The role of understanding in human nature

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1. Introduction

Why is understanding so important in the life of humans? We can easily imagine a life where we follow a set of rules without understanding why these rule are there. However, achieving understanding is a strong motivational factor for many of our endeavours.

Understanding is a central concept in cognitive science since it concerns the coherence of a cognitive system and how the system evaluates its own coherence. Despite the enormous progress during the last centuries there are surprising lacunae in our scientific knowledge. The very concept of understanding has often been overlooked in educational, philosophical and psychological research. In the early stages of cognitive science the functioning of the brain was seen as similar to that of a computer. Bruner notes in his book *Acts of Meaning* (1990) that if thinking is seen as information processing, questions about meaning and understanding disappear. But a theory about human nature cannot be based on "information," "processing" and "behaviour" only – it must contain some account of what it means to understand. Among other things, this involves putting the acts of humans in a social and cultural context.

Understanding is nothing mysterious, but very little is known about how understanding arises. Within the humanities one finds the hermeneutic tradition concerning "Verstehen". However, this tradition focuses on the possibilities of interpreting cultural products – books, paintings, symphonies, etc. Research is still in its nascent stage as regards the role of quotidian insights, for example in ordinary students' learning – what happens when you discover a connection you have not sensed before. A new insight is often connected with an aha-experience. However, when it comes to describing what happens in our heads when we understand, science has little to say.

In this article I will focus on the role of understanding in culture, education and science, and more specifically, on how to use abstract theories to make sense of the world. However, first of all I must provide a general background to how I understand understanding. As a working hypothesis, I shall propose that *understanding consists in seeing a pattern* (Gärdenfors 2007, Gärdenfors and Lindström 2008). I shall begin by discussing how this idea, which derives from Gestalt psychology, is interpreted in modern cognitive science in terms of "hidden variables". In particular I will show that the minds of humans are tuned to seeking causes and to reading the minds of others.

As a first application of the ideas, I argue that what patterns are seen is to some extent dependent on the culture one lives in. The second application concerns education. It seems obvious that the goal of education should be that students understand the material they study. I propose that this is achieved by helping them to discover patterns that they cannot find on their own. I present some educational techniques such as visualizations, simulations and virtual agents that can be used to make students see the relevant patterns in a knowledge domain. Finally, I discuss the role of understanding in science. I argue that current proposals can be subsumed under the idea that understanding is seeing a pattern.

2. Understanding is seeing a pattern

We find more or less abstract patterns at all levels of thinking, from seeing the stripes on a cat, to identifying the musical structure of a fugue by Bach or understanding the role of microorganisms in diseases. Some of the patterns we perceive are given by our biological constitution, some are learned during our childhood and our continued education, some are given by the culture we live in and some are provided by science. As I shall argue, perception of patterns is one of the most central cognitive processes. However, while relying on patterns increases our capacity to solve new problems, it can also hamper our ability to approach situations with an open mind.

Above all, we perceive patterns visually. However, it should be noted that the idea of understanding by experiencing a pattern is viable in all sensory modalities. For example a sommelier can distinguish a fine wine by identifying acidity, sweetness, etc.; a bilingual child has learned fluently different phonemes from two languages; a perfume maker can create new scents by altering combinations of oils and flower extracts; and a sculptor can capture all the aspects of an ageing body with stiffened joints, muscles and wrinkled skin. All these are examples of experiencing a pattern that results in a better understanding of a knowledge domain.

After attending a concert or visiting an art exhibition we say we are full of impressions. But it is a myth that our sensory experiences are "impressions", in the sense that there is something that is pressed into our brains. Our brain is not a passive receiver of images and sounds from the surrounding world. It actively seeks patterns and it *interprets* what it receives. This continuously running process is the basis for all understanding.

Our brain's search for patterns, whether we are aware of it or not, takes place at a variety of levels. At the bottom of our understanding, there are biologically determined mechanisms that strongly control the way we perceive the surrounding world. At the top, one finds the cultural patterns that are required in order to interpret works of art, poetry, music, dance, etc. However, when we master the patterns, they also influence our perception of the cultural products. As a consequence, we don't all see and hear the same things – there is no "objective" description of the world (Gärdenfors 2007). As Goethe writes: "Es hört doch jeder nur, was er versteht."

To illustrate that the search for patterns is ubiquitous, let us begin with an example of a biologically controlled mechanism from the visual modality (see figure 1).

