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Introduction

Quantum-like models & metacognition

Quantitas Project

PREFACES

Introduction. Reinventing the wheel? No, its operation

Didactics has existed as long as humans have. Ever since literacy started to become normalized around the globe, all sorts of different methodologies, techniques and systems have been tried out when it comes to education. Therefore the idea isn't to reinvent the wheel. But during the second half of the 20th century dramatic changes have taken place in how we understand the nature of learning, shifting the focus from “what” to “how”. Especially with regards to how to improve skills in solving CUN (Complex, unfamiliar and non-routine) problems and situations.

Using a historical example, just as when an equivalent to modern music theory was discovered (solfège), we now have the need to accelerate learning in the face of the increasing complexity of learning. Indeed, before the onset of the pentagram, musical notation was not accurate because the only indications for singing were in the text and only indicated whether the melody rose or fell. This system prevented the piece from being able to be sung properly without some minimum prior idea of the musical intonation. All this changed with the invention of staff notation by Guido d' Arezzo. It was a system of four lines that allowed notes to be positioned at different heights according to their tonalities, so that the text in the inferior part could be separated in syllables to associate them with the correct melodic intonation. As a result, the song became independent from the oral transmission because sufficient tonal information had been facilitated thanks to the new discovery.

Today we are in a similar situation with regards to education, as the grading system only provides information on the rise or fall of student learning in tests or periodic assessments (the ‘what’). However we do not have the precise information needed to deepen and advance education based on the different cognitive abilities of the students (the how) and its evolution.

The increasing complexity of our society is teaching us harsh lessons through increasing unemployment. Many of the skills and formal knowledge acquired in the learning stage become irrelevant or are insufficient to the need to adapt to the rapid qualitative advances that occur in advanced economies. Therefore, a change analogous to the historical significance of the emergence of solfège music theory is required, so that learning is evolved to be a facet of future adaptive development for every person in the society in which they live. One of the keys to obtaining this is what understood as 'metacognition'.

Metacognitive knowledge has two essential feedback strands.

Important advances in the theory of knowledge (The Essence of Knowledge, Canals 1987) have gone deeper into precognitive principles or 'a priori'. These new works have allowed what Flavell understood by ***metacognition*** to be extended upon (The Developmental Psychology of Jean Piaget, Flavell 1963), obtaining a more radical frame of reference then its definition as the ***capacity that intelligence has to know itself***. Being secondly and consequently the practical knowledge of control of cognitive processes of that intelligence.

From this new point of view, the habitual activity of intelligence goes beyond the fact of knowing the outside because it incorporates a permanent reflexivity towards ones' own intelligence. For the present case about learning, what you discover it is that the strategies used by students when they learn are in no way at all neutral, as they highlight a previous personal reflection on the act of learning itself and therefore on the personal characteristics of each individual process in acquiring new concepts.

It is possible to observe these characteristics more clearly with non-CUN problems. The methodical nature of the routine of solving exercises is manifested at the superficial level of learning reflected in their grades. But then you can achieve a more radical second level in the rhythms observed care-neglect, activity-passivity, order and cognitive vector fields (more on this concept in the second pdf attached), to the extent that quantifies for discover that particular mark of intelligence of each student.

To provide a well-known audio-visual example, the cognitive and learning processes occur in a very similar way to that of how different processes of post-production also generate different points of view on the same cinematographic scene. In the same way, the processes used by different students to understand and to learn the same concept takes place according to 'differing and particular intellectual assembly'. And when better to appraise this then in the resolution of the non-CUN exercises, because thanks to their order, simplicity and familiarity, sufficient information is able to be collected beforehand to later analyze the variations in those `assemblies'. To continue with other examples, the student's intellectual profile can be found by the student themselves, in the same way that a painting is recognizable as belonging to one painter and to program algorithms that imitate them, or in a musical piece it is possible to discover an unique composer and to imitate them with cognitive software that creates new melodic structures that mimic the author, or can even be created by a user on the Internet by the movements made with their mouse.

The success of this recognition is due to the intellectual processes (and the learning) that each person (and student) must take control of in a cognitive form of what they want to know (or to learn). The only way to obtain this is by means of an assimilation of the understanding of that which is wanted to be known (or to be learnt) from personal heuristics, that already have been worked and sharpened by intelligence in each learning previously developed. In theory this heuristic would have to go back until the evolution from crawling to walking and until the process that forms in a child of the beginnings of the first basic elements of the mother tongue. Therefore, each new assimilation and learning leave a unique mark that is at the same time double and reciprocal: **the intelligence learns and forms the learning and at the same time this learning manifests in the form of intelligence**.

Metacognition obtains practical strategies that facilitate learning and also serves to discover the personal profiles of those learnings. Metacognition thus becomes the motor that ignites cognitive processes and at the same time reveals the intelligence behind those processes.

