active, they will acquire functional autonomy and, barring aberrations or supersession (how?), will remain active indefinitely. One will continue to notice and be irritated by conceptual infelicities. This analysis supposes that mastery of cognitive skills creates many affective states.

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[14] The concept of cognitive itch needs to be articulated in designer terms, to surpass the limitations of conceptual analysis. The term cognitive itch has been used independently by Beaman (2010). The 'itch' I am describing is a state in which one detects a cognitive infelicity and wants to do something about it (whether or not the motives surface or one deals with it). Beaman's "itch" is better renamed and classified as a cognitive perturbance (Beaudoin, 1994), which is one of many possible states that a class of motive processing systems can generate, rather than merely as an arbitrary phenomenological state.

Detecting conceptual infelicities in talk about grief

This section uses a scenario to illustrate the role of motive generators in applying previously developed understanding of two complementary theories of emotion —Sloman's perturbance theory (Sloman, 1987) and Ortony, Clore & Collins's (1988) cognitive structure theory. The likelihood that (and ease with which) knowledge can be applied depends on a number of factors including the criteria for understanding described by Bereiter (2002). The scenario deals with a case in which one had acquired a certain mastery of the two theories but allowed it to lie fallow (inert) until critical developments led to its application— some motive generators became productive.

Suppose the wife of a happily married software engineer, somewhat familiar with the aforementioned theories, dies in a car accident. His grief subsides; but he is sufficiently troubled (and intrigued) by the remaining perturbance to wish to understand it and to better control his mental processing.

In discussing his situation with loved ones and a psychologist, he becomes annoyed by the welter of affective concepts that prevent him from thinking clearly about his experience. Even the psychologist's concepts and terms do not seem right to him.[15] Hence, our grieving engineer becomes motivated not merely to understand his grief, but emotions in general. He (correctly) feels that perhaps this understanding will help him take a healthy distance from that which causes his negative affect and improve his mood.

He is thus motivated by the *potency* of the theories he had encountered which now acquire *additional* value from being instrumental to his goal of feeling better. (How did this recognition trickle down to his (cognitive) motive generators?) His conversations trigger a cognitive itch in him; questions arise somehow from his previous understanding of relevant theories.

- Psychologist: "Your anger is real and it must go somewhere" (Worden, 1991, p. 43). Engineer: "But emotions are not substances that can be shunted. If anger is 'real', what *is* it really?"
- Psychologist: "You are not consciously aware of your feelings" (p. 44). Engineer: "In my understanding, feelings may be fleeting, low level, unverbalized or unacknowledged but not unconscious. It is not my feelings that I need to better understand, but the mechanisms in my mind that produce my feelings, thinking, deciding, planning, assessments, my manifold appraisals, etc." See also Worden, 1991,.
- Psychologist: "Perhaps you feel guilty because you are not experiencing enough sadness?" (p. 45). Engineer: "You are over-emphasizing feelings and

[15] I have argued that clinical psychologists in particular should be trained in conceptual analysis (Beaudoin 2013).

neglecting the cognitive structure of emotion. How can I understand feelings without reference to a taxonomy of emotion?"

While the engineer's responses are sophisticated and interesting in themselves, our issue lies in the interval between his interlocutor's statement and the engineer's articulation of his cognitive *concern* or *itch*. In a brief but complex moment he *becomes* genuinely dissatisfied with his interlocutor's statements. He notices that something is wrong. Through his prior learning, he had understood important ideas about affect. But this knowledge had remained relatively inert. Faced with a pressing need to understand his experience he became sensitive to his interlocutors' and his own ignorance. His prior learning established motive generators that allowed him, years later, to detect possible knowledge gaps in himself and others, whereas his interlocutor seems oblivious to the problems. (This is not to suggest that the CogAff and Ortony theories would have satisfied his curiosity. They are incomplete advances. But his knowledge of them leads him to detect knowledge gaps to which he otherwise would have been blind.)