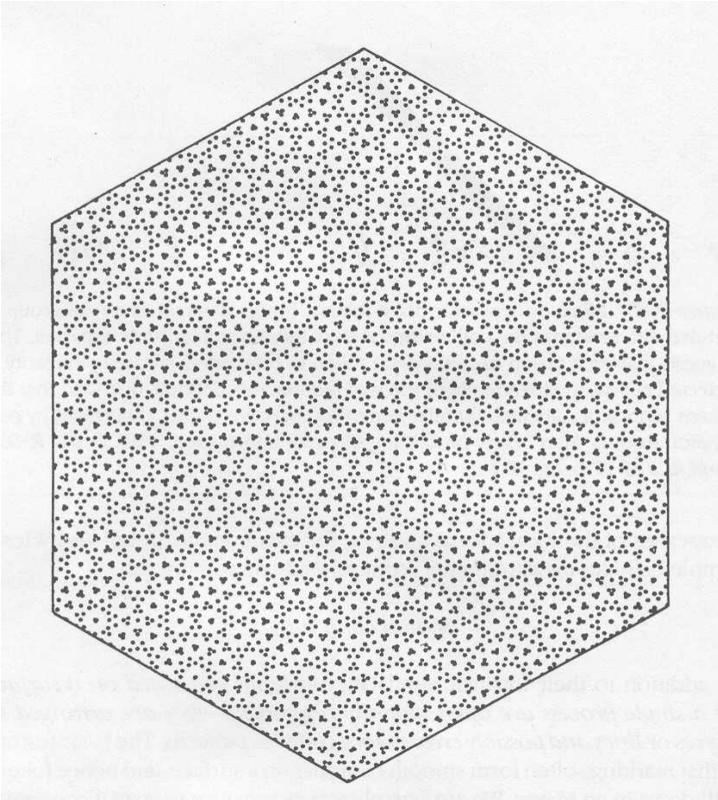

Figure 1. (From Marroquin 1976)

At an early stage of the visual process, the brain tries to find patterns among all the dots. We perceive circles of different sizes in the figure. An interesting aspect is that one circle is soon replaced by another that suppresses the first, etc. The figure "lives" even though not a single dot is moving. You may even discover Maltese crosses in the figure. If you do, the crosses will block the perception of the circles – and vice versa. The figure has no global meaning, but our visual system searches incessantly for patterns. There is therefore no unequivocal answer to how one "perceives" the figure.

The brain is full of mechanisms that *fill in* what falls on the retina, the eardrum or the other sensors. The experienced result is often a pattern in the form of a *Gestalt*. These processes were studied by the Gestalt psychologists in the first half of the twentieth century, but they have received a renewed interest since we are now beginning to understand the brain mechanisms behind this form of filling in. For example, consider Figure 2. We immediately perceive figure A as a circle and a rectangle, that is, we decompose it as in figure B, although there is no logical reason why it should not be decomposed as in figure C or D.

QuickTime och en
TIFF (okomprimerat)-dekomprimerare
krävs för att kunna se bilden.

Figure 2. Perception of Gestalts

The mechanisms that fill in are important from an evolutionary perspective: Bad lighting conditions or occluding objects do not prevent us from discovering danger or food, which clearly increases our fitness. If one sees the tail of a tiger, one will surely understand that there is a whole tiger in the vicinity. Therefore, we will have a better chance of surviving in our environment.

Our brains have constructed a large repertoire of patterns. We are often not aware of them, but they can be elicited by various tricks. For example, look at the two pictures in figure 3. What do they depict?

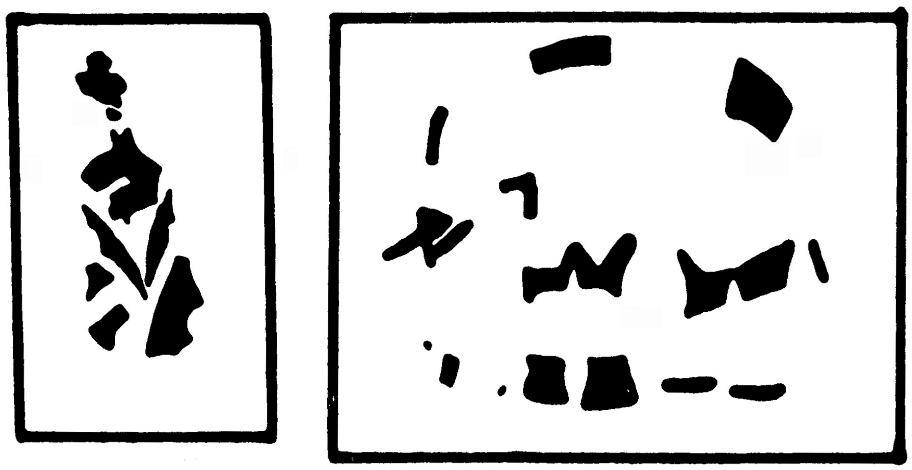

Figure 3. Incomplete depictions of objects.

