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SENSITIVE DEPENDENCE ON INITIAL CONDITIONS: A COMPLEX DYNAMICAL SYSTEM'S KEY FOR THE UNDERSTANDING OF INTELLECTUAL AUTONOMY'S DEVELOPMENT

DEPENDENCIA SENSIBLE A LAS CONDICIONES INICIALES: UN RASGO DE LOS SISTEMAS COMPLEJOS CLAVE PARA ENTENDER EL DESARROLLO DE LA AUTONOMÍA INTELECTUAL

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ABSTRACT

In recent decades, interdisciplinary teams at the Santa Fe Institute of New Mexico, have analyzed the mathematics that underlies the evolution of complex dynamical systems. Thanks to computing, we can graphically see a curious property of these: the sensitive dependence on initial conditions (SDIC). Some mathematical aspects of complexity have been verified with significant approximations in physics. Translating to human behavior is a task still very far from our reach: the level of complexity is incomparably greater, and human freedom seems to prevent any prediction; However, several authors point towards the study of the human psyche from this perspective. We do not expect to verify mathematical constants yet, but finding features or patterns can be transcendental for educators to understand the complex processes that hide behind the appearance of linearity of human development. What do teachers think about sensitive dependence on initial conditions in the development of intellectual autonomy? With the help of the ATLAS.ti program we can process qualitative data and obtain relationships between them. To what extent is the human being marked at the beginning? What factors can condition or reverse the process? Hundreds of interviews with teachers and the opinion of some geneticists, seem to confirm that the human psyche behaves as a complex dynamic system. A hopeful result for the teacher if this dependency goes beyond the beginning and allows for a significant change in the educational trajectory, even when it has been negatively marked from the beginning.

Palabras clave:
dependencia sensible, autonomía intelectual, condiciones iniciales.

RESUMEN

En las últimas décadas, equipos interdisciplinares del Santa Fe Institute de Nuevo Méjico, analizan las matemáticas que subyacen en la evolución de los sistemas dinámicos complejos. Gracias a la computación, podemos ver gráficamente una curiosa propiedad de estos: la dependencia sensible a las condiciones iniciales. Algunos aspectos matemáticos de la complejidad se han verificado con aproximaciones significativas en el ámbito de la física. Trasladar al

comportamiento humano es una tarea todavía muy lejos de nuestro alcance: el nivel de complejidad es incomparablemente mayor y la libertad humana parece impedir cualquier pronóstico; sin embargo, varios autores apuntan hacia el estudio del psiquismo humano desde esta perspectiva. No esperamos verificar constantes matemáticas todavía, pero encontrar rasgos o patrones puede ser trascendental para que la mirada de los educadores comprenda los procesos complejos que se esconden tras la apariencia de linealidad del desarrollo humano. ¿Qué opinan los profesores sobre la dependencia sensible a las condiciones iniciales en el desarrollo de la autonomía intