Making a geological map through an ecology of practice
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Introduction

This article considers the idea of *creativity in the making* involved in making a geological map. Although this is a fictitious story I am drawing on my early career experiences as a field geologist. I make use of the narrative and my experience to offer a perspective on how creativity, that is specific to this disciplinary domain, features in the process of making important artefacts in this domain. In particular, I develop an ecological perspective to explain how creativity emerges in the making of what I would call, complex knowledge-based artefacts. In the narrative I try to embrace and connect many of the perspectives offered on making in the #creativeHE conversation (ie making as a project or as growth, making is connecting, making involves thinking through all the senses, making involves imagination).

What is a geologist?

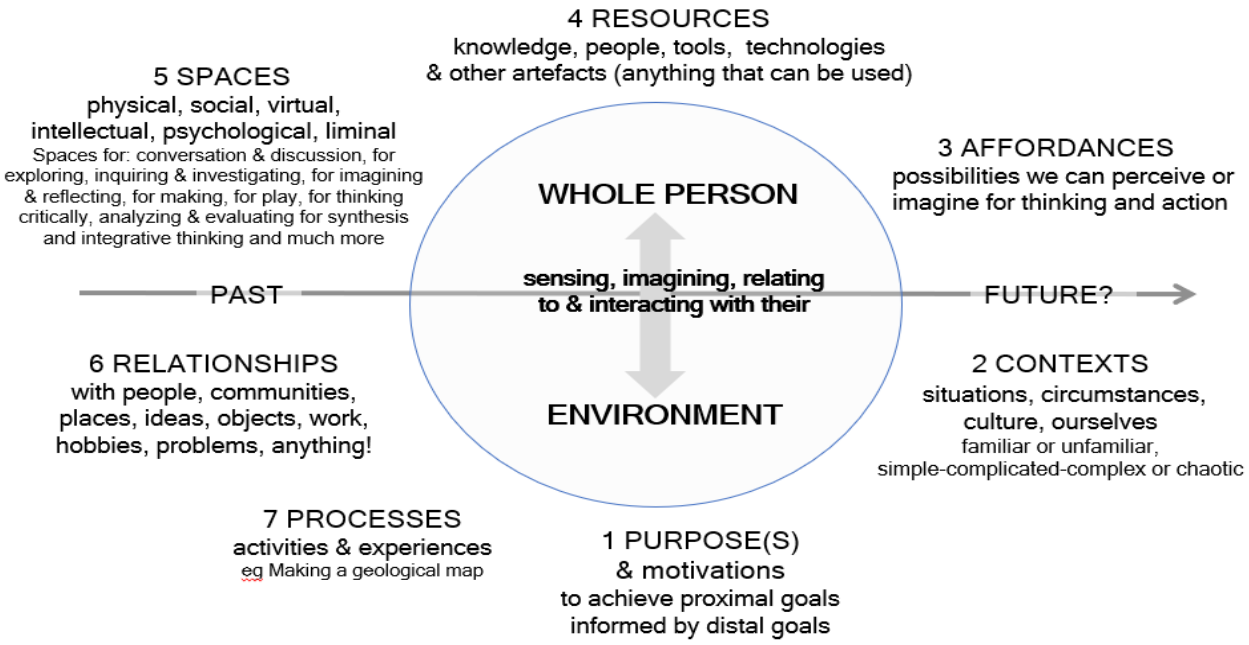
Geologists are 'knowledge workers', that means their work involves developing and applying knowledge in "non-routine" problem solving involving critical and creative thinking using scientific approaches of the natural sciences.[1,2] Geology is the study of the earth, its rocks and landscapes and the processes that formed them. To perform the role of a geologist a person must develop a substantial body of knowledge to enable them to perceive (see, recognize, interpret and understand) the rocks, structures and landscapes they are studying. They have also to develop the practical skills to describe and identify the rocks and structures in the field (and laboratory) and understand their relationships to each other. This is the specialized domain of knowledge and skills used to apply the knowledge to non-routine problem solving.

Geologists are 'knowledge workers' involved in developing and applying knowledge to domain specific problems: learning is at the core of their professional work. Based on this reasoning we can use the concept of a learning ecology[3] to represent the key features of a geologist's relationships and interactions with the domain specific environments they inhabit (Figure 1). In effect, their ecology for learning is also their ecology of practice.

Making a geological map is a domain specific challenge that a geologist will encounter in his or her work. A geologist's ecology of practice is lived in his unfolding present but connected to his past experiences of making other geological maps and studying geology as a subject. Its purpose is to accomplish the

proximal goal, to learn about and understand the geology of the area and make a geological map. But this practical near future objective is connected to the more distal goal of becoming the 'better version of the geologist he wants to be': he knows that his project will provide him with opportunities to use and develop his knowledge and skills as a geologist.

Figure 1 Key features of an ecology of practice (adapted from my own concept of a learning ecology[3]) The framework or model shows key relationships and interactions between the person and their environment. It is underpinned by a metaphor and through the relationships and connections it portrays it interprets and re-describes reality[4]. The ecological framework is a heuristic to help us imagine some of the complexity involved in acts like making a geological map. Labels explain an aspect of the ecology but do not say how they interact which is revealed in the story of making. The components of the ecology do not stand in isolation: they can and do connect, interfere and be incorporated into each other.

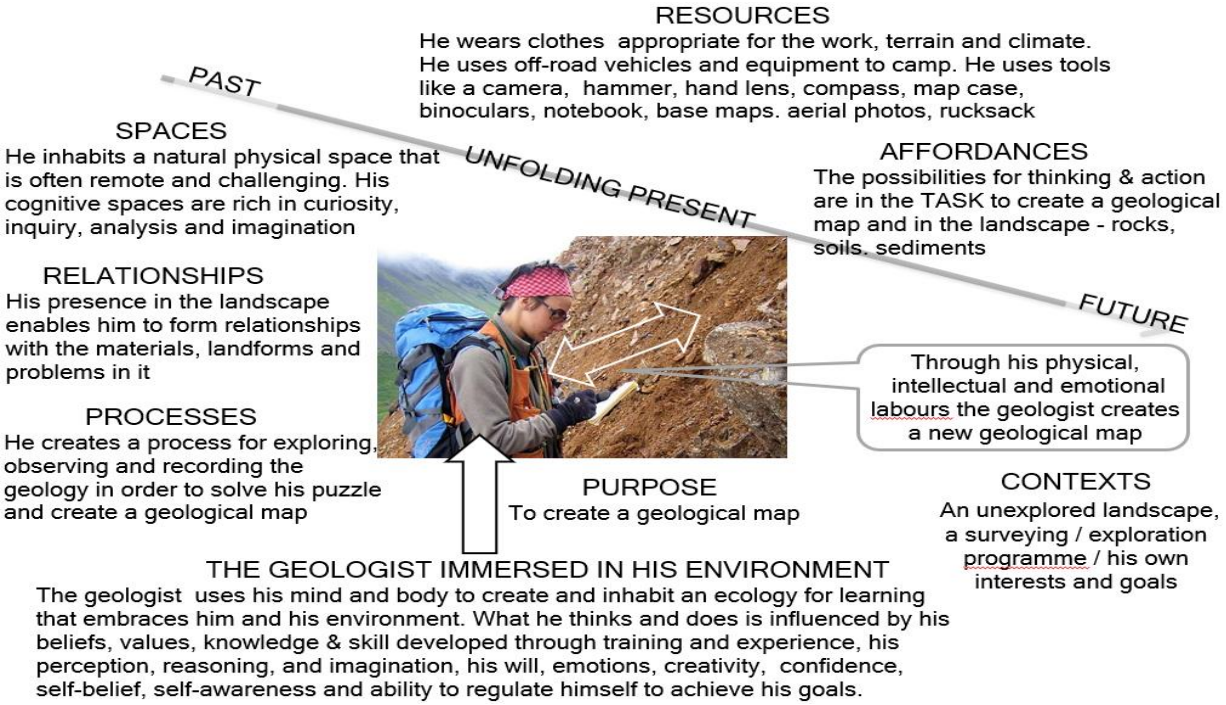


His ecology of practice comprises himself, his environment, his interactions with his environment and the learning, development and achievement that emerges from these interactions. As he begins his project he is, in effect, entering a liminal space[5] with all the uncertainty, perplexity and ambiguity of not knowing. The ecology he creates is his means of working in this liminal space in order to develop his knowledge and make the transition from a lower to a higher level of understanding and awareness.

His ecology of practice includes his work activities and processes using specific tools and technologies. His domain specific practices involve him physically covering the ground and gathering and processing lots of information through particular skillful tasks and actions - like locating the position of a rock outcrop on a geographic map or aerial photograph, measuring the dip and strike of bedding or other structures in rocks, breaking rocks and examining fresh surfaces with a hand lens and perhaps testing them with dilute HCl, photographing and sketching outcrops and annotating sketches with observations, and where there is little outcrop examining the soils. In these actions he is searching for meaning in his environment: meanings that have been learnt through years of study and practical experiences in a range of environments.