It may not be difficult to see that the left is a picture of a violin, but for many observers a clue is needed for the picture to the right – a salient feature that deciphers the content. It is an *elephant* (with its head to the left). Suddenly the pieces fall into their places and one can interpret the picture – it becomes a Gestalt. The different parts become *meaningful*. For instance, one of the black blotches suddenly becomes the tip of the trunk. An interesting feature of such Gestalt experiences is that once you have seen the pattern, you cannot let it go away again.

For some category systems, the effects of a categorization are *amplified* by the perceptual systems so that distances within a category are perceived as being smaller and distances between categories are perceived as larger than they "really" are. This phenomenon is called *categorical perception* (see, for example, the articles in Harnad 1987). This finding implies that a reality where there are no sharp borders is sorted into distinct slots by our cognitive mechanisms. The categories can be seen as a kind of pattern. They are normally a product of learning, most of which is implicit.

A simple but illustrative example of categorical perception is provided by figure 4:

Figure 4. An example of categorical perception.

If you focus on the upper row, the sign in the middle is seen as a B, while if you focus on the lower row, the very same sign is seen as 13. The example illustrates that the *context* determines how we understand the information that our senses receive. This mechanism makes our processing more efficient, but it also locks us into certain interpretations. The patterns above are culturally transferred since they form part of basic Western education that uses Latin letters and (adapted) Arabic numerals.

The mechanism of categorical perception has been found in many domains, but has been studied in particular for phonetic systems (see, for example, Petitot 1989). Understanding a language presumes that one can correctly categorize the sounds of the language and group them into units we call words. Even though a set of sounds may be produced by an articulatory parameter that varies continuously (output variable), the auditory system perceives this variable in a categorical way so that when the articulatory parameter is varied along its scale, the perceived sound (input variable) seems to remain constant for a large interval and then suddenly jumps to a new sound that is relatively stable too.

3. The causal drive

Humans have a more or less innate drive to seek patterns in their experiences. Above all, we have a strong tendency to seek *causes* in the happenings of the world. In a previous book (Gärdenfors 2006), I called this tendency our *causal drive*. There are good evolutionary reasons why we should look for casual connections since they help us understand how the world hangs together. By reasoning about causes and effects we become much better at predicting the future. And human beings are, more than any other animal, dependent on their prospective thinking (Gärdenfors 2003).

As a matter of fact, there is a very strong connection between seeing patterns and understanding causes. A causal variable is a kind of pattern that connects causes and effects. Conversely, seeing new patterns means that one sees new connections between phenomena in the world. A pattern thereby functions as a way of creating new causal explanations and offers new ways of solving problems. For example, if a parent discovers a connection between a grumpy child and that the child has not eaten for some hours, the parent can help the child by feeding it. If the parent then learns the variable ”low blood sugar level” as a causal variable behind the whimpering and understands what kind of food quickly raises the blood sugar level of the child, the problem-solving capacity of the parent becomes even better.

Humans have a unique talent for extracting the *hidden variables* of the world. These variables often form the backbone of the patterns that we discover. Within philosophy of science they are called theoretical variables. A prime example is the *forces* we use to interpret and categorize the events and actions that are presented to us by our perception. On a more abstract level, various physical, social and other variables can help us understand a phenomenon that initially was a disconnected blur. The hidden variables that are used to perceive causal relations are fundamental examples of the patterns that humans are particularly apt at discovering.

In support of my notion of a causal drive, Leslie (1987) argues that infants not only can follow objects with their gaze, but they also have a special mechanism or module in the brain that calculates the forces influencing an object. Such a system, if it exists, would be a paramount example of how the human brain can exploit the hidden variables that govern the world around us.

My interpretation of the difference between humans and other species is that our inner worlds are much more efficient in exploiting hidden variables to make predictions about the future. The causes are not given to us by our senses, but our brains fill them in. White (1995) even claims that that we literally perceive the forces, just as we perceive the contours of objects even if they are not contained in the visual information that reaches the eyes.