Returning to the example of music, what has been possible to observe is that there exists a didactic analog to the separation of notes carried out by Guido d' Arezzo, and the multiple intelligence profiles discovered by Howard Gardner. But in addition it has been discovered that it is precisely in the metacognitive sequences of distraction-attention and the interim analysis of the heuristic evolution while completing non-CUN exercises and problems, where it is possible to classify those intelligences without the need for a parallel test. This is because it is possible to discover them in the form in which exercises are solved.

And yet it has been possible to arrive even one step further, which wasn't anticipated in the initial research:

1. When the metacognitive sequences are displayed and made explicit to the students regarding their form and how they are derived from their own knowledge, two surprising things happen: The students reinforce and optimize the heuristic cognition by themselves, exactly equal to how they learned to walk or to speak alone without the help of anybody else because it was impossible. This is why **the learning process accelerates**.
2. The introduction of CUN metacognitive problems is very helpful, as a self-reflective metacognition has already been developed and now can be directed towards the metacognition of the problem or exercises. That is to say, **the metacognition necessary for CUN problems evolves in a spontaneous way**.

Continuing with the musical analogy, non-CUN problems allow previous metacognitive work to position the students in 'orbits' of intelligence, within a didactic vectorial field (explained in the attached document), in the same way that notes can be placed in a pentagram or electrons can be detected in a neutral energy zone. This first step facilitates the second metacognition for CUN problems because it informs on how to personalize them. This is exactly the same as how the advance in the solfège allowed for the personalization of music with the introduction of choral voices (sopranos, tenors, etc.) and the progression from polyphony towards more developed harmonic studies, until the pinnacle of symphonic musical complexity was reached.

Metacognition is revealed therefore like a coin with two sides, because at the same time that learning occurs on a problem, how students learn is also immediately generated. This allows not only for the structuring of complex information from the proposed problems and exercises, but also for part of the complex information that appears on the very act of learning, while you are learning. And the uniqueness of this premise is that when the teacher inputs both sides of metacognition, customized for each student, into their education, a cognitive feedback that facilitates the learning of complex, unstructured and non-routine problems occurs.

After establishing this principle, it would be impossible to move forward if a scientific method founded on rigorously verifiable principles of the universality pairs was not available. This is where quantum mathematical modelling enters the game. The next point is a very brief discussion of some aspects of these models as they are applied to learning. In the second PDF, three mathematical demonstrations have been developed showing the possibilities opened up by quantum analyses for the analysis of Didactics. For now, we will only focus on the most general principles and their possible application to multiple intelligences.

The potential of quantum mathematical models to be applied to learning

With incredible and counter-intuitive ramifications, quantum theory is the scientific theory that has been best empirically proven of all time. Its application to human cognition is not merely a simple extension of a very successful scientific construction. It is driven by thousands of perplexing findings and persistent challenges in psychological literature, in addition to deep similarities between the basic concepts of quantum theory and the psychological conceptions of intuitive learning. It is also due to the potential to deliver consistent explanations and mathematical principles based on the challenges and perplexities that appear in research on human knowledge and learning. To be analyzed from a quantum point of view does not mean that has to do with quantum mechanics, it is in fact an approximation to cognitive models using the mathematical principles of quantum theory, quantum structures or quantum modeling.

Quantum physics was created precisely to explain incredible discoveries that were impossible to understand with traditional physics theories. In the process of creating quantum mechanics, physicists had to also accept radical new ways of thinking that finally ended with a whole new way of understanding probabilities. Nowadays, it is possible to observe the same process in the areas of cognitive science.

Psychological concepts on conflict, ambiguity and uncertainty

Traditional cognitive models assume that at any moment a person is in a defined state with respect to certain judgments and knowledge. But when we examine this, the reality is that the true state of a person is always unknown. Thus any model can only assign a probability to a cognitive response with a specific value at any moment. This type of model is stochastic because what it produces is not based on the state of the person analyzed in each specific situation. In contrast, a quantum model allows for the assumption that a person is always in an indefinite state called a 'superposition state'. This means that all the possible values defined in the superposition have the potential to be expressed at every moment. This state of superposition allows for an intrinsic representation of the conflict, the ambiguity and the uncertainty that people usually experience in many cognitive processes. In this sense, quantum modelling allows for the discovery of the state of a cognitive system in space over time until some kind of change is reached, at which point this state collapses into a definite value. That is to say, by not presupposing the state it is possible to include in the analysis information tactically found in each selection or learning.