To understand this example of transfer, one must address designer-based questions (beyond conceptual analysis) such as:

- How does prior understanding lead to later cognitive itches?
- What information processes constitute the 'cognitive itch' and the question? I.e., the aforementioned moment needs to be mechanistically described from the designer stance.
- How were the monitors established originally?
- What are the monitors connected to? What are their inputs? What precisely are the monitors looking for?
- What are their outputs?
- What might have happened internally, in mechanistic and architectural terms,[16] such that the engineer would have applied and developed these motive generators ever since he 'learned' the theories? (i.e., had the knowledge not remained inert).
- Before his loss, were similar motives generated but not insistent? Or were they not generated at all?
- What is the mechanistic (not merely the 'content') difference between the engineer, as he notices an infelicity, and the interlocutor who is oblivious to it?
- How did these monitors divert attention?
- What are the dimensions of variation of, and the structural variations between, the various motive generators involved in detecting conceptual infelicities?
- How can such motive generators be established such that they persist almost indefinitely?

[16] Notice that some of the epithets that a designer uses in his quest for understanding are a modernization of Wertheimer's 'internal structure' talk. The designer is concerned with internal functional architecture.

- How can new understanding dismantle or attenuate motive generators that are no longer relevant?

These are all deep questions about understanding and transfer.

Developing Attitudes

The scientific case for motive generators in attitudes is not difficult to make, if one accepts that attitudes are "dispositions, or perhaps better, predispositions to like some things, e.g., sweet substances, or classical music or one's children, and to dislike others (e.g., bitter substances, or pop art or one's enemies)" (Ortony, Clore & Collins, 1988 p. 328) and that goals involve a motivational attitude towards information (Beaudoin, 1994). A state that does not tend to generate motives is simply not an affective state. That opens many questions about *how* motive generators develop and operate as part of the information processing substrate of attitudes.

The main question relevant to attitudes that arises in this paper is: how can one develop attitudes, and hence the motive generators underlying them, through interaction with objective knowledge? An expert (e.g., outside cognitive science) might read about the role of an attitude and infer that he needs to change his attitude(s). But how is this accomplished? Attitudes, moods, intricate cognitive-behavioural dispositions and beliefs are not all states that one can simply decide to change.

Some psychologists have practical recommendations regarding personal attitude change that may be relevant here. For example, many of John Gottman's recommendations for improving relationships are directly aimed at changing attitudes. Gottman advises his readers to nurture their mutual fondness and admiration, which requires attitudinal change. For this he suggests taking turns in complaining; not giving unsolicited advice; showing genuine interest; communicating one's understanding; taking one's partner's side; expressing a “we against others” attitude; expressing affection; and validating each other's emotions Gottman (2001).

The desired change is unlikely to occur without extensive, self-regulated practice of the theory (e.g., analyzing bids for connection and developing love maps.) Experts may benefit from guidance on how to modify *arbitrary* attitudes based on any specific, practical and useful objective knowledge they may encounter. This involves a separation between descriptions of attitudes and descriptions of the means for developing those attitudes. Productive practice, described below, is a general shell that permits its users to regularly engage in elaborative practice and exercises derived from specific content developers. If practical authors (such as Gottman) are correct about the implicit possibility of changing one's motive generators, and certainly much of clinical psychology makes this tacit assumption, then such a shell may be of use to those seeking attitude change.

The next section tries to shed some additional light on this, and on how skills and conceptual understanding are similarly developed.