The great advantage of the causal drive is therefore that it improves our ability to forecast the future. But sometimes it becomes excessive: Even pure chance events, such as lottery prizes, are seen as a result of luck. But “luck” does not exist – it is a pure figment of our minds. The fact that we talk about luck is just a sign that our brains are obsessed with finding causes for everything that happens. If there is no cause, we must invent one. The causal drive is therefore a strong factor behind the creation of myths and magical thinking. Magical thinking is particularly strong in children’s thinking. Piaget (1930: 174) writes:

> The child fills the world with spontaneous movements and living “forces”; the heavenly bodies may rest or move as they please, the clouds make wind of themselves, waves “raise” themselves, trees swing their branches spontaneously to make a breeze.

This idea can be extended to adult thinking: one can interpret magical or animistic thinking as just an application of psychological causality to physical phenomena – *agents* are seen everywhere as causes of events. Magical thinking does not only occur in children but is common, in different forms, at all stages of life and in all cultures. If you have once had an accident after seeing a black cat running across the road from left to right, you become worried next time you see a black cat. And you should not walk under ladders or open umbrellas indoors, and so on, ad nauseam.

I submit that the human understanding of physical forces has developed via animism and anthropomorphism. Presumably, we have long interpreted the physical events with the aid of social variables such as power and eventually understood how to think in terms of impersonal physical forces. This accords with Collingwood (1972), who writes: “Causal propositions […] are descriptions of relations between natural events in anthropomorphic terms.” It should be noted that it is only during the last few centuries that we have created a purely mechanistic description of the world.

4. Reading the minds of others

The causal drive of humans does not only concern the physical world but also the mental one. Apart from physical forces, we can perceive the *mental forces* that govern the behaviour of others. Perceiving these forces forms the basis for intersubjectivity. In this context, intersubjectivity means *the sharing and understanding of others' mentality*. The term "mentality" is taken here to involve not only beliefs and other proposition-like entities, but all sorts of forms of consciousness such as emotions, desires, attentional foci and intentions. In the philosophical debate, intersubjectivity is commonly called having a "theory of mind" (Premack and Woodruff 1978, Mitchell 1997). (I avoid this term because it often presumes that one can understand the beliefs of others, something which, on the account presented here, is but one aspect of intersubjectivity.)

Along with becoming better at imagining the inner worlds of others, we have become more skilled at creating hidden variables that can explain the thoughts of others (and of ourselves). First of all we must understand the actions of others, since we generally derive the mental states of others from their behaviour (including their speech). This mechanism can be seen as a variant of the one that allows us to derive physical forces from the movements of objects. The *intentions* we ascribe to others are the hidden forces that make other agents behave as they do. Because we can imagine what others know and do not know, we become good at cooperation, something that has fostered the evolution of human language, culture and societies (Gärdenfors, to appear). A downside of this is that our knowledge about the knowledge of others also makes us more skilled at deception and counterdeception. If I can imagine what others know about what I know, it will be possible for me to foresee the potentially deceptive moves of others.

In previous works (Gärdenfors 2003, 2008), I have distinguished different *levels of intersubjectivity* in order to understand the cognitive capacities of animals and children at different ages.

1. Understanding the *emotions* of others. At this level one can, for example, understand that someone else is in pain. This is what is usually meant by *empathy*. Even though one can understand others' emotions, it does not mean that one understands what they believe or want.

2. Understanding the *desires* of others. This capacity involves understanding, for example, that others don't like the same things as you do.

3. Understanding the *attention* of others. This means that one can understand, for example, what someone else is looking at. However, this ability does not presuppose any conception of other parts of their inner world.

4. Understanding the *intentions* of others. This capacity means, above all, being able to understand the objective that may lie behind another individual's behaviour.

5. Understanding the *beliefs* and *knowledge* of others. This ability involves, among other things, understanding that others don't know the same things as you do.

A final step in the development of intersubjectivity is small but crucial for self-consciousness in its proper sense: I must realize that the inner world of my opponent does not only contain a representation of myself as a bodily agent, but as *an agent with inner representations as well*. I believe that it is only after this insight that the agent can become self-conscious in the sense that it can form representations of its own representations. Some support for this point can also be obtained from results in developmental psychology (see e.g. Wimmer and Hartl 1991, Gopnik 1993, Carruthers, to appear). Along the same lines, Dilthey, one of the forerunners of the hermeneutic tradition, writes that to understand is to connect an expression with an experience to learn to know a *Geist*. According to him, all understanding involves a "rediscovery of the I in the Thou." Anticipating the modern debate he explains: "The understanding of self requires me to approach myself as others do, that is, from the outside to the inside." In other words, *self-consciousness* can develop as a shortcut in the representations involved in higher forms of intersubjectivity: in my inner world I can have a representation of my own inner world.

