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Learning Evaluation in Engineering Studies: Cognitive Assessment, Informational Scaling and Systemic Modeling of the Knowledge Acquisition Process

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Abstract

The research work presented is in line with previous work on the complexity of the learning process. This complexity is approached through the study of perception, regarded as a non-deterministic system of interactions that evolves over time. The activity of these interactions is achieved through the various senses mobilized by learners.

We have conducted a study intended to define a reliable procedure to measure learners' perceptions of the skills expected through the engineering training curriculum, as well as their impact on the way these learners mobilize, under the influence of these perceptions, environmental and personal resources with the goal of achieving success. These learners thus generate their own environment for the purpose of their professionalization, as well as their personal and cognitive development. The processing of the descriptive, inferential and confirmatory results of the study led us to observe the evolution and variation of skills perception in engineering students over their five-year course. Temporal variability can be observed in perceptions, depending on the nature of the skills and on the phases of the course study marked by the temporal evolution of learning processes. These markers processes shed light on the dialogical relation found between educational science and sciences of perception.

Keywords

perception, systemic organization, skills and learning process, evolutionary systems, vicarial interaction

1. Introduction

1.1 Learning Process, Perception and Environmental Interactions: Positionings

1.1.1 Learning and Educational Practices

One of the functions of the learning process is about enabling individuals to adapt to the various types of environments they are confronted with, the aim being knowledge integration as well as knowledge and skills building. Understanding and comprehending the processes implemented among learners in order to integrate and develop these skills constitutes a focus of research in several fields of study, including that of learning theorists. From this perspective, sociocognition gives specific attention to learning processes, with a special focus on knowledge integration, by examining the effects on tensions, interrelations and mutual interactions between the actors and their respective environments. The more specific issue of the reciprocal triadic influence of factors internal to individuals, of external factors related to their environment and their behavior (Bandura, 2002, 2007) is central to descriptive, explanatory and comprehension patterns. These processes come within the scope of ecological spaces in which the personal dimension of individuals is considered to be decisive when it starts playing an active role and when it is in tension with environmental factors. For this purpose, practices are studied through their unique way of unfolding in their environment as a result of the perceptions of individuals. From the perspective of information theory, these practices convey "partial concordance" of sensations between the sphere of the learner and that of the knowledge provider, as these spheres are linked to each other by a channel in which circulate messages, as well as tangible and intangible elements of the environment, thus conveying sensations, perceptions and experiences by way of what Moles (1988) calls vicarial interaction (translated from French "interaction vicariale").

Indeed, observing educational practices contributes to providing a better understanding of the teaching-learning process, as a communication process. Understood as the action of making an individual (the learner) participate in the *stimuli* and environmental experience of another individual (the knowledge provider), this process uses knowledge elements that the former and the latter have in common to obtain mutual enrichment. However, such level of description is not sufficient to account for the way in which practices are held, that is to say, to connect the latter to "forms of organized activities" (translated from Altet, 2009). From this perspective, the point is not to identify the determinants of these practices but rather the processes governing the latter in their temporal unfolding. This search for what is governing these practices leads to tracking regularities and variations, which are indicative of learning, as a particular type of cumulative communication. Such regularities and variations, which belong to intra and inter individual phenomena, shall thus be studied through a temporal analysis of the vicarial interaction between the learner and the knowledge provider.

Based on research conducted about these perceptions, and particularly about the role played by *sensory stimuli* in the environmental interaction, the practices thus studied are examined with respect to the categories of resources found in the environment of these individuals. This environment, also known as "phenomenological sphere", otherwise called "personal shell" by Moles (1988), is affected by *stimuli* stemming from the perceptual environment, the *Umwelt*, which is a constituent of the environmental resources of the individual. In its original meaning, the notion of *resource* is associated, through its French etymological origin, with the means available to individuals (Petit Larousse, 2010), therefore it plays a key role towards practices (Jehanne, 2009). This notion is not only frequently used for the purpose of ecological and situational theories, but it may also be used metaphorically for the purpose of human behavior studies (Scallon, 2004). The resource itself shall thus play a decisive role with regards to the environment in order to study the modes of organization of practices. By setting our study at the environmental level and by taking into consideration the various modes by which are orchestrated the resources that are arranged as they are being perceived, individuals are therefore able to activate their potential when faced with a variety of situations of communication, including the ones involving learning.

1.1.2 Learning Conditions: Perceptions, Resources and Strategies

Learning presents several types of personal factors (cognitive, psychological, metacognitive, for instance). Among them, perception of learning concerns the way in which the learner interacts with his environment through his senses. Indeed, since learning is a particular type of communication defined by the fact that it involves the overlapping of the environmental sphere of the learner and that of the knowledge provider, it is determined by the use of our senses. In fact, in this study, senses are viewed as personal elements in individuals; as individual resources that can be deployed for the purpose of learning. In this respect, they represent mediation channels that may be defined as resources, whenever the learner uses them intentionally. The latter is then able to use his perceptions and his senses to detect, feel and make sense of the information conveyed by a learning object within the dynamics, tensions, and interrelations with the environment in which this object is situated. In situations when a learning object requires to be visualized, for instance a concept or a technical skill, the individual uses the senses required for this visualization process. This way, in an educational or training environment, sight, hearing, touch, gestures and posture constitute genuine educational mediators. In order for these channels to become resources for education players, the latter must fit their training environment with these channels. To this end, the "imprint" mechanism is the core process of learning, the one towards which individuals focus their perceptions, according to their profile as learners. In this study, the focus is directed towards the perception of their learning environment as a whole. This approach is a constituent part of a hypothesized relationship to the world, expressed and examined through the filter of perceptions and senses. This allows us to take on a less rationalist approach of communication whereby intuition and self-confidence constitute fundamental aspects. Indeed, such dynamics of interaction increase individuals' personal belief in their own efficiency (Bandura, Safourcade), hence making skill acquisition easier for them.

The hypothesis put forward is therefore as follows: the evolution of contextual, behavioral and internal variables in individuals prompts the evolution of sociocognitive functions of dynamic interactions with the environment through the individuals' perception of their learning.

In that sense, learning can be defined as an inherent form of “perceptual strategy” whereby the aim is to reduce the complexity of the information supplied through rephrasing, by means of structured sets (“words”) matching the “integration functions” of the sensory system. These functions have corresponding modes for the assembly of *stimuli* (for instance, by characterizing an atmosphere by means of visual, sound, thermal and olfactory stimulation) and symbols (such as letters gathered to form words and then structured into sentences). From a structuralist perspective, Moles (1988) refers to them as “super-signs”. The interlocked structure of the latter, in other words the “informational architecture”, allows for the integration of new recognition elements of the environment as part of the learning process.

“Beyond neural networks, cognitive systems are based on environment recognition mechanisms in order to adapt to it through learning mechanisms. The various evolutions of these functions can be induced by sensory perception (whether it be exogenous or endogenous), or by the activities of the cognitive system itself, and may be compared to one another using recognition mechanisms. When recognition is not performed, then it triggers a number of cognitive (driving) endogenous and exogenous actions on the environment, the consequences of which, once perceived, restore recognition, and eventually, the adaptability of the body to its environment. In this respect, a number of learning difficulties are formulated as part of viability (adaptation) and capturability (task learning) issues”. (Aubin, 2005)

According to this evolutionary perspective (Aubin), the ecological paradigm (Bronfenbrenner), the social cognitive theory (Bandura) as well as that of ideoscenes (Moles, Barker), or that of “image schema” (Lakoff) shall shed light on this integration function of the learning process by a temporal analysis of the way individuals function, by the unique way in which they acquire knowledge midst the tensions linking together the personal and environmental components of their training.

In order to match perception modalities with knowledge integration functions, the present study links the “perceptive functions of learning” to the “operations leading to the integration of knowledge in diverse contexts”. Results shed light on emerging specific forms of the process controlling inference observed through senses, and hence the one concerning the perception of the individual, considered as a complex integration function of environmental information.

1.2 Perception and Learning Complexity

1.2.1 Perception and Stimuli

From psychophysics to constructivism

The Latin etymological origin of the word “perception”, *perceptio*, means “gathering”, “collecting”. It conveys the senses of the soul (Quicherat, 1926). The study of perception lies at the intersection of several scientific disciplines, giving it a transversal dimension. From the angle of inference and empiricism, the work of Helmholtz (1924) links together “perception” and “sensation” by means of the inference process, based on past experiences. From his sensations, the individual deduces “the nature of the object” (Rock, 2001, p. 12).

In so doing, the “inference” theory demonstrates that the behavior of individuals are predictive and derived from objects based on “stimuli”, depending on the value granted to objects by individuals (Bruner, 1957, 1958).

Work achieved by J. Bruner and through the “probabilistic functionalism” approach have confirmed that perception is not only defined by the sensory message, but is also influenced by factors related to experience, emotions and values. This way, stimulations convey information from which perception only takes a number of indicators, “while classifying the stimulus into equivalence classes” (Bertrand, p. 84). Psychophysics, also known as the theory of *stimulus*, links perception with *stimuli*, which are revealed by the information present in the environment (Condamines, 1986). Thus, this trans-discipline proposes a phenomenal aggregation of physical and subjective aspects, while including into this combination all sensory interactions with corresponding physical phenomena, in keeping with a theoretical framework grounded in statistical experiment.

The constructivist theory, in turn, defines perception as “the result of the construction made by the individual, based on data provided by active observation of the *stimulus*” (Bagot, 1999, p. 9).

These theories are part of a hypothetico-deductive approach by which hypotheses about the nature of objects shall be invalidated or confirmed by information conveyed by stimulation. In that respect, the process of perception is assimilated to that of resolving the issue concerning the environmental recognition of the world as it is experienced. This is about determining which object produces a stimulation pattern, in order to identify the structure of sensory sources causing the environment to be recognized. The solution is provided by the knowledge constructed by the individual about his environment throughout his life, which may therefore infer on the nature of the object (Goldstein, 2007).

Developed as part of a hypothesized global interaction between humans and their environment, these approaches call forth the object-subject dualism in a comprehensively objectifying experimental perspective, in other words one that complies with the “independence-reproducibility-repeatability” criteriology. Hence, it is based on a foundation of factual observations put together with a theoretical construction which is generally removed from the time variable in its evolutionary sense, that is to say, set aside from the temporal qualification of its constants (physical and subjective time).

Perception, cognition and the sensorial system

The cognitivist theory considers perception as “the result of all mental operations which make it possible to provide meaning to sensory input” (Bagot, 1999, p. 11). Information processing is tied to several processes related to the characteristics of the stimulus at various levels of information processing: the ones derived directly from the stimulus and the ones that draw on pre-existing knowledge and individuals' cognitive schema.

In this respect, perception constitutes the "set of procedures allowing us to discover the world around us and make our own mental representations of this world" (Bagot, 1999, p. 5). Perceiving is therefore a permanent activity based on partially automated complex mechanisms, and fed by information coming from the object, in fact, not from the object itself, but via the channels of various sensory systems such as sight, smell and hearing. Perception thus makes use of sensations over space and time, by identifying, sorting and indexing them in a typology of recognizable forms, in keeping with the "Gestalt theory" (Guillaume, 1992).

> According to Valade (2016), sense is an apparatus comprised of four receptor organs, to which the sense of touch should be added, allowing "specific processing of information from the outside world" (p.33). Among the various senses, taste and smell are associated with emotional sensations while sight is rather linked with intellectual operations (Valade, 2016). In addition, research conducted in the field of musicology, as well as soundscape studies suggest that the sense of hearing and that of touch are part of the twofold scope of effect and affect, through a dual experiential and existential interpretation of the surrounding reality (Porteous, Mastin, 1985, Truax, 1996). Perception is thus considered to be linked with the properties of the object, although it remains independent from its objective understanding (Note 1).

Within the framework of a sociocognitive approach, the theory of perception sheds light on interaction dynamics between the sensory organs and *stimuli* from the external environment by focusing on the interactions between the environment and internal factors in the individual. The light shed on these dynamics by the theory of perception contributes to making sense of the process involved in interactions with the environment when the individual apprehends reality he has developed based on his own judgments. Therefore, from a sociocognitive perspective, the teaching-learning process brings into play the judgments of the individual based on inferred or captured reality, which constitutes the foundation of perception, although it does not represent perception in its entirety. When education professionals or learners need to evaluate their own skills or that of others, they may do so based on inferences developed during teaching-learning situations, and relying on the use of external or internal *stimuli*. They may otherwise use work-related situations during which individuals "copy" reality, and thus find themselves in a vicariance process, that is a form of recognition of their environment. Within the framework of the teaching-learning process, the reliability of these judgments should be questioned regarding its ability to guide human behavior. Thus, cognitive operations for the processing of environmental information will infer the judgments and behavior of the actor: the learner.