Using the framework provided in Figure 1 we can identify the elements of the geologist's field-based ecology of practice for making a geological map (Figure 2), noting that the complete ecology will also contain elements that are desk- and laboratory-based.

Figure 2 A field geologist's ecology of practice for making a geological map



The mental processes of perceiving, imagining, reasoning and reflecting enable him to develop hypotheses about what is being perceived and experienced and these thoughts and feelings influence his actions. The activities he chooses to undertake enable him to test and evaluate his theories, to find the pieces of the geological puzzle he is trying to solve (rock outcrops and structures), sense (observe, feel, measure) the rock materials, and record (often sketching or photographing and making notes) what has been perceived. In this entangled of thinking and action he uses tools like a hammer, compass, clinometer, camera, notebook, base maps, and aerial photographs to help him sample measure and record information that is important and relevant to his problem solving. In this way ideas about the geology are tested, advanced or abandoned as his actions unfold.

Making a geological map is like solving a giant jigsaw puzzle where most of the pieces are missing. The geologist's learning project is one of continuous inquiry driven by his curiosity and need to understand. His project requires all forms of reasoning and the use of imagination to speculate and project from the known into the unknown to try to visualise and make sense of the patterns and the stories he is seeing in landscape. He draws on the full range of his cognitive space as he strives to understand his problem while interacting physically, intellectually and emotionally with the physical spaces of his natural environment. As he works and learns he constructs a narrative to represent the geological history of the area: a story that embodies his own interpretations and theories and all the uncertainties and unknowns that drive further inquiry.

Making is connecting

'Making a domain specific artefact' is at the heart of his map making . At the start of his book 'Making is Connecting' Gauntlet[6] offers three propositions:

> Making is connecting because you have to connect things together (materials, ideas, or both) to make something new; Making is connecting because acts of creativity usually involve, at some point, a social dimension and connect us with other people; And making is connecting because through making things and sharing them in the world, we increase our engagement and connection with our social and physical environments.'[6:2]

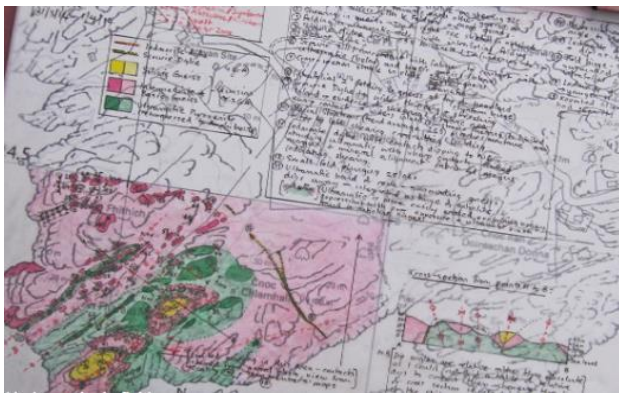
These propositions are all valid to the geologist's map making. Through his interactions with his field environment he collects and connects the evidence for his geological jigsaw puzzle and as he thinks (perceives, imagines and reasons) he connects these pieces in particular ways and in a particular time frame to produce something new and tangible. While the social element is not so visible, he will be connected to other members of his team and his artefact will be used as a mediating tool with his team and with other geologists and people working in allied disciplines.

Seeing and understanding that something has the possibility for connection in the first place, whether in advance or as the situation presents itself, are important in this process of making. The geologist does not connect random things, there is a thoughtful process going on which leads him to connect only those things that are useful and fit his evolving mental models. In this way his process of connecting draws together, combines and integrates things that are meaningful in the context of his map making and the construction of a geological history.

The act of 'making a map' is an emotional as well as an intellectual experience. The geologist experiences joy in the work he is doing often in a landscape that often has aesthetic appeal. He feels satisfaction as he makes progress in work that means something to him[7]: he loves the challenge and he likes solving the puzzle which sustains his motivation. But he can also experience feelings of frustration when he spends many hours searching for answers but cannot find them. He is often uncomfortable: it rains a lot so he is constantly wet and it's not easy to keep his field slips and map dry. It can also be painful as slipping and falling is part and parcel of the scrambling over the loose rocks and occasionally, as he pushes himself to climb a cliff, he feels anxiety and fear.

These complex sensory experiences and intense interminglings of the physical, intellectual and emotional states of being enable him to form deep relationships with his work and the objects of his work - his landscape and the rocks in it. His emotions contribute to the investment he is making in his own meaning making process and encourage feelings of pride and resilience as he pursues his goals in what is a fairly inhospitable environment, knowing that he is making a contribution to the knowledge of his domain.