5. Understanding other cultures

A culture is not just people in an environment, but, more importantly, a particular way of understanding the world. Each culture brings with it a different set of patterns of interpretation. One problem is that it may be difficult to perceive the patterns of other cultures. Since they do not fit with those of our own culture, we often experience them as "strange", "odd" or simply foreign.

Musical scales are clear examples of how cultural patterns can actually influence perception itself. When Westerners listen to Arabic or Indian music, they perceive many of the tones as being out of tune. The reason is that the Western music scale is based on twelve tones, while in Arabic music the scale can contain seventeen tones and in the Indian scale twenty-one. Western ears fail to sort the tones from an Indian raga or an Arabic love song into the twelve slots given by the standard scale. They do not fit with the categorical pattern of Western music. An alternative pattern in the form of a different scale must be picked up before the music can be fully appreciated.

Cultural educational programs have a tendency to focus too much on teaching facts about other cultures and too little on understanding the basic patterns underlying cultural practices or belief systems. For this reason, education that strives to bridge cultures should focus on conveying the relevant patterns rather than facts about other cultures. In section 8, I shall discuss possible educational techniques to guide students in the recognition and comprehension of the relevant patterns of other cultures.

There are strong ties between the patterns we perceive and the language we use. Patterns give meaning to the concepts we use when structuring the world. Language then names the patterns, not the single sensory experiences. Linguistic differences in cultural patterns often create mismatched expectations. For example, "breakfast" is translated into "prima colazione" in Italian. Yet the concept stands for radically different phenomena. I believe that an Italian seeing a full English (or American) breakfast for the first time will be as taken aback as an Englishman is disappointed when encountering the minuscule *prima colazione* at an Italian hotel. Examples like this are ubiquitous in translations between any two languages and they can even occur within a language when it is used in two culturally different regions.

Cultural patterns can be subtle. A striking example of hidden categorical perception comes from the way in which a pharmaceutical company attempted to sell headache medicine to a new market. This company wanted to globalize its business and launched an advertising campaign in North Africa. Because a large proportion of the inhabitants were illiterate, the message was presented in the form of a cartoon (see figure 5).

Figure 5. An advertisement for a headache medicine

The campaign was a failure. Those who could read, read Arabic, which is read from *right to left* and would only conclude that the medicine caused the headache. The intended meaning of the cartoon was thus interpreted in the opposite way. Those who could not read interpreted the cartoon as three separate figures and they could not understand the intended causal connection between the pictures. In Western cultures, people are so used to reading a cartoon from left to right and adding causal connections between the pictures that it does not occur to them that this could be a culturally induced pattern.

6. The role of understanding in education

It is a miracle that curiosity survives formal education. – Albert Einstein

Providing students with facts is a superficial form of education. Helping them create knowledge by teaching them how to interpret and evaluate the information is a much better form. However, human understanding goes beyond knowledge The best form of education results in the students understanding the material they study. In our opinion, this is achieved by helping them to see patterns that they cannot discover on their own.

What kind of understanding is relevant in learning is of course dependent on the goals of education. In some contexts, learning practical procedures is in focus; in others, facts about the world; in still others, learning abstract theories. An encompassing goal of education would be to understand how theories make sense of the world and provide explanations for practical procedures.

Selz (1924/1981) proposed that insight occurs when a problem solver fills in a gap in the structural complex. For example, a child who realizes that the letters in a text correspond to separate speech sounds has cracked the reading code. The child has seen the pattern of language as formed by different phonemes and how they are connected to each other to make meaningful utterances. The rest is practice. Or a music student who suddenly understands how a Bach fugue is composed will be able to improve her performance by expressing more subtle variations.

Every student recognizes the joy of suddenly understanding a difficult problem or suddenly seeing a pattern in a complicated domain. An elementary example is to understand that a negative slope in a graph represents a decrease of a variable. An experienced teacher can easily perceive when a student has understood. The experience of *insight* is subjectively experienced as: *"Aha, now I get it!"* The emotional aha-insight occurs when the pieces fall into place in the pattern, and the insight means that the student has achieved a more refined understanding of the domain.

From the cognitive neuroscience perspective one would also be interested in understanding what happens in the brain when, for example, a student experiences an aha-insight and what emotional and motivational responses correlate with such an insight. As a side remark, it can be noted that Land (1982) defined insight as "the sudden cessation of stupidity". There are some recent exceptions (see for example Jung-Beeman et al. 2004), but, by and large, these processes have not been investigated. Although I lack the empirical data to support my position, I am convinced that the more often one experiences true understanding, the more *motivated* one will be to pursue one's studies. In brief, I submit that understanding is a key motivational factor in education.

An aha-experience is a strong scaffold in the process of meaning making, as it provides the student with an affective receipt attesting to an understanding of the salient features of a pattern. This internal information is useful for the student as a success feedback to her learning. It may also be useful as external communication to a tutor who may draw attention to the factors that generate the student's aha-insight. A skilled teacher can analyse the learning situation and pinpoint personal, environmental and emotional factors leading to the understanding of the pattern.

There is a saying that education is what is left when you have forgotten what you have learnt. This seems paradoxical because it is difficult to fathom how there can be any knowledge left when one has forgotten it. The paradox arises from the way we generally appreciate the concepts *information* and *knowledge*. My solution to the paradox is that *education consists of the patterns you have assimilated during your life*. To assimilate knowledge is to incorporate new knowledge in a form that is understandable to oneself. A pattern can remain even if the facts used to discover it are forgotten. The patterns are more important than facts since the former can be used for solving new problems that go beyond the training set. The deeper you understand, the more you can generalize your knowledge. And when you have understood, it is also much easier to explain your knowledge area to others. In other words, the one who understands can teach.

7. Understanding and transfer

Achieving understanding within a knowledge domain leads to an increased ability to solve new problems and to answer new types of questions relating to the domain. This is essentially what is called "transfer" in educational research. In this section I will use the survey article by Bransford and Schwartz (1999) as a point of departure to describe the connections between understanding and transfer.

Bransford and Schwartz (1999) reconsider some of the traditional ideas about what constitutes a demonstration of transfer. Instead of focusing on the ability to answer new questions within a knowledge domain, they want to emphasize how the ability to *pose* relevant questions within the domain has developed. For example when fifth graders and college students were asked to provide a plan for protecting Bald Eagles from extinction, the proposed plans of both groups failed on several accounts. However, when considering the questions asked by the two groups, there were decisive differences. The fifth graders tended to focus on individual eagles

(What do they eat?) while the college students focused more on interdependencies between the eagles and their habitats (What about the predators of eagles?) By this view of transfer, it seems that the college students had learned general biological principles that they could now transfer to generate more relevant questions. By exhibiting a greater repertoire of patterns they could apply to it, they demonstrated a better understanding of the problem. In brief, learning with understanding is important for enhancing performance on subsequent transfer tasks.

As an alternative, Bransford and Schwartz (1999) want to broaden the notion of transfer by focusing on the students' "preparation for future learning" (PFL). They write:

> So, rather than evaluate whether people can generate a finished product, the focus shifts to whether they are prepared to learn to solve new problems. For example, one determinant of the course of future learning is the questions people ask about a topic, because these questions shape their learning goals. [...] [T]he ideal assessment from a PFL perspective is to directly explore people's abilities to learn new information and relate their learning to previous experiences.

In my terminology, PFL involves extracting the relevant patterns so that the understanding they provide can be applied to future problem situations.

Bransford and Schwartz (1999) also argue that *contrasting cases* are important as guides to seeing patterns and thus to understanding. They describe an experiment as follows:

> The goal of our studies was to explore ways to help college students understand memory concepts (e.g., a schema). [...] Our experiments compared the effects of reading about memory experiments and theories versus actively analyzing sets of contrasting cases relevant to memory. Students in the contrasting cases condition worked with simplified data sets from original experiments. [...] Their task was to "discover" the important patterns in the data. Students in the other condition wrote a multipage summary of a textbook chapter. [...] [W]e assumed that the use of contrasting cases would better prepare students to learn new information than would the activity of summarizing the text. As a means of examining this assumption, the new learning experience took the form of a lecture on memory theories and experiments. [...]. Students received a final prediction task that presented them with a new memory experiment and asked them to make predictions about the likely outcomes. Students in the "summarize plus lecture" group did not do nearly as well as students in the "contrasting cases plus lecture" condition.

They also argue that the PFL perspective highlights the importance of learners actively *interacting* with their environments. When learners have opportunities to get involved with reality and receive feedback, their learning improves quite dramatically and the importance of their previous experiences is revealed. Furthermore, studies show that information presented in the context of solving problems is more likely to be spontaneously utilized than information presented in the form of simple facts.

Finally, Bransford and Schwartz point to the role of *intersubjectivity* in PFL: "An especially important aspect of active transfer involves people's willingness to seek others' ideas and perspectives. Helping people seek multiple viewpoints about issues may be one of the most important ways to prepare them for future learning."