1.2.2 Learning as an Evolutionary Function of Perception

As part of knowledge acquisition, reasoning takes place based on the current state of knowledge and on estimating future changes in this state. This dual concern is not only linked with combinatorial problems, but also with the dynamics of knowledge evolution systems. This issue has to do with a precise description of the initial context, with the constraints of the problem (relating, for instance, to the management and availability of educational resources), and with the description of the dynamics of self-assessment states of skills.

The modeling of these systems thus reflects the complexity derived from the combinatorial and dynamic nature that characterize the evolution of the learning process. As a whole, it defines an analytical framework of "evolutionary systems" through which time is considered as a standard of evolution, as it compares the evolution of a reference variable to that of other environmental variables (Aubin, 2005).

Unlike "deterministic" systems which correlate only one evolution with each initial state, these non-deterministic evolutionary systems link each initial state with several evolutions of its variables, in "state space". In this respect, the learning system, which is generally considered univocal (associated with one purpose only), thus becomes multivocal, meaning that it is associated with numerous future, potential states. Similarly, these states may be compared to phenotypes in the domain of biology, to goods in economics, to behavior in sociology or to knowledge in educational sciences. They change depending on regularities which are inherent to the system, represented respectively by genotypes, prices, cultural codes and knowledge.

Biological and social sciences, (which) are riddled by evolutionary systems, are indeterminists, as they can produce, at any time, multiple evolutions from which a certain regularity is to be detected, and a number of interesting properties are to be selected" (Aubin, 2002).

These systems determine the evolutions subject to viability or optimality constraints by bringing about feedback loops, making it possible to regulate the system, by finding selection mechanisms in order for them to be implemented. This way, the intrinsic regularities of the system are indicators of environmental adaptation processes, in which the feedback loops of actors about their own learning, allow for the emergence of specific forms in situations of interaction.

1.3 Perception as a Learning Regulation Process

1.3.1 The Role of Sensoriality in Learning

Perception-action inference

The proactive nature of perception contributes to an understanding of the "action-perception" pairing when it comes to regulating actions towards the environment. Based on information selected from the context, they activate organized sequences of actions (Rock, p. XI). Indeed, depending on the type of information perceived, individuals act in accordance with the production mechanisms of perception which are saturated by the time constraint introduced by immediacy and contingency. While immediacy "stifles" reality, contingency is an "anamorphosis" of reality. Research work carried out by Mendel (1998) approaches the definition of action in relation to the notion of action by representing what goes through the mind of the subject "regarding both the action still viewed as a project and the continuation of this project as the action is taking place, or regarding the action once it has taken place" (p. 8). The action is expressed as an interaction of the subject with a reality entailing an element of unknown, a sense of strangeness. It is set after "per action", and it is conveyed by the concepts of motivation, intention, planning, and will. In addition, it requires the ability to act towards a form of unknown which would result in a reassessment of reality and an intelligence of the doing.

Therefore, perceptions have different functions, such as information processing interface, action regulator or knowledge integration device, allowing individuals to infer reality both by means of cognitive operations (Helmholtz, 1924, 1962; Bruner, 1958; Rock, 2001) and direct grasping through their sensory interfaces.

Sensoriality as a learning resource

According to Tardif's typological approach (2003), internal resources (psychological, cognitive, metacognitive, or conative, for instance) and external resources (social, cultural or material, for instance), are able to activate reflection in, on and based on action. They also contribute to the self-regulation involved in skills acquisition in individuals. Certain internal resources play a significant role insofar as they respond to needs which are considered important. Others are deemed peripheral, and yet relevant to teaching-learning situations (*ibid*, 2003). External resources, however, have to do with "anything that is provided by the environment in terms of resources for action: human, material or technological resources, for instance" (*ibid*, p. 40).

It is therefore based on the role played by *stimuli* that the notion of resource is hereby highlighted as a key element of the learning process. Unlike previous studies which were mainly focused on resources of various nature (such as psychological, cognitive, conative, metacognitive, human, material, enabling, spatial), this type of mnemo-sensory resource is hereby elucidated and linked to the process by which learners perceive skills.

Sensory resources are therefore defined here as the set of senses that individuals can potentially use for the purpose of learning. Considering senses as usable resources means that special attention is paid to the unique way in which sensory procedures are employed by learners in order to make their own choices, identify and sort through the numerous resources that map their profile.

Perceptive integration

By considering learning as a process of gradual specialization of a "totipotent" (Note 2) situation over time, the archetypal and symbolic economy of the cognitive treatment of information consists in integrating the various phases of the interaction in action into the process of environmental inference.

Integration is an operation which makes it possible to go from a discrete to a continuous logic, by combining a single measure to a discrete set of state variations (signal).

Etymologically, the term "integer" means "whole, entire", hence the idea of a continuity in learning cognitive processes, in which integration is linked with the notions of resources, objectives and skills. Roegiers (2010) introduces a general definition of integration as follows: "an operation by which different elements which are initially dissociated become interdependent so that they can operate in an articulate manner depending on the purpose" (p. 62).

Furthermore, Roegiers (2010) states that a skill is considered as the "possibility for an individual to mobilize, in an internalized and reflective manner, a comprehensive set of resources in order to face any situation pertaining to a set of situations (p. 242)". Research conducted by De Ketele & al (1988) perceive learning as a sequence "run through consecutive integration of increasingly complex objectives. A more integrated objective contains and reinforces less complex objectives, while securing their integration at the same time" (pp. 99-100). This notion of integration is influenced by the need to understand the cognitive equilibration process required to formalize the change of state prompted by the act of learning, in keeping with Piaget (1975) and Vygotski (1934) who shed light on these different balanced and unbalanced states involved in learning.

Therefore, "integration" is the function consisting in the association of all the elements of the vicarial interaction based on which intelligible structures (formatting) are formed, in order for the individual to assimilate and become aware of his environment.