Deep understanding requires deep involvement

> I think there is only one way to science — or to philosophy for that matter; to meet a problem, to see its beauty and fall in love with it; to get married to it, and to live with it happily, till death do ye part —unless you should meet another and even more fascinating problem, or unless indeed you should obtain a solution. But even if you do obtain a solution you may then discover to your delight, the existence of a whole family of enchanting though perhaps difficult problem children for whose welfare you may work, with a purpose to the end of your days. (Popper, 1983 p. 8)

Developing an understanding of objective knowledge and developing concomitant motive generators is not instantaneous; it poses a challenge to breadth seekers. The requirements for understanding objective knowledge described by Bereiter (2002) and Perkins (1995) follow a pattern that is similar to the designer stance of Artificial Intelligence (Sloman, 1993); that is: (1) knowing the environment of the object; (2) knowing its requirements or purpose; (3) knowing its structure (design); (4) knowing its implementations; (5) analyzing how the design meets the requirements, and the implementations meet the design specification; (6) understanding how changes in requirements, designs and implementations relate to each other is a form of what Perkins called "knowing your way around".

Bereiter (2002) argues that deep understanding of objective knowledge involves using the information to solve deep problems. He emphasizes that actually building new conceptual artifacts with objective knowledge is important for this. (The designer stance, including building computer programs to develop and test one's understanding, is an example of this.) From the problem solving literature, we know that experts use examples in particular ways (VanLehn, 1996). We know that expertise often takes a long time to develop. From Boden (1991) and some artists, we gather that creative discoveries usually involve dedicated, and intimate involvement with problems and solutions. Based on his extensive interviews of Albert Einstein, Wertheimer (1959) reports that Einstein was concerned with his great problem for 7 years before making the conceptual discovery about time that led him to write his paper on relativity in a mere 5 weeks (while holding an unrelated day job). Perkins proposed a useful geographical metaphor for intelligence and expertise: knowing one's way around thinking and domains, respectively, which requires deep involvement with the domains. Experts tend to interact extensively with each other directly or through their documents. The examples used by each one of these cognitive scientists calls for a motivational explanation.

How one asks the question "What motivates the process of expertise?" will determine the answer. If one reads this as "what do people aim to get out of this process", some may well answer "flow" Csikszentmihalyi (2008), i.e., that "it actually feels good" or some other end or reward for which expertise is an instrument. Also perceived self-efficacy (PSE) has been shown to play a great role in individuals' progress (Bandura, 1997); but PSE is an *enabling* factor.

The concept of *cognitive zest* is important for understanding expertise. Cognitive zest includes perceived cognitive self-efficacy towards the classes of cognitive problems one selects. Zest entails PSE but PSE does not entail zest. Cognitive zest includes an additional enthusiasm for solving problems of understanding on the way to solving other problems (such as creating new objective knowledge) and enthusiasm for the tasks that inherently lead to knowledge building. Experts are not constantly in "flow" nor are they necessarily seeking flow. They spend just as much time practicing, debugging, reading dry papers and dealing with adversity and setbacks. Winston Churchill, whose zestfulness is described as such by Jenkins (2002), said of courage what one may say of zest, "[it] is going from failure to failure without losing enthusiasm."

Interpreting the foregoing motivation question in terms of what people seek is the major source of degenerating research programs concerning affect. The answers point to surface requirements. People seek things for many motives; and many motives have functional autonomy. Many have argued that we don't tend to things for the pleasant feelings the activities *sometimes* generate (Ryle, 1949; Reiss, 2000) Something else is at play in the pursuit of excellence and what R. W. White (1959) referred to as *effectance motivation*.

From the designer stance, one interprets the question very differently. "Where the [motive-generating] mechanism comes from and what its benefits are are irrelevant to its being a motivational mechanism: all that matters is that it should generate motives, and thereby be capable of influencing selection and generation of behaviours." Sloman (2009). One would ask questions like: How do motive processing mechanisms work to evince and sustain the process of expertise? How do they develop *internally*? How do they satisfy their requirements? What might the architecture, mechanisms and representations of a mind be that sustain progressive problem solving?

Cognitive zest is neither content, data nor a mechanism of the mind. Rather, it is a requirement of explanations of experts' information processing that they should do justice to cognitive zest. Even if one cannot create an expert robot mind —expert in challenging environments, that is—without that mind being zestful, zest might still only be a second-order intentional property. But cognitive zest, perceived self-efficacy, and flow, ascribed without knowledge of the workings of the mind, entail something about how the robot (or human) develops motive generators. The mechanisms — not those second-order categories —will explain behaviour.