The geologist embodies his learning. He needs to get his body, and engage his senses and his mind, to the places he needs to be in order to find the evidence to test his working hypothesis. Where he needs to be is determined by where he has been and what he has discovered through being there. It's an evolving process as he criss-crosses the landscape (his self-determined walking curriculum[8]). He has to get himself into the physical spaces that have the highest potential for solving his problem and then know how to act to enable his senses to gather the information he needs. While this is essentially a rational and analytical process my own experience has shown me that intuition and instinct might be involved. Sometimes it just feels right to do



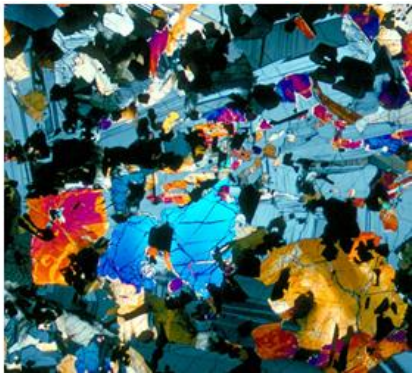
something without really being able to immediately explain why.

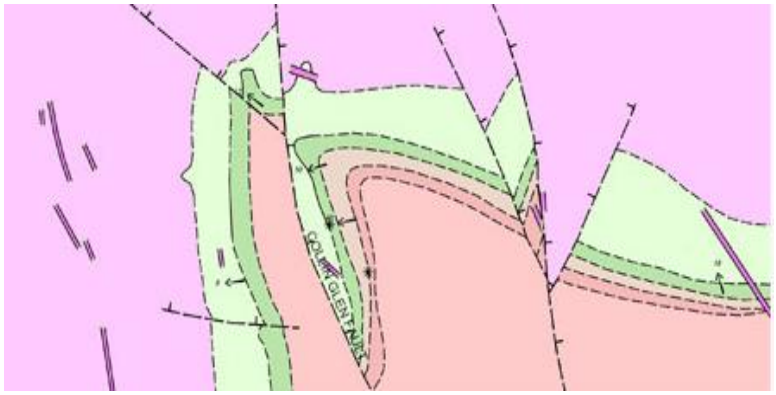
The geologist accurately records his field observations on a field slip (right) and in his notebooks. The process enables him to relate and synthesize disparate pieces of information to create a clearer and bigger picture of his puzzle and enable him to search more selectively for missing pieces. Notebooks containing field skectches can be like artists' sketch pads full of aesthetic and emotional value as well as well as scientific meaning.

Once back at camp, there is further pondering and reflection on what has been discovered as the day's observations recorded in notebooks, digital photographs or video, are revisited and plotted on a cleaner base map (like the one on the left).

This reflective process is an essential part of his sense making process. It's the way he consolidates what he has learnt, checks his theories and working models and through which new insights and possibilities emerge. It's a stimulus for imagination and time for careful reasoning – two processes that intermingle in this reflective space rich in memory and recorded observations.

These analytical and conceptual processes continue after the field experience has been completed as rock samples are analysed and understood better. New artefacts and data are produced through these analytical processes. For example, geologist's use microscopes to study the mineral composition, textures and structures of the rocks they have sampled using thin transparent slices of rock (30 microns thick). Thin sections (example right) are important artefacts produced from natural materials that reveal the beauty in the rocks and minerals and enable those materials to be understood, characterised and classified. Through laboratory study the accuracy of the geological map and report the geologist is producing can be improved.





Producing the geological map is essentially a drafting process in which information is carefully transferred from field maps and notebooks onto a new base map and digitized using the cartographic conventions and symbols of geological map making.

The process of reworking this information can stimulate further integrative thinking. But there is also an artistic element in the making of a map as pens or digital tools are handled and used to create the map. The final product is a beautiful artefact containing a representation of reality and a story of how that reality came into existence, explained in the image, the key and in an accompanying report, about the geological history and mineral resources of an area. The map is also a

tool that can be used to make decisions about how a landscape and its resources might be used and managed in future ie it contains the information necessary for future action.

The geologist's mission is to accurately describe and represent what he observes and understands so that anyone returning to a particular location on his map will observe the same thing. But the geologist also attempts to understand the significance of what he is observing and this leads to interpretations and speculations of how particular rocks and structures came to be. Interpreting the geological history of an area and the environments in which rocks formed combines both reason and imagination (speculation) as working hypotheses are developed, considered and tested with available evidence. For example, a series of fossiliferous limestones might be interpreted as an ancient coral reef complex or mineral veins and alterations in a granite might be interpreted as evidence of a fossilized hydrothermal system. Use of imagination in this way to interpret what has been observed is also part of the process of connecting information order to gain deeper understandings. Such interpretations provide tools for predicting in future inquiries: for example, in exploring for economic minerals.

How does creativity feature in this ecology of practice for *making* a geological map?

As can be seen from this description of a geologist's ecology of practice, the geological map and accompanying report which explains the map, are the domain specific artefacts of his wholesome physical, intellectual and emotional relationship and interaction with his challenge, his environment and the materials (rocks and structures) that are in it using the tools and resources available to him. Making these artefacts involves bringing something new into existence: objects that are the means by which the geologist's understandings and interpretations are shared and communicated to other practitioners (principally geologists and engineers with the field specific knowledge).

Anthropologist Tim Ingold offers two perspectives on the idea and process of making namely[9:20-2]: *making as a project* , 'we start with an idea in mind, of what we want to achieve, and with a supply of the raw material needed to achieve it. And it is to finish at the moment when the material has taken on the intended form', or *making….as a process of growth'*, 'the maker from the outset [is] a participant .. amongst a world of active materials. These materials are what he has to work with, and in the process of making he 'joins forces' with them, bringing them together or splitting them apart, synthesising and distilling, in anticipation of what might emerge.'

Making a geological map can be understood in both of these senses of making. The geologist certainly begins with an idea of what the outcome from his making process will be, he might even have a rough idea of what his map will eventually look like, and the length of time it will take him to make it. But he is totally ignorant of the detail which only emerges through the *dynamic process of participation and growth* in which he will be involved 'amongst a world of active materials'.

This view of the geologist growing as he participates in his making is consistent with the idea that making is an ecological phenomenon. In my illustration of a geologist's ecology of practice there are many affordances for creativity and many tangible expressions of his creativity. Some of these expressions emerge in the artefacts he produces to record and represent the geology he has observed in the field (field slips, notebooks, maps) that can be used and valued by other people who have the knowledge to understand their meaning. Some of the geologist's creativity is embodied in the narrative he creates and communicates through his reports, that convey his understandings of the geological history of his field area carrying his own interpretations, theories and synthesis. Through words and illustrations, he creates a story that both describes (represents symbolically) and accounts for the geology of the area, interpreting, hypothesizing and speculating, and connecting the factual pieces of the geological puzzle into a new synthesis.

But much of his creativity is embedded in the narrative that is rarely told: the narrative of his making. Anthropologist Tim Ingold has much to say on the making of cultural artefacts that grow through a unique person interacting with purpose with their social, cultural and physical environment. Here are three

connected perspectives that seem to capture well the nature of creativity in the geologist's field practices.

'I want to argue that what Klee said of art is true of skilled practice in general, namely that it is a question not of imposing preconceived forms on inert matter but of intervening in the fields of force and currents of material wherein forms are generated. Practitioners, I contend, are wanderers, wayfarers, whose skill lies in their ability to find the grain of the world's becoming and to follow its course while bending it to their evolving purpose'.[10:92]

'what people do with materials [*ie geological materials*]……. is to follow them, weaving their own lines of becoming into the texture of material flows comprising the lifeworld. Out of this, there emerge the kinds of things we call buildings, plants, pies and paintings' and, in our example, geological maps and reports.[10:91]

'[*Geologists*] ……. are itinerant wayfarers. They make their way through the [*landscape*] bringing forth their work as they press on with their own lives. It is in this very forward movement that the creativity of the work is to be found. To read creativity 'forwards' entails a focus not on abduction but on improvisation[11:3]. To improvise is to follow the ways of the world, as they open up, rather than to recover a chain of connections, from an end-point to a starting-point, on a route already travelled.' *(my customization in italics* [10:97])

An important question, as far as creativity is concerned is, 'how does imagination feature in the geologist's map making process?

French philosopher Paul Ricoeur offers some interesting perspectives on imagination. Firstly, he asserts that imagination and perception are intertwined, "imagination is not something marginal to or occasional in thought but rather permeates all thought and conceptualization…..perception is always structured by physiological and imaginative processes." "imagination is not at all an alternative to perception but [is] an ingredient of perception. It's encapsulated within the framework of perception."[12 citing 6] He draws a distinction between 'reproductive' imagination, which relies on memory and mimesis, and 'productive' imagination, which is generative.[6, 13,14]

He asserts "there are two main types of 'reproductive' imagination: the first refers to the way we bring common objects or experiences to the 'mind's eye' in the form of an image…The second refers to material representations whose function is to somehow copy or 'take the place of' the things they represent (e.g., photographs, portraits, drawings, diagrams, and maps)."[13]