1.3.2 The Temporal Structures of Learning

A structural formulation of learning

Learning is hereby comprehended as a hypothesis-forming mechanism to be gradually compared with the perception of the environment. Indeed, this deals with internalization behaviour, which is the core principle of the inference mechanism of vicarial interaction, as part of the interaction process. During the course of this interaction, the learner receives, in his anthropocentric realm, a flow of sensations, perceptions, information and messages which get arranged and memorized as "scenes" coming in succession in his consciousness, going from a continuous flow to structured discrete impressions known as "ideoscene", a notion introduced by Barker (1957, pp. 155-156) and taken up by Moles (1988). During this "vicariant correspondence process" (Aubin, 2010), ideoscenes are assembled, distorted and recombined to take part in the complex representation of information associated with the environment. They are then reorganized at a more tangible–therefore cognitively more economic–level of representation. Analogy, which is the highest level, carries out a direct symbolic transfer of perception into vicarial interaction ("Umwelt"), while the lower end of the metaphorical projection performs an archetypal transfer in which the kine-perceptual impression ("Merkwelt", coined by von Uexküll (2004), reflecting all virtual modes of interaction between an individual and the world) assists the teleological construction of the perceiver, by means of an abstract formalization of a contemplated situation or environment. Perceptions are thus part of integrative structural models. They are also involved in behavior organization based on their capacity to "extract invariants or regularities from the abundant stimulation that reaches sensory organs" (Delorme, 2003, p. XI).

Learning acquisition evolutionary patterns: regularities and temporalities

Therefore, in order to make sense of the fields of experience on which people have no direct grasp (including affects and percepts), we call forth this process which generates ideoscenes in the form of patterns, called ideoscene structures. Furthermore, Lakoff, (1990, pp. 39-74) and Turner, (1990, pp. 247-255) consider them as image-schemas, viewed as mental structures emerging from the domains of experience understood directly by people. The place where these patterns find their mental anchoring relies on a regularity which makes it possible for us to understand our direct experience of the environment, without any precondition or analysis procedure, by allowing gradual solidification of acquired knowledge elements. Integrated knowledge therefore derives from a set of knowledge, such as know-how and interpersonal skills. It is linked with a high level of knowledge command. Indeed, the "accumulation of knowledge" performed through learning reflects the logic of solidification of the oldest strata of "experienced" data. The latter are considered as high-level knowledge evolving more slowly than that from lower levels, associated with specific learning temporalities. Since evaluative and behavioral knowledge are older, they present, due to their inertia, longer hysteresis paths (Note 3), causing greater temporal remanence than those observed at lower levels, for instance descriptive knowledge, which are less inert and more fragile over time. The cognitive demands required to renew each one of these knowledge strata are then closely linked with their inertia: the more ancient/inert the knowledge, the more difficult it is to forget, question, or substitute with new knowledge. The integration of these various levels of knowledge is frequently performed following several retroactive research processes in the form of consolidation/elimination of pre-existing environmental information (learner's "repertoire"), through an analogical-metaphorical hysteresis path (Figure 1) which could shift towards an attractor, in other words, a preferred path for knowledge state variables. These trajectories are described through an evolutionary analysis of the learning correspondence, for the purpose of detecting any pattern in the behavioral regularities of interaction.

The emergence of these regularities provides a basis for the interpretation of our recurring experiences, thus allowing us to understand directly one area of our experience based on the history of our interactions with the environment via the process of metaphorical projection: "Metaphor is not conceived here as a figure of language, but as a fundamental cognitive tool, which allows us to understand a field of experience in the terms of another: it partially and systematically projects the structure of a target domain on a source domain, so that inferences and implications which are specific to the source domain are applicable to the target domain" (Fastrez, 2002, p. 4).

The feedback loop of environmental inference

Through the metaphor, the act of perception complies with the principle of "unconscious inference", formalized as a feedback loop instantly reconstructing image-schemas from past experiences: the "experientialization of the environment". It is in this capacity that, during the learning process, memorial strata organize into a hierarchy prioritizing its sensory resources, through a structuration into various levels of a process of environmental inference. By creating a loop with analogical construction on one side and metaphorical projection on the other (Figure 2), the "feedback" of the environmental inference of the subject in a situation of perception and action allows us to develop a complex "cognitive map" of the recurrent patterns of sensations. The real and imaginary elements of this map represent the duality of "existence" (essence, in phenomenological terms) and "experience" (interaction, in the axiological sense). It is in fact a dual comprehension of real and imaginary aspects of perception, reflected in a alternation between "Umwelt" and "Merkwelt":

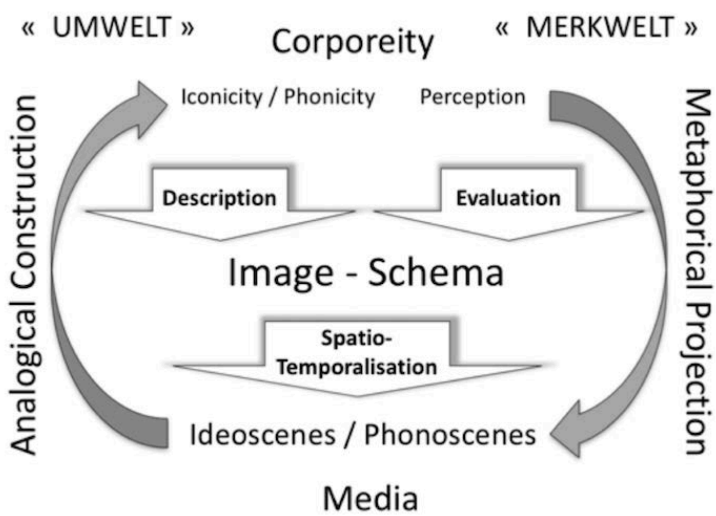

Figure 1. Inference as Analogical-metaphorical System of Image-schema Feedback (Woloszyn 2014)

This is where the feedback loop between the learner and his environment (analogical construction/metaphorical projection loop, Figure 1) develops the projection of the individual towards his sensoriality, in such a way as to best utilize his senses in interactional situations and contexts specific to learning. Among all of the internal resources which can be used during the interaction process, those that appear to be directly linked to learning objects have to do with analogy. They are connected to experiential and descriptive perception, thus conveying an objectifiable semantic message, while the resources of their symbolic construction are generated through the mechanism of metaphor (evocation, imagination). The existential qualification of the latter has to do with a connotative emotional charge (Woloszyn, 2019).

By defining the cognitive system as a mechanism combining a set of behaviours to each image-schema (Woloszyn, 2018), "vicariant correspondence" (Note 4) is thus associated with "perception correspondence" (sensoriality) and "action correspondence" (motricity) which, as they are being combined, define the "learning correspondence". We hereby attempt to provide a definition for the dynamics of the latter. Through sensory-motor action of the student in a learning situation, the ideoscene and, by extension, the image-schema, represent the “integration” of kine-perceptual experience through its sensorimotor landmark, connecting perception and action by determining an “adaptive learning rule” from the inference process. This feedback system, which forms the basis of the knowledge acquisition process, involves the hysteresis phenomenon. The *panarchy* principle (Note 5) of the latter (Dauphiné & Provotolo, 2013) defines the set of trajectories (feedback loops) which are “required” for knowledge integration to be performed.

2. Method: A Measure of the Temporal Structure of the Learning Process through the Filter of Perception in Engineering Students

2.1 A Description of the Study

Carried out jointly by the CREAD Research Unit (Center for Research on Education, Learning and Didactics) of the University of Rennes 2 and Laplace laboratory of the University of Toulouse 3, the study was conducted among 500 engineering students (Safourcade, 2017, 2020; Albero & Safourcade, 2014). This research aimed to measure the perception of skills expected as per the curriculum for engineering training, and listed in the national directory of professional certification. For each of these skills, respondents were asked to estimate, on a scale ranging from 1 to 10, their level of perception of a number of skills. Based on this data, the objective is to determine a law of order by analyzing its evolution over the five-year course at the school of engineering. By considering perception as a variable dependent on the year of study of learners during their course, using theories developed by Stevens and Fechner (Bonnet, 1998) allows us to validate the development of laws of order about perception, in relation to the integration process.

The main categories of skills expected to be acquired by the end of the engineering training can be divided into three types. Academic skills (4 items) refer to knowledge and understanding of fundamental scientific disciplines (skill C1), the ability to analyze and summarize, in connection with the acquisition of fundamental disciplines (skill C2), the ability to mobilize fundamental knowledge and techniques associated with a discipline (skill C3), command of methods and tools of the engineer for problem resolution (skill C4). Professional skills (3 items) refer to the learner’s ability to become integrated into an organization, to lead this organization and make it evolve (skill C5). It also refers to the ability to take into account professional issues (skill C6) as well as the ability to work internationally (skill C7). Cross-cutting skills (3 items) are defined as the learner’s ability to implement the principles of sustainable development (skill C8), the ability to take into account and uphold societal values (skill C9) and the ability to make career choices (skill C10).

2.2 Theoretic Foundation and Quantification Tools

2.2.1 Regulation Rules for the Learning Correspondence

The mobilization of acquired knowledge through senses during the learning correspondence is thus represented by means of analogical/metaphorical feedback loops on the experientialization of the environment (Fig. 1). Throughout this correspondence, selection mechanisms re-encode *stimuli* subsections into higher level archetypes, called “super-signs” (Moles, 1988), in order to achieve the reification of information, the latter become cognitively more “economical”. Derived from “nested levels of perception”, these super-signs optimize the encoding of the message to be transmitted (Shannon & al. 1949b), in accordance with the “principle of the least effort” (Zipf, 1949). They are subject to specific laws of organization which are unitarily decoded during perception, while being approached in their overall structure (Gibson, 1986). The resulting cognitive state then uses a “behavioral directory” which has been stabilized at a given moment, and then has been encoded into super-signs by acquired knowledge. These repertoires form the “common knowledge bases” used by the person who provides knowledge and by the one who is learning, during the learning correspondence. The integration of these super-signs as part of the action of perception may then be symbolically quantified by combining it with a quantity of information called “generalized entropy” (Shannon, 1949). By transforming the signs of a message into super-signs or into image-schemas, the perceptive act therefore contributes to reducing the complexity of environmental information. This act involves the memory of regularities in vicarial interaction, which leads to a minimization in the quantity of exchanged information, in other words, its entropy level (Note 6).

2.2.2 Using Entropy to Quantify Interaction

Entropy, which is hereby understood as the predictability level of information exchanged during this correspondence, makes it possible to quantify the similarity of transmitter-receiver directories, taking into account all of the complexity of their dynamics. Specifically, the quantification of this complexity is comprehensible through “differential entropy”, which characterizes the transmission channel between the professor and the learner, determined by calculating the “originality output”, generally measured in bits/second. As a measure of the dynamics of the learning process, this entropy level thus constitutes an adaptive function, which asymptote corresponds to the coincidence of source-transmitter-receiver directories (Moles, 1990). By measuring the limit of the level of information in the temporal transmission channel based on the “weight” associated with each category of skills, it is then possible to develop a quantification of the learning correspondence dynamics, based on the temporal evolution of the skill levels assessed by learners, for the duration of the learning period.

This correspondence is hereby quantified in terms of differential entropy through temporal analysis of the skill levels perceived between two self-assessment states.

2.2.3 Order Spectrum, Linear Regressions and Informational Dimension

The linear regression method allows us to obtain, for every couple of years and for a 5 year course, ten affine equations representing the evolution of the perception of the ten skills identified, based on the five years of study undertaken by engineering students. These are $yi=aix+bi$ equations where yi is known as the “perception” dependent variable, for a given school year.

The *ai* coefficient is the integration indicator of skill perception, while *i* represents the type of skills and varies from 1 to 10. The geometric analysis of gradient evolution provides information on the sensitivity of each perception indicator, depending on the school year. As for *ai*, it is the leading coefficient of the tangent at a given moment of the learning process (M). It is the portion of the evolution curve, in other words the global gradient of the learning process.

$$ai = \int_1^4 y(t)dt$$

∫y(t)dt represents the integration of skills perception

This method allows for the formalisation of the order spectrum linked to the evolution of skills perception by learners over time. This order spectrum sheds light on the evolutionary potential of learners during the learning process, whilst determining the multi-scale behavior of data sets at different levels of the learning process.

Linear regressions calculated over each measurement interval reveal the structural relationship between the number of occurrences of information sources and their rank (as per Zipf's law (Note 7)), which allows us to express this regression as a quantified relation by "informational dimension" *Ds*, as in:

$$D_S = \frac{\sum_{x \in X} p(x) \log \frac{1}{p(x)}}{\log k}$$

where *p(x)=ai* is the occurrence of element *a* of rank *k=i*, that is the self-assessment level *a* of skill *i*, at moment M. The numerator of this dimensional expression constitutes but the canonical expression of entropy *H*.