Learning strategies for experts

Given that productive learning requires deep involvement with problems and objective knowledge, how are experts to remain abreast of broad literatures and derive deep benefits from it? There are many problem-centered ways to address this question (and indeed many questions to raise from them). Selye (1964) tells his imagined son, "Either read or skim through literature, but do not try to do both." Perhaps part of the practical solution is to estimate and take control of the percentage of time one spends processing documents as a function of the quality of the information, one's goals, constraints, and the tools and types of strategies that one uses, ensuring that enough of one's attention (across one's multiple devices) is kept on the highest potency information. One could get by with rough estimates. Commercial time tracking software and mobile operating systems do not adequately support this objective.

The education literature and practical guides describe many learning strategies Flippo & Caverly (2009). Even if they were suited to experts learning with technology (which they are not all necessarily), experts would have an adaptive decision to make when processing documents: which of the multiple strategies to use and when to use them? I agree with Pressley & Afflerbach (1995) that promoting fixed-sequence strategies (e.g., SQR-3) is not consistent with how experts read or one ought to read. Still, one can propose specific tools and partial workflows derived from the most potent findings in cognitive science for the experts to choose from.

Productive practice

I propose the concept of *productive practice,* a deliberate practice analog of progressive problem solving (Scardamalia & Bereiter, 2003), a form of deliberate, question-and-answer based learning. It leverages direct and indirect test effects, and several potent psychological principles. It is aimed specifically at experts and expert-like novices with high cognitive productivity demands. It explicitly repudiates rote learning. It aims to promote the manifold purposes of learning sketched above, i.e., deep understanding, transfer, the psychological workings of knowledge building, etc. It is also amenable to automation.

Productive practice involves creating, answering and revising questions about what one aims to learn, remember, understand and master, before, while and/or after one initially processes it; and practicing answering these questions (through time and in an elaborate manner) with productive practice software that optimizes the practice schedules (i.e., to minimize effort and maximize the learning benefits). Space does not allow a full description of productive practice. At a minimum it should be noted that the kinds of questions one asks and the kinds of answers one articulates influences the productiveness of practice—e.g., problem-centred vs. referent centred (Bereiter, 2002). For designing productive practice software, I've introduced the concept of meams, which are data structures about specific information to learn. Meams have a type (e.g., generic, vocabulary, procedure, person, event, self-regulation, verbatim document), one or more pairs of equivalent questions and answers, references, links, and other information (Beaudoin, 2013). Practice is progressive through being integrated in continual learning (and often knowledge building) that enables one to progressively extend one's ability to solve problems while maintaining prior knowledge that ought to survive the test of cognitive time (i.e., would otherwise lie fallow).

The strategy as described here is original in its combined emphasis of the manifold purposes of learning sketched above, regular practice, processes of expertise outside of formal education, technology-laden workflows, and cognitive productivity.

The effects of testing on remembering has been the subject of extensive empirical research. One 'naturally' tends to forget information which one does not practice recalling. Practicing recalling information can suspend forgetting and improve speed of recall. This is not to deny one-trial learning nor the relativity of remembering and forgetting— see Roediger (2008). The potency of test effects is overlooked by too many in formal education and expertise, though several researchers are spreading the word, e.g., (Karpicke & Blunt, 2011; Roediger & Finn, 2010).

Roediger & Karpicke (2006) propose that there are direct and indirect effects of testing. When self-testing is used for rote learning (e.g., with traditional paper or software flashcards) it mainly leverages the direct effects of testing. Indirect effects include, for example, motivating the learner to study and providing feedback.

Self-testing is used extensively, systematically and successfully by many students; but, despite its potential benefits (Roediger, Agarwal, Kang, & Marsh, 2010), after graduation from university, I conjecture that most of these same people (even if they become knowledge workers) do not as systematically engage in such practice. The next section briefly explores why knowledge workers don't and why some of them should.