Ricoeur locates the productive imagination in fiction, in the "nowhere" that fiction provides, the paradox is that fiction provides a new dimension of reality. Examples include inventions like novels and fables – which are not intended to be straightforward descriptions of the world.[13] Ricoeur argues that "creating a story is an act of semantic innovation. In narrative, the semantic innovation lies in the inventing of another work of recombination and synthesis. The productive imagination 'grasps together and integrates into one whole and complete story multiple and scattered events, thereby schematizing the intelligible signification attached to the narrative taken as a whole'. 'To understand the story is to understand how and why the successive episodes led to this conclusion, which, far from being foreseeable, must finally be acceptable, as congruent with the episodes brought together by the story' [13 citing 4.] Ricoeur extends his idea of productive imagination in fiction to models, which in science are used theorize and to 're-describe' phenomenon….. Models refer to, but do not reproduce, a pre-existing original. They allude to common attributes between the model and the underlying characteristic/s to which it refers.[12 citing 4.]

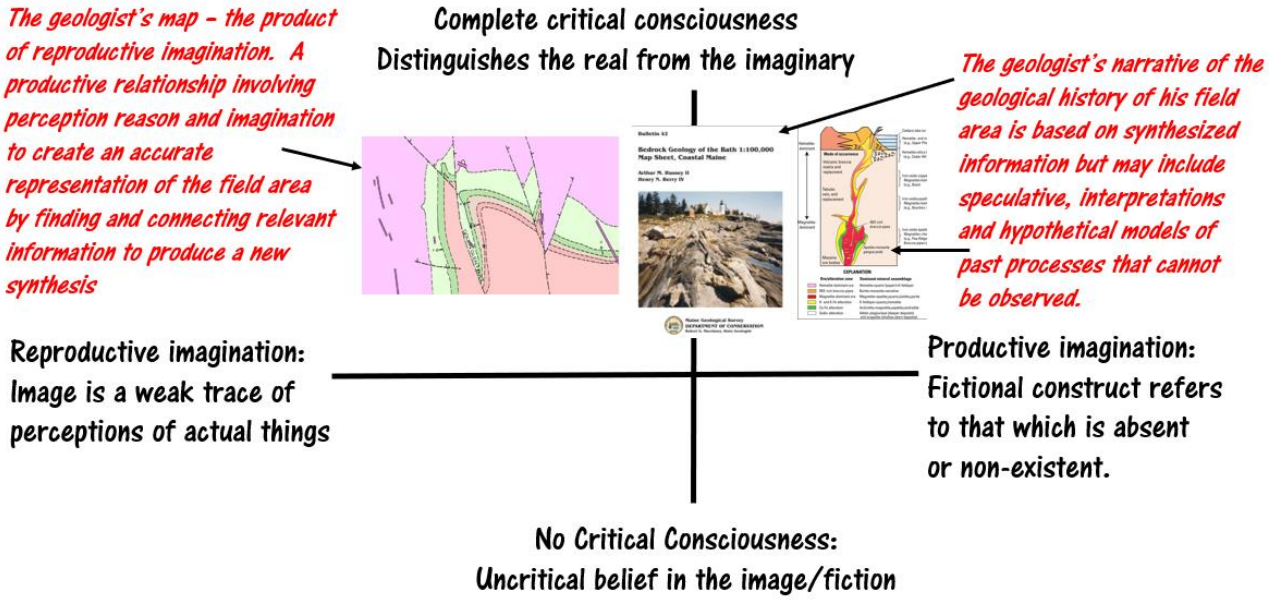
Figure 3 Provides an interpretation of the way imagination features in domain specific artefacts produced by a field geologist when he makes a geological map. His map is an accurate representation of the geology of his field area using the symbolic cartographic language of the domain. This artefact would appear to fall into the category of reproductive imagination in the sense of the representation "'takes the place of' the things they represent (e.g., photographs, portraits, drawings, diagrams, and maps)."[12]

Similarly, the geologist's synthesis narrative of the geological history of the area is also a factual representation of what can be observed, but in order to move beyond what can be observed, it may well include informed speculations and hypothetical models or theories that represent his interpretations of past environments and geological processes that cannot be directly observed. In this sense they are, in part, the products of productive imagination.

Ricoeur's schema (itself a good example of the use of imagination) is a representation of two possible configurations of imagination. The way I have positioned the geologist's artefacts is perhaps not surprising. Geology is a natural science dependent on accurate observations and representations of the world in order to interpret how the world works. Its foundational principle is 'the present is the key to the past': observe how rocks form in the present and you can extrapolate these understandings into the past.