For the purpose of the study, temporal sampling measured by dimensional information takes place during the transition period between each year of the course (first order indicators), and over a rolling period of three years (second order indicators). All of these results therefore represent data concerning the evolution of skills perception across the overall course, quantified by the differentiation of the level of information pertaining to each state of perception.

The analysis of this evolution is carried out by means of a subdivision of the different time steps of self-assessment levels, adapted to a step function (function *f* over the measurement time interval, f remaining constant over each sub-interval *]ai – 1, ai[*, for *i = 1, … , n*.).

Thus, by refining the first order subdivision with that of second order, then a partial order over the subdivisions of the intervals is defined, which makes it possible to draw nearer to the dynamics of the evolutionary scheme of information during the course of the learning correspondence.

3. Results: Evolution of Skill Perception Expected as per the Curriculum over the Five Year Engineering Training Course

The integration of survey results over the full course by the calculation of ten linear regressions makes it possible to compare the evolution in the perception of each of the skills over the entire learning period (Fig. 2):

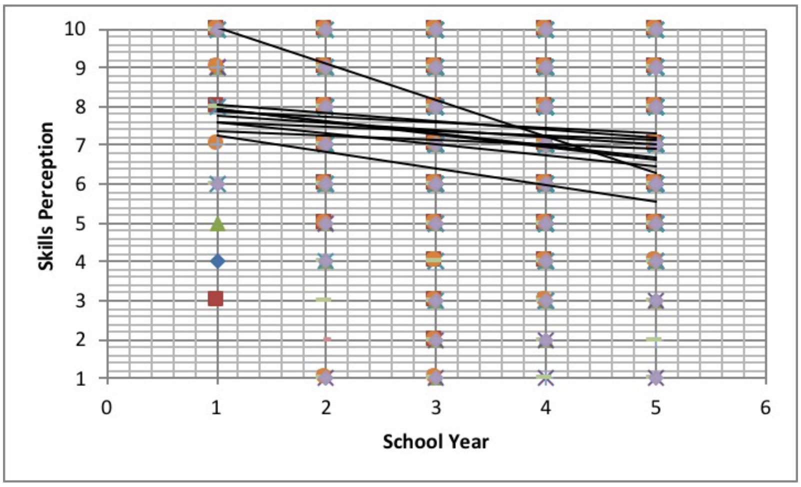

Figure 2. Evolution of Learners Perception for each of the Ten Skills Expected as per the Curriculum over the Five Year Duration of the Engineering Training Course

The slopes of the lines illustrate the evolution of entropy in the learning system over the entire course, for each of the targeted skills. The diagram highlights consensual behavior for all lines, except for those concerning skills C1 and C7. These analyses involve the scalar indicator of informational dimension, calculated from the slopes showing the evolution between two successive states in self-assessment levels by three-year, then annual intervals.

Variations in skill perception states in engineering students during their training course

In this regard, we consider three sub-periods of the course, as three-year time periods. The value obtained by calculating the difference between the leading coefficients of two successive linear regressions represents a second order value as follows:

Table 1. Second Order Temporal Sampling Calculation Table

Annual steps	$a_{1=(1,2)}$ (1 ;2)	$a_{2=(2,3)}$ (2 ;3)	$a_{3=(3,4)}$ (3 ;4)	$a_{4=(4,5)}$ (4 ;5)
Second Order Temporal Sampling	{(1,2) ;(2,3)}			
Second Derivative	0.0436-(-1.7048)= 1.7484	0.7867- 0.0436=0.7431	0.0334-0.7867=-0.7533	
Third Order Temporal Sampling	{(1,2) ;(2,3) ;(3,4)}		{(2,3) ;(3,4) ;(4,5)}	

This overview of the evolution of skills perception over three-year time periods allows us to assess the linearity of the characterization of skills perception for each time period. The chart below (Fig. 3) presents variations in skills perception states among engineering student over three periods:

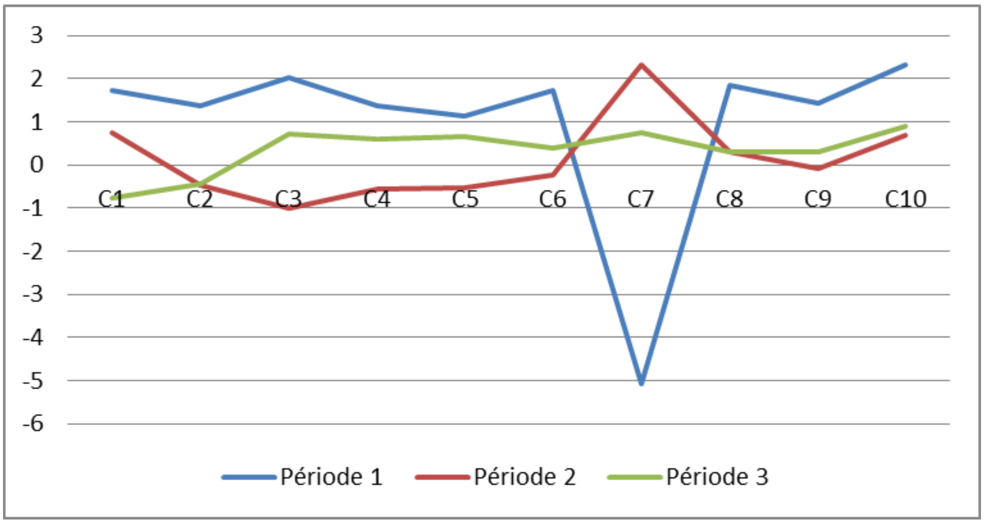

Figure 3. Variations in Skills Perception States in Engineering Students during the 3 Periods of their Course

For each skill (C1 to C10), a curve represents the perception of learners over a three-year rolling time interval. Period 1 situates the time interval from the 1st to the 3rd year, period 2 from the 2nd year to the 4th year, and period 3 from the 3rd to the 5th year.

In this regard, it is then possible to comprehend the linear nature of each of these three periods by detecting the values showing the evolution of the skills perception which break with the overall linearity of the system. Skills perceptions essentially follow the same pattern, although they display state variation. There is a first learning period during which learners have a greater perception of the evolution of their skills, followed by a lower level of perception, which eventually evolves positively by the end of the course to an "intermediary" level. Skill number 7 "the ability to work internationally" presents a high marker level during the first and second periods, which can be explained by the fact that engineering schools organize a number of programs of study that include a period of work experience abroad planned towards the end of their training.