The (neglected) benefits of productive practice

The concept of productive practice has not been sufficiently articulated and disseminated. Rather than describe its structure in detail here, I explore why productive practice is not an explicit part of the cognitive toolkit of most experts. Then I list anticipated benefits which can be interpreted as requirements or criteria for assessing this cognitive tool.

- Question and answer practice tends to be confounded with rote learning and repetitive practice.
- Productive practice, theoretically, is not understood as distinct from one of its components, distributed recall practice which itself is often characterized in (nebulous) terms of "memory traces". Yet, to paraphrase Sloman (personal communication), there are more types of information, more ways of acquiring information, more ways of storing information, more time scales over which information is processed, stored, and used than trace theory allows. Similarly, the procedural-declarative distinction is a naive dichotomy (familiarity with computer programming structures suggests manifold types of mixed data, e.g., Gibson (1994). Reproductive memory, for example, can be implemented by mechanisms that can reconstruct explicit forms of knowledge at a later point through stored procedures. Productive practice is not dependent on trace-based explanations.
- Although there are multiple purposes of learning, distributed recall practice is not typically aimed at many of them (but productive practice is).
- Although the test effect has been studied, technology has not been developed to collect pertinent information from hundreds of thousands of users to optimize productive practice software.
- Experts have not been exposed to productive practice workflows that leverage other potent principles and concepts, such as goal setting (Latham & Locke, 1991), optimal cue generation (Norman & Bobrow, 1979), progressive problem solving (Bereiter & Scardamalia, 1993), elaboration by argument (Wiley & Voss, 1999), re-representation, self-explanation (Chi & Vanlehn, 1991), perceived self-efficacy (Chi & Vanlehn, 1991), challenge point (Guadagnoli & Lee, 2004), etc.
- Some of the current vocabulary for practice is awkward and misleading (e.g., "distributed recall practice", "self-testing", "reviewing", "flashcards"). New concepts are also required (e.g., meams, equivalent questions,[17] linkback, practice engine,[18] meam kits[19], etc.)

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[17] I.e., members of an equivalence class, referencing tightly related information in different ways.

[18] The software module that controls the interactions between the user and meams in practice mode.

- Deliberate practice is not considered as pertinent to professional knowledge work as it is to performance sports, performance arts and formal education.
- There may be the perception that practice is for novices, not experts. Yet many experts do implicitly practice (e.g., through teaching, writing and using their knowledge). Yet those who frequently present on varied and difficult problems practice *de facto* and often deliberately.
- The problem of transfer is not factored into popular learning strategies or tackled head on as a tractable psychological engineering problem (whereas productive practice is aimed squarely at transfer).
- Productive practice strategies, which are integrated with knowledge acquisition workflows and technology, have not yet been widely disseminated.
- There is a tendency towards over-reliance on external memory aids, including the Internet, which is at odds with the requirements of productive understanding.
- Educational psychology focuses mainly on formal education and developmental students rather than on lifelong learning and expertise.
- Experts might feel they are too busy to practice, not realizing (a) that they can decrease (re) reading time and obtain more lasting benefits with practice (i.e., productive practice is a cognitive productivity practice); (b) mobile and other productive practice opportunities exist; (c) elaborative practice is an important component of expertise that can be systematized.

Productive practice is meant to address all of these concerns. Here are some additional *anticipated* benefits of productive practice.

- The well-documented benefits of distributed recall practice apply to it.
- Unless one's life involves frequent presentations and meetings about target knowledge, without productive practice one might not sufficiently articulate, develop and truly understand potent knowledge.
- Productive practice can be integrated in opportunistic and systematic reading and learning workflows, e.g., distilling information from documents and selecting the essential subsets to not only understand but master.
- Productive practice allows one to systematically control mastery of objective knowledge in conjunction with one's goal setting practices.
- Productive practice supports multiple learning purposes mentioned above, not merely factual knowledge. For example, if John Gottmann is correct, then regularly answering questions about *bids for connection* within a couple may help members become more mindful and emotionally satisfied (Gottman & DeClaire, 2001 pp. 65-69).
- Productive practice addresses problems many people have in how they practice (cf. Guadagnoli, 2009).
- Productive practice facilitates the detection and management of (sometimes subtle) knowledge gaps and cognitive opportunities (e.g., to connect or elabo-

[19] A package of meams developed by a learner or content developer for mastering related information (e.g., as a companion to document).

rate information) while improving one's current and future judgments of learning.