The sensitivity of cognitive systems to measurements

Traditional cognitive models assume that what is measured and recorded at a particular time reflects the state of the cognitive system as it existed immediately before the measurement occurred. For example, the answers to an exam would have to reflect the cognitive level of the student immediately prior to being asked. But one of the more provocative lessons that is learned with quantum theory is that the very act of the measurement of a system also at the same time creates and registers a property of that system. Immediately before making a question, a quantum system can be found in superposition state. The answer that is obtained therefore, from this system a very precise interaction between the state and the formulated question constructed. This interaction creates a strongly defined state from the same state of superposition. Every one of us that has had to face an exam or an important test will know that stress affects our answers and can negatively affect our final grades. This therefore demonstrates that a grade can reflect in addition to the cognitive state, an underestimation caused by the stress of the same test.

For that reason, before facing these controls it is also necessary to learn to develop customized strategies that help to create a calm attitude and personal confidence, provided that the exam has been properly prepared. The quantum principle of the construction of reality between people's undefined states and the questions asked, is consistent with the constructive point of view in psychological research and the idea that choice can alter preference. In fact, it corresponds far better with the psychological intuition in the case of complex judgments, decisions and other types of cognitive measurements as compared to the classic assumption that the measured answer is simply a register of a previous state.

The effect of the order on cognitive measurements

The change in cognitive states that results from responding to a question can cause the person to respond differently to the questions that come next. In other words, the first cognitive measurement often changes the context of the following measurement. So the order in which the measurements are made is of great importance. To use the same previous example, all teachers know the results in exams are worse when the first question is the most difficult one. These effects related to order had been recognized and described in research studies on opinion surveys and in psychology. But when there has been attempts to formalize a cognitive model it has not been possible to simultaneously define the probability of joint responses, but rather assign a sequential probability. In quantum physics the measurements dependent on order are *non-commutative*. Many of the mathematical properties of quantum theory arise from the development of a probabilistic model with non-commutative measurements, including the principle of uncertainty proposed by Heisenberg in 1927. The measurement of the effects of order, such as the order in which questions are given or the explanations are developed, have been studied with great detail and attention in research into attitudes, judgments and decisions. This has been in order to look for a theoretical understanding on the effects of order equivalent to quantum theory in physics.

Understanding violations of the laws of classical probability in studies on learning and decisions

Human learning and judgments do not always obey classic laws of logic and probability. Classic probability that it is used in the present models of learning and decisions derives from the axioms of Kolmogorov, which assigns probabilities to events defining them as sets. The families of sets in the theory of Kolmogorov obey the axioms of Boolean logic. One of the important axioms of this logic is distribution and from this is derived the theorem of the total probability, that provides the basis for inferences with Bayesian networks. However, in many psychological experiments the theorem of total probability is violated. The quantum probability is derived from Von Neumann axioms, that assign probabilities to events defined as sub-spaces of a vectorial space. By representing events by means of sub-spaces, one is able to fit them in to different logics and therefore one is able to save the distribution axiom of Boolean logic. This implies that quantum models do not always obey the theorem of total probability. Essentially, quantum logic is a generalization of the classic, and quantum probability is a theory of generalized probability. Thus as suggested by an accumulation of empirical findings that violate the classical principles of probability, this theory may be too restrictive to explain human learning.

Thus we have finally arrived to the metacognitive aspects related to the profiles of intelligence and how these quantum principles can reveal aspects that enhance teaching.

Multiple intelligences, metacognition, teamwork and ICT systems

In 1979 a group of investigators associated with the Faculty of Education at Harvard University received a grant from the Dutch foundation Bernard Van Leer, which is a member of the 'Human Potential Project'. This grant was given to develop a scholarly work on the nature of human potential and how to catalyze it. Howard Gardner received the directive to write a book on what has been established about human knowledge and learning, from the point of view of biological and behavioral science. This is how the research program was born that led to the theory of multiple intelligences, combining literature on the study of the brain, genetics, anthropology and psychology in an effort to determine the most accurate taxonomy possible of human capacity.

The research produced three very important aspects:

1. The naming of these human capacities 'multiple intelligences'.
2. To extend the concept of 'intelligence' to a set of eight criteria, defining each one.
3. The educational implications of the theory of multiple intelligences, because it has been educators rather than psychologists who have found the theory most interesting. Although initially the theory wasn't developed directly to have educational implications, as individuals differ in their intellectual profiles it makes sense to keep this in mind when engaging in learning. The most ambitious effort was 'Project Phantom', which had the objective to create a series of measurements by means of which it was possible to establish the intellectual profiles of young children, in pre-school and primary school. The team ended up developing fifteen different tasks designed to determine different intelligences in the most natural way possible.

Multiple intelligences do not have to be in and of themselves an educational objective, although they serve to facilitate early detection of talent in children. But once the goal is established, the observation of multiple intelligences is helpful to understand and enhance customized metacognitive strategies. For example, this approach is especially useful when it comes to teaching how to solve complex and unstructured problems evolving from the traditional mechanical way of problem-solving.