Any artefacts that are created will inevitably attempt to represent actual things (rocks and structures) in the observable world through the language, symbols and graphical representations of the discipline, and they will fall into the left hand field of this conceptual framework. But such close to real world representations are the essential platforms for more expansive, imaginative ways of thinking and the creation of theories and speculative models of, for example, past geological histories or formational processes. This way of thinking might suggest that, for the geologist (indeed any scientist) the route to generative 'productive imagination is via the activities and artefacts of reproductive imagination.

Figure 4 Ricoeur's conceptual framework[4] as a tool to understand the role of geologist's imagination in his geological mapping project – informed and stimulated by Joy Whitton's account of fostering imagination in higher education[12]. My hypothesis: as a natural scientist the geologist first builds novel artefacts that are, in part, the product of reproductive imagination. These provide the platform for further artefacts, like models and theories, that are the result of productive imagination.



Once created, the products of reproductive or productive imagination must be subjected to critical thinking. Questions need to be asked about their validity and utility. In this way we can see that imagination and reasoning go hand in hand. Now we can recognize the significance of Ricoeur's axis of belief (Figure 4) which distinguishes between critical consciousness and uncritical belief in the imaginative products. Critical consciousness comes about through a process of critical reasoning and reflection and continual critique by peers, either through a process of formal peer review or from peers

more generally once artefacts have been published. In this way the products of an individual's imagination become the shared property of the field.[12]

Geologists, like all knowledge workers, are generating and processing large amounts of complex information and with such complexity the devil is always in the detail. Such detail can only ever be appreciated by the geologist himself. Only he will know when he connected 'things' in a way that changed / transformed the way he perceived something and created new meaning, perhaps triggering new imaginative ideas that spawned new actions and outcomes. Such detail might be revealed in the story of how he made his map, since his creativity is embedded and embodied in his unique process for engaging with his challenge, and the unique way he connected the parts of his puzzle to create his synthesis. Carl Rogers seems to grasp the emergent, situated and ecological nature of creativity in his synthesis description of the creative process, 'the emergence in action of a novel relational product growing out of the uniqueness of the individual on the one hand, and the materials, events, or circumstances of their life'[14]

Let's revisit the scenario described in this article. I am suggesting that the field geologist connects, accommodates and integrates many things when he creates an ecology to tackle his field-mapping challenge that will tax him physically, emotionally and intellectually over a considerable period of time. If the field area, and the geological problems it contains, are entirely new to him (quite likely) he will enter a liminal state in which he is forced to make new discoveries in order to progress his understanding. Add geological complexity and poor rock exposure to the situation and we have a difficult challenge requiring scientific (inductive, deductive and abductive) reasoning and a lot of imaginative speculation.

Through the challenge of making a geological map the intermingling of perception (observation), imagination (speculation and conceptualization), reasoning (analysis and judgement), reflection and emotion, offer endless possibilities for creating new understanding and meaning. When we explore and try to solve a problem, challenge or opportunity, we use both our imagination and our critical ways of thinking in a complex synergistic interplay: what Ann Pendleton-Jullian and John Seely Brown call 'pragmatic imagination' 'a productive [and purposeful] entanglement of imagination, reasoning and action'[15]

Pragmatic imagination sees thought and action as individual and reciprocal. These authors represent thinking as a continuum including perception, reasoning and imagination (Figure 4) with imagination having the potential to be connected to both perception and reasoning. 'In our framework for the pragmatic imagination, the role of the imagination has expanded from a simple imagination versus reason dichotomy to an entire spectrum of activity from perception, through reasoning, speculation, experimentation to the free play imagination we associate with artistic creativity'[16:73]

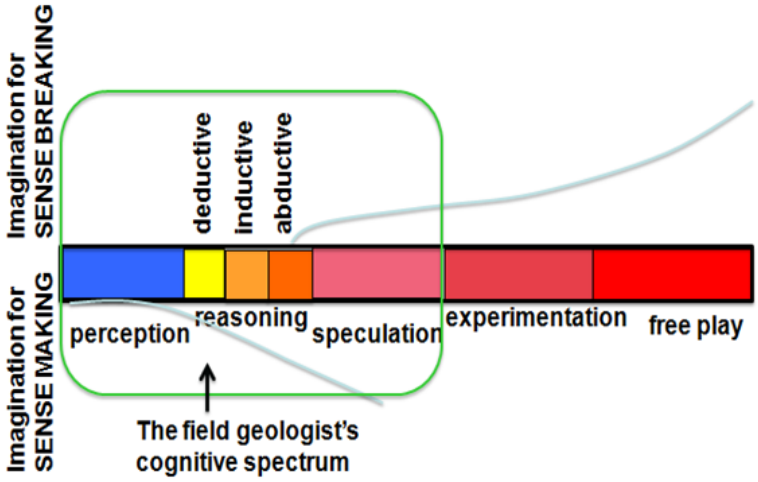


Figure 4 Representation of the cognitive spectrum[15] It is perhaps not surprising that in the mileu of cognition and emotions stimulated by the challenges, practices and ongoing actions and interactions, *that novel relational products grow out of the uniqueness of the individual on the one hand, and the materials, events, or circumstances of their life*.