The study of skills perception thus reveals the dynamic and organized nature of learning practice in engineering students. Over the three periods, skills perception among learners undergoes significant fluctuations marked by stability and variations. Depending on the periods, perceptions get reconfigured (Pastré, 2007) by the internal resources which shape and reorganize the practice of learners depending on their learning environment.

Annual evolution of the perception of dimensional information, depending on the nature of skills

The study of perception is hereby set out for each of the three main types of skills (academic, professional, cross-cutting) and for a given interval, representing one year of the training course. The difference between the two subsequent variations observed in the perception levels is calculated as dimensional information. For each annual interval, dimensional information assesses the level of hierarchy of the interaction process.

Table 2. Table Showing the Annual Evolution of Information Dimension for each Skill

Annual steps	$a_{1=(1,2)}$ (1 ;2)	$a_{2=(2,3)}$ (2 ;3)	$a_{3=(3,4)}$ (3 ;4)	$a_{4=(4,5)}$ (4 ;5)
Information Dim D1	2.7048	0.9564	0.2133	1.0334
Information Dim D2	2.1923	0.822	1.3002	1.1272
Information Dim D3	2.7692	-0.2692	1.724	1.0187
Information Dim D4	2.4333	1.0571	1.6251	1.0185
Information Dim D5	2.05	0.197	1.4477	0.7872
Information Dim D6	2.641	1.0836	1.3287	0.93
Information Dim D7	-0.8846	4.1934	1.8592	1.0993
Information Dim D8	3.4872	1.655	1.3578	1.0512
Information Dim D9	2.7309	1.3133	1.3959	1.0836
Information Dim D10	3.1026	0.7749	1.4719	0.582

The four following diagrams thus present the annual evolution of learners' perception for each type of skills Figure 4:

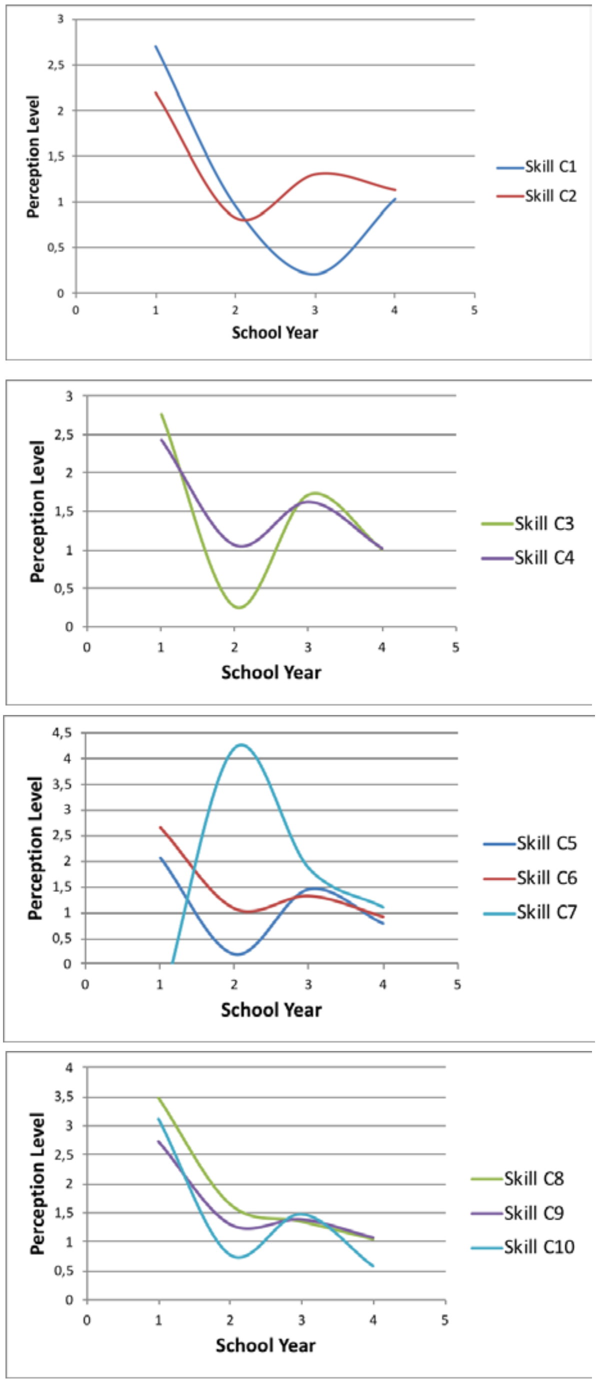

Figure 4. Temporal Evolution of Perception for the Three Types of Skills: Academic, Professional and Cross-cutting

Apart from skill 7 whose singular pattern has already been mentioned, the remaining skills present similar evolution, or at least, an affine evolution, in the temporal form of a "damped sine" (Fig. 4). This signal of the interaction of the learning correspondence into damped sine *(sinx/x)* reveals an evolutionary regime which is specific to the complexity of the learning process, analyzed through the filter of perception. It constitutes the signature of the feedback circuit which is part of the knowledge acquisition process, involving the hysteresis phenomenon. The latter describes the sensory interaction of the learner with his environment; a step preceding knowledge integration occurring at the end of the learning process.

Regarding the set of skills examined, changes in perception states which display a high degree of perception during the second year can be observed, as well as a marked decrease during the third year. All of the evolutions observed regarding skill perception stabilize around 1 during the fifth year. This asymptotic value confirms the end of the learning correspondence through knowledge integration.

This temporal signature of the learning process dynamics, which is measured by dimensional information of the entropy level of the learner's vicarial interaction, makes it possible to describe the temporal adaptive function of the learning correspondence during the interaction. This learning correspondence becomes gradually stable over time. The signal of its temporal evolution thus reveals the process of information consolidation among learners up to the final asymptotic level of skills acquisition, at the end of the course.

Perception of specific skills: using contextualized evolutionary process to configure learning

As can be observed from the temporal evolution curves, the evolution of skills varies according to an affinity coefficient, depending on the type of skills perceived, whether they be academic, professional or cross-cutting.