8. Educational techniques for understanding

I now turn to the challenge of how education should be organized in order to boost the students' understanding by making them discover the relevant patterns within a knowledge domain. If we follow Piaget's constructivist view on education, students should not be taught the patterns, but they should discover them themselves. They should only be scaffolded with the right kind of material for the process. However, practical educational experience shows that this method is far from optimal. An orthodox constructivist viewpoint puts too high demands on the students: They are supposed to discover the patterns that it has taken scientists and professionals centuries to uncover.

A teacher who introduces the theoretical structure within a knowledge domain will thereby present abstract patterns to the students. The pattern can, for example be a grammatical rule or a method of composing music. The pattern is often constructed from theoretical variables that are not given by experience.

In education, merely introducing theories is not sufficient to achieve understanding. In high school and at college, scientific knowledge is presented via abstract theories, often in the form of equations or other symbolic notations. Yet, many students do not understand the theoretical elements beyond mechanically manipulating the formulas. For example, they pass their exams in physics by putting in the right numbers in the equations, without understanding the pattern expressed by the equation. In this way, students hardly achieve any deeper knowledge, let alone any understanding of the underlying patterns in physics.

I believe that certain educational information technology (IT) tools, in the hands of an experienced teacher/supervisor, can be effective in promoting understanding In particular, I want to point to tools for *visualizing* abstract data and correlations, that is, visualizing the patterns, and to programs for *simulating* various processes relevant for grasping the patterns.

When a teacher wants to convey patterns in abstract theories, visualization is an excellent method for promoting understanding, because it can pinpoint salient features in the pattern. In mathematics a third-degree equation suddenly becomes comprehensible when drawn as a graph, the connection between demand and supply in economics becomes graspable when drawn as curves in a diagram, and the development of a historical battle is easier to remember if presented by blocks and arrows on a map. Presenting theoretical patterns visually makes it easier for the students to connect to their own experiences and thereby their understanding will be considerably enhanced.

If we consider the problem of conveying cultural patterns, I would point out that visualizations could be excellent tools in language education. In traditional dictionaries, words are explained by other words. But there are also “pictionaries” where some words are explained with the aid of pictures. For example the differences between the English “breakfast” and the Italian “prima colazione” could quite easily be expressed using pictures.

A *simulation* replaces a real course of events by a dynamic model where the most important variables are accounted for. Simulation programs can be said to be a form of visualizations – namely visualizations of dynamic systems. In the computer game SimCity the player can construct a complex virtual city with water supply, electricity, streets, schools, industries, etc. The goal is not to conquer anything, but to keep the dynamic system representing the city in balance so that the city can develop in a harmonic manner. There must not be a shortage of electricity or too expensive streets. The simulations do not give you real experiences of city planning, but they provide *virtual experiences*. When it comes to understanding a process, such experiences are valuable substitutes. Because the student can *interactively control* a number of variables, she may acquire a rather rich experience of different causal connections in the system and thereby achieve a better understanding of it. When involved in a simulation, a student will be more likely to understand how different variables interact and affect other variables.

The virtual world of a simulator can complement the real one by providing situations that a student, for various reasons – ethical, economic, physical or temporal – cannot be allowed to experience directly, for example crisis management, stressful events such as a complicated surgical operation, and dangerous chemical experiments. Such virtual experiences become much more embodied and they stick to memory much more strongly than if the student just studies a text or abstract equations. On the other hand, the theories that are presented in textbooks can be supportive when interpreting the experiences. Understanding a knowledge domain builds on the interplay between theory and experience.

Different kinds of media can be exploited to bring out patterns. When I want to learn about a knowledge domain, I already rely on books, television, movies, recordings, etc. These media give us *substitute* experiences. *Role-playing* offers simulations of social interactions that can also provide students with valuable "virtual" experiences that they can later exploit in real life. If the students enact situations involving people from other cultures, the clashes between the cultures may become tangible without being embarrassing and without causing real problems. And then analyses of the clashes, together with a teacher or a supervisor, will be a very efficient method for understanding the underlying cultural patterns. If the teacher can act out the seemingly "odd" sides of the knowledge domain in a way that brings out a pattern, the students will be assisted to see its rationale. Because role-playing involves *interactivity*, it is much more emotionally engaging than using traditional media.

Today, teachers are accustomed to use various IT tools as a complement to their teaching and for providing a richer learning environment for their students. *Intelligent tutoring systems* are computer programs that function as a virtual tutor, albeit in a rather limited form. By using such a system, a student can practice a task at their own pace, repeat it as often as they like, and at the same time be given support by the systems at various points in the task.