My interpretation of the typical cognitive spectrum for the geologist (green outline in Figure 4), opens up the idea that different disciplinary/practitioner fields might have a different continuum. For example, a chemist might use experimentation as a vehicle for his imaginations while an artist will use the domain of free play and experimentation as the playground for their imagination and inspiration.

Puccio et al[16] also recognized the productive entanglement of thinking, emotion and action in solving complex problems suggesting that specific cognitive and affective domains are activated at different points as a problem is explored and resolved. For example. in the early stages of problem solving the individual assessing the situation, is driven by their curiosity and imagination to comprehend the problem but also uses their diagnostic skills such as observing, describing, analyzing and selecting in order to determine the best course of action. Puccio et al[16] note that openness to novelty, tolerance for ambiguity, and tolerance for complexity, together with will and ambition, underlie all stages of creative problem solving suggesting that attitudes and orientations also feature in this complex intermingling.

Another perspective on the involvement of integrative ways of thinking during complex explorations and problem solving is provided by Conklin[17], who cites Rittel and Webber's study[18] of how a group of engineers solved the problem of designing an elevator control system for an office building. The analysis showed that the designers worked simultaneously *on understanding the problem* and *formulating a solution*. They exhibited two ways of trying to understand the problem: firstly, they tried to understand the requirements for the system (from a one page problem statement they were given at the beginning of the process); secondly they created mental models and simulations (e.g. “Let’s see, I’m on the second floor and the elevator is on the third floor and I push the ’Up’ button. That’s going to create this situation....”). This pattern of thinking in which perception, reasoning and imagination are productively and harmoniously engaged as their problem unfolds, is typical of opportunity-driven learning, because in each moment the expert practitioner is seeking the best opportunity for progress toward a solution.

This is an example of creative thinking (the productive integraton of perception, reasoning, imagination and reflection) in action in a design domain but it can apply equally to a geologist implementing his field mapping project. Of course he begins by carefully gathering information but almost immediately he has identified the type of rocks he has found, he will draw up on his knowledge of how these rocks have formed and begin to create mental models of the environment in which they are likely to form and through this mental imagery he will start to form a hypothesis which he can then begin to test. In this way he begins to engage in opportunity-driven patterns of learning and problem solving. This is the way creativity emerges from our ecologies of practice when tackling novel and challenging problems in a particular context.

The elements of a geologist's cognition and bodily actions work together in a merry dance through field, laboratory and office (writing, processing and cartographic) environments and the knowledge and understanding that is developed is codified and explicated in the domain specific artefacts he makes. Creativity is involved in this process of making but it is so intermingled with what might be termed, non-creative doings, that it is well-nigh impossible to isolate and say this particular bit of thinking and practice is creative and this is not. As a former field geologist, I agree with Tim Ingold when he says, ‘Rather than reading creativity ‘backwards’, from a finished object to an initial intention in the mind of an agent, this entails reading it forwards, in an ongoing generative movement that is at once itinerant, improvisatory and rhythmic.’[10:91] Perhaps this is the generative movement described by Rittel and Webber[18] in which perception, reasoning and imagination are productively and harmoniously entangled as the geologist works with his unfolding problem. Perhaps also it is the movement of imagination that results in products that reproduce some aspect of the world from which new expressions of reality emerge (Figure 3).

The synthesis products of this purposeful, itinerant, improvisatory and rhythmic process are the meaningful artefacts resulting from the geologist’s ecology of practice. In the words of Rogers, these

artefacts *'emerge in action'* as *'novel relational product[s] growing out of the uniqueness of the individual on the one hand, and the materials, events, or circumstances of their life'*[14] Circumstances that the geologist, through his own history, learning and actions, has helped determine, but which are also shaped by the environment, materials and unfolding problem he is working with.

End Note

A version of this article was published in Creative Academic Magazine CAM#9 December 2017. In the coming issues of CAM#9 we will develop further examples to illustrate how creativity features in the ecologies people create in order to practice in a particular domain. We welcome contributions to this ongoing project.

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