This is because **quantum mathematical models allow for different intelligences to be separated in vectorial sub-spaces to observe how they interrelate in each heuristic solution process, after each exercise and educational sequence**. Through a system of cognitive computing such as Watson-Analytics it is possible to bring together all of the tacit information that escapes the attention of the teacher, structuring it into predictive quantum fields and providing personalized teaching methods better aligned to the intelligence of each student to occur on non-commutative logic and allow modeling that violates in a single subspace the principle of total probability, but which is met when everything is included.

This theoretical construct transferred from physics also helps to scientifically explain why the pedagogies that affect metacognition are more efficient in collaborative environments and also why its effectiveness is improved when addressing both cognitive as well as emotional dimensions.

This affect aspect has to do with the capacity to motivate each student in a specific way based on the characteristics of their personal intelligence. The improvement relates to the fact that **students compare their reasoning and heuristic interactions completing different intelligences to achieve a higher level of knowledge than results from the individual sum, because it**

integrates logic in different subspaces that are complementary within the vector space in which they form part of. Taking into account that what is complex for one student can be simple for another, working in small groups integrates intelligence into a unity that would be impossible to achieve individually as each subject would be locked in the vectorial subspace that facilitates their own knowledge.

Finally, teachers and students find it particularly difficult to apply metacognition to ICT environments. For that reason, it is essential to construct a software that incorporates metacognition. Most text books and educational exercises focus on the repetition of activities and non-CUN problems. By all means the goal is not the elimination of this form of repetition in education, but rather to include it at an earlier stage before later arriving to CUN approaches.

CUN activities must end up being the central nucleus to all didactics, it is necessary to advance towards an education that harnesses in the first place metacognitive capacities and collaborative pedagogies that balance out the deficiencies and strengths between the students. Furthermore, because this type of public instruction is the paradigm best suited for developing those abilities that advanced and innovation guided societies need, which is excellence and meritocracy.

Non-simultaneous and heterogeneous objectives of the 'Quantitas Project'

EDUCATION	COGNITIVE MODELS	QUANTITAS SOFTWARE
Increase PISA level	Laboratory in real time on cognitive modelling	Hybrid Cloud Model
To automate good educational practices according to objectives and precise categories identified with massive data collection	To look for mathematical-physics principles that make the educational predictive system in the points indicated in the pdf	Flexible platform programming
To detect an intellectual profile for the solving of non-CUN exercises	Abstraction of the mathematical layer to other sociological, economic and industrial cognitive scopes.	Unique user experience, `evolutionary design'
Establish evolution strategies towards CUN with the data obtained from non-CUN activities	Evolution by reverse-engineering towards robotic systems	**Model of didactic standardization, as Google is to internet searches and Facebook is to social networks**
Automatic and early detection of talent	Transfer of quantum models	Integration with Bluemix and Watson Analytics
Detection of the best educational practices based on each student, of each class and the group of students working in a team	**Find metacognitive quantum modelling, to automatically discover intelligence profiles**	Model 'dark-data' and graphical representations
To construct a system of cognitive prediction (by accumulation of experiences and data) whether it is a student of students and teacher of teachers	Prepare optimal metacognitive scaffolding to be able to personalize the evolution of non-CUN problems towards CUN problems, always based on previous modelling	Standardization of data adapted to different public administrations
Categorize metacognitive abilities	Pose mathematical models similar to the double-slit experiment, for attention/distraction cycles	To pose a system of searches, that allows the teacher to find what they need and peer support if necessary
Categorize the didactic that develops metacognitive abilities on four levels: planning, monitoring, control and reflection	Pose a mathematical model equivalent to the Heisenberg uncertainty principle for cognitive distortions.	Automate the system of educational recommendations
Categorize how the cognitive and emotional processes are regulated in the two mentioned strands of meta-knowledge	To pose an equivalent to the equation of Schrödinger dependent on time for cognitive theory	Automate the student guide
To categorize the models of collaboration and the best combinations to deepen metacognition	To pose the cognitive equivalent to the Pauli exclusion principle	
To learn from the irrationality and to include it as a necessary part of learning and the capacity to harness it	To detect the influence of the order and the optimal order for each student	

To link with learning motor skills	To find automatic patterns automatic that compensate the effort-grade relationship	Establish the limits of communication between students, teachers, families and administrators
Establishcognitive exceptions that can distort the samples, medicated students or students with special needs	To find the mathematical form analogous to the vectorial field for the model of 'vectorial field', in a single issuer/multiple receiver structure.	
	Finding the equivalent to 'atomic orbital' in regards to the intelligence profile, on quantum models of cognitive theory and decisions	
		Management of hardware and software in the schools
		Separate Internet connectivity
		Include IMPROVE + MINT + Literacy evolution
		Demarcate free and paid levels partly by analysis of cost levels: Free, basic, standard and Premium