Along the same lines, *virtual pedagogical agents* can provide useful tools (Gulz 2004). A virtual pedagogical agent can be thought of as an embodied intelligent tutoring system or a visual representation of the system. Such agents can serve as a virtual tutor in a tutoring system. For example, suppose a student is working with social problems in society. By encountering virtual tutors representing different perspectives, the student can be made to see that a problem can be approached in different ways that partly contradict and partly complement each other.

9. Understanding in science

As a final topic I shall compare the proposal that understanding is seeing a pattern with the debate concerning the role of understanding in science. This is currently a much discussed topic (e.g. Trout 2002, de Regt 2004, de Regt and Dieks 2005, Kvanvig to appear, Mulder no date, Kischenmann 2008; see also the review article by Keil 2006).

In contrast to the early accounts of explanation and understanding (e.g. Hempel 1965, von Wright 1971) it is now widely agreed that understanding and what counts as an explanation is relative to the epistemic situation of the scientist, not anything universal (van Fraassen 1980, Gärdenfors 1980, de Regt 2004: 103). This means that scientific understanding is pragmatic and context-dependent. For example, in the heyday of classical mechanics, Lord Kelvin is famous for having said that "the test of 'Do I or not understand a particular subject in physics?' is 'Can I make a mechanical model of it?'", but this ideal of understanding in physics has nowadays lost its appeal (de Regt and Dieks 2005: 138). It should also be remembered that for Newton's contemporary colleagues his notion of forces that operate at a distance was mysterious, while today hardly anybody with a scientific background will find it unintelligible.

One can divide the contemporary theories of understanding in science in two broad classes: causal and unificationist (de Regt and Dieks 2005). As an example of the causal theories, let us take Salmon's 1984 book *Scientific Explanation and the Causal Structure of the World*. According to Salmon, "underlying causal mechanisms hold the key to our understanding of the world" (Salmon 1984: 260) because "causal processes, causal interactions, and causal laws provide the mechanisms by which the world works; to understand why certain things happen, I need to see how they are produced by these mechanisms" (Salmon 1984: 132). In my view, this account of understanding does not conflict with the one presented here. On the contrary, as I argued in section 3, causal structures are special cases of patterns that can be discovered via the scientific process or via more mundane experiences.

The alternative approach to scientific understanding, the unificationist conception, has been defended by Friedman (1974) and further developed by Kitcher (1981, 1989) and others. Friedman writes that science unifies our knowledge since it "increases our understanding of the world by reducing the total number of independent phenomena that I have to accept as ultimate or given. A world with fewer independent phenomena is, other things equal, more comprehensible than one with more" (Friedman 1974: 15). Later, Kitcher argued for the fundamental role of patterns in this unificatory process: "Understanding the phenomena is not simply a matter of reducing the 'fundamental incomprehensibilities' but of seeing connections, common patterns, in what initially appeared to be different situations. [...] Science advances our understanding of nature by showing us how to derive descriptions of many phenomena, using the same patterns of derivation again and again, and, in demonstrating this, it teaches us how to reduce the number of types of facts we have to accept as ultimate (or brute)" (Kitcher 1989: 482). Again, it should be clear that the unificationist approach to scientific understanding, in particular in Kitcher's version, can be subsumed under the idea that understanding is seeing patterns.

After reviewing the causal and unificationist approaches to understanding in science, de Regt and Dieks (2005: 151) propose their "Criterion for Intelligibility of Theories": "A theory T is intelligible for scientists (in context C) if they can recognise qualitatively characteristic consequences of T without performing exact calculations." De Regt and Dieks attribute the general idea behind this criterion to Heisenberg. As examples of intelligible theories they mention the molecular theory of gases, "potential vorticity" in meteorology and "field lines" in electrostatics with the aid of which scientists can make purely qualitative predictions. However, it is clear from their descriptions of the examples that scientists use the theories to *visualize* the qualitative properties (de Regt and Dieks (2005) emphasize this themselves on p. 155). In other words, the scientists can *see the patterns* that are relevant for making the predictions. Once again, I conclude that also their Criterion for Intelligibility of Theories falls under the general idea of understanding as seeing a pattern. It should be noted however, that their criteria make understanding relative to the scientist who see the patterns – there is no thing as an absolute understanding within a scientific theory (a similar point is made by Mulder no date).

10. Conclusion

In this article, I have focused on the role of understanding in human nature. The central hypothesis has been that understanding is experiencing a pattern. I have shown how this general idea can be applied when we look at understanding different cultures, understanding in education and understanding in science. However, there is a great need for research in order to obtain a deeper understanding of the cognitive and motivational processes involved in various forms of understanding. Among other things, there is a lack of psychological tests for *when* understanding occurs during a learning process. We also need to find out much more about how understanding generates motivation for further learning.

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