- Productive practice helps one to develop long-term working memory (Ericsson, Krampe, & Tesch-Ro¨mer, 1993; Ericsson & Kintsch, 1995) of the information that matters.
- Productive practice sharpens one's abilities to ask and answer productive questions, to distill documents (if it is integrated with a document processing workflow), and regulate one's learning.
- Productive practice helps one apply knowledge: one is not merely passively primed with target information but one actively recalls, reconstructs and processes it. Moreover, one can practice it in different environments, which fosters generalization and transfer.

In accordance with the Section on deep understanding above, productive practice requires effort. For most people, it will represent a change to how they process documents with technology. Existing technology is still not perfected to optimally support productive practice and cognitive productivity.

Future research

In keeping with the theme of this symposium, hard problems in the study of cognition, I have raised more questions than I have answered. I conclude by raising the ante.

Mechanisms underlying the effects of testing are poorly understood and in need of deep explanation. I believe the expression "the test effect" is as much of a euphemism in cognitive psychology as "the gravity effect" would be in physics. Existing conjectures—which the literature refers to as hypotheses—in terms of desirable difficulty (retrieval effort) (Schmidt & Bjork, 1992), elaborative retrieval (Carpenter & DeLosh, 2006), transfer-appropriate processing (Carpenter & DeLosh, 2006) , mediator shift (Pyc, 2010), and adaptiveness (or rationality) of memory (Anderson & Milson, 1989) are a source of cognitive itch in my mind. It is not that they are empirically wrong. It is that they do not describe mechanisms nor are they derived from mechanisms or architectures. As such, they do not explain the important phenomena they address. These conjectures are nonetheless relevant and potentially useful. Moreover, despite competing experiments, they are not all incompatible. In my opinion, their potential is at the level of requirements. Requirements are an important part of theory: they are meant to drive designs. Rather than proposing more hypotheses or running experiments to test them, we need to develop designs that explain the basic phenomena and from which hypotheses may be rigorously derived. In exploring potential underlying mechanisms and architectures, I expect the distinction between direct and indirect testing effects will give way to a collection of distinctions. The test effect seems to get at something so fundamental that I further suggest, in the vaguest terms, that its explanations will be tied to major mechanisms of autonomous agency, i.e., motive processing (including motive generators).

There are two strands of research that are in need of integration. The problems addressed by broad theories of self-regulated learning (Winne, 2001) overlap substantially with the problems addressed by the CogAff project (and some other architecture-oriented theories in cognitive science, e.g., (Winne, 2001)). Winne's (2001) statement that "Metacognitive monitoring is the key to self-regulating one's learning" is consistent with the thesis of this paper that motive generators (i.e., monitors) are deeply involved in transfer. While this paper focused mainly on motive generators, there are also many questions to be raised about how other motive processes, representations and entire architectures make transfer possible.

Empirical studies on productive practice should not involve rote learning (e.g., paired associate tasks) but focus on authentic, meaningful and conceptual learning in the spirit of Bartlett and Wertheimer. When recall is the only concern, "distributed recall practice" is a more apposite term to use (not that retrieval practice is necessarily rote).

Productive practice needs to be specified in more detail than space allows here. Only then will the anticipated benefits described in the previous section need to be assessed empirically —though many of them are to be expected given that they are based on some of the most well researched theories, principles and findings in cognitive science. Cognitive productivity software is poised to become an important area of application (and development) of cognitive science.

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