Academic skills (2, 3 and 4) display a shorter period, with a more rapid stabilization of the degree of perception than professional or cross-cutting skills. These contrasting evolutions indicate that the perception of a skill concerning knowledge or involving scientific disciplines and engineering methods undergoes greater level variations over the five year course. At the beginning and at the end of the training, two periods show high and lower perceptions coming in succession. The level of perception of academic skills is due to learning practices being redefined when learning evolves. For instance, at the middle of the period, it integrates fundamental disciplines (such as mathematics) required to tackle more complex disciplines (such as robotics) or specific tools pertaining to engineering functions, which are introduced to students during the second part of the training course.

Professional skills are activated by means of specific situations of professionalization (such as case study, project management or internship), informed by the temporal analysis of their interactions. The results of the study thus confirm that the perception of these skills presents variability, due in particular to the conditions of their activation. When engineering students work in groups on specific projects (such as robot construction or platform development), they promote their learning, both socially and among their peers, thus increasing interaction levels. This relationship can develop during internships, for which such promotion no longer occurs among peers but among new teams of professionals, which translates into a longer periodicity for learning correspondence interactions. Furthermore, the relatively low temporal signal of interaction indicates that surveyed engineering students give relatively low consideration to the cross-cutting skills hereby identified (societal values, sustainable development). These “didactic effects” of acceleration (phase) or intensification (levels) of the interactions that take place between the knowledge provider and the learner are thus revealed by the temporal analysis of the learning correspondence, as their question teaching-learning practices through the relation developed by future engineers with their profession.

4. Discussion

The study of skills perception among learners with an interest in engineering jobs shows that their relationship with the training environment is built through the filter of perception. In the field of learning, the issue of acquired knowledge perception therefore stands as a substantive element drawing upon the personal resources of individuals. The sensoriality of learning is thus emphasized since senses are an integral part of personal resources, which can be used by learners for skills development. In this study, learning is approached through senses, which are the means that individuals can use to perceive their environment and make sense of the way they carry out learning. They may either activate them, objectify them or become aware of them. In this research, senses are examined implicitly through their mediating role and their connection with the perceptual function, which can be observed through the temporal evolution of its process. It is precisely the temporality of this perceptual function that this study has endeavored to represent through an examination of the learning correspondence, by identifying stability and variation in the perception of engineering students over their five year training course. By shedding scientific light on the issue of perception among individuals in the learning process, the role of senses is thus emphasized.

The study of the temporality of learning reveals high instability in skills acquisition, alternating between peaks, oscillation and stabilization. The disparity observed in the temporal evolution of knowledge acquisition processes therefore offers differential reading between the categories of skills expected to be acquired by the end of the engineering training, whether they be academic, professional or cross-cutting. Indeed, the specific temporalities of learning practices pertaining to these fields are described through analyzing the evolution of the perception of associated skills. By discriminating the temporal behavior of perception linked to sensory resources, this study unveils the sociocognitive mechanism shaping and reorganizing learning practices at the time of the learning correspondence, for each group of disciplines. Changes observed in the level of skills perception analyzed in this study through the filter of learning practices thus makes it possible to define the field of learning over its temporal process. This way, the complexity of the interaction system can be apprehended by the “power spectrum” of the pace of the temporal fluctuations of the learning correspondence. Its “probability density” being thereby approximated by the temporal evolution of its entropy level.

By means of a symbolic construction based on the observation of states and interaction regularities, the learning correspondence can then be modeled as a “regulation correspondence”, based on an “adaptive learning rule”. The time constants of the latter reveal the type of skill which has been acquired depending on the adaptation of the learner’s sensory-motor system to its context. Indeed, the laws of action and perception of the latter are constantly adapted to the environment, by successive leaps, and are modeled by means of feedback loops, finding themselves between a metaphorical encoding and an analogical reification of the perception-action inference, as part of a cyclical logic of knowledge reification.

By considering time as a scale encoding the interaction phenomena occurring between the learner and his environment, this temporal signature of the learning correspondence can be used to define the resources needed to achieve knowledge “acquisition and strengthening goals”. It takes the form of an asymptote towards which the evolutions of the perception of acquired knowledge are tending. This formalism allows us to focus on the definition of temporal frameworks adapted to sensory resources in particular, which are needed for the acquisition of each type of skills.

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Note(s)

Note 1. Rock (2001) contrasts the mental constructs that characterize perception with "direct recording of reality" (p. 6).

Note 2. A totipotent situation can generate a very large number of diversified situations, similarly to stem cells, which constitute totipotent elements of the body. This means that they are able to develop into any form of organic organization.

Note 3. Hysteresis" outlines the property of a system to remain in a certain state when the external cause which had initially produced the change in the state ceases to exist as in the phenomenon of electromagnetic induction, for instance.

Note 4. A "vicariant process" is a process allowing several potential paths between a given stimulus and its response. Therefore, it is multivocal, as opposed to the univocity of stimulus-response processes as defined by behaviorists, from Pavlov (Todes, 2000) to Skinner (Catania & Harnad, 1988). The notion of "vicariant correspondence" resulting from it describes the mechanisms of encoding or acknowledgement of an organism by a regulation system (Aubin, 1991).

Note 5. One of the essential features of panarchy is that it turns hierarchies into dynamic structures. Individual levels have non-linear and multi-stable properties. They may be stabilized or destabilized through the connections occurring at different levels. Panarchy outlines the way the states and dynamics of (sub) systems (including their situation with regards to their adaptive cycle), lying higher or lower than the scale considered, affect the system, either directly (from the lowest scale) or by altering its overall stability (from the highest scale).

Note 6. The work of Claude Shannon and Norbert Wiener, published in the Bell System Technical Journal in 1948 [Shannon, 1949] and [Wiener, 1954], introduced the mathematical definitions of information quantity. The definition of entropy by Shannon is constructed from discrete case by quantifying a sequence of symbols, whereas that of Wiener is rather in a continuous logic, studying the variation of a signal. Through its synthesis of engineering disciplines, these definitions are based on a major conceptual innovation: the use of probabilities. By building bridges between physical statistics, engineering sciences, life sciences and cognition sciences, the notion of entropy allows the transfer of the notion of information throughout all of these disciplinary fields.

Note 7. Zipf's law [Zip-49], also known as "rank-frequency law", has been revealed by American linguist George K. Zipf . It examines how frequently words occur in a language. According to this law, the frequency of occurrence of items, arranged in descending order with regards to their frequency of occurrence, are organized according to the terms of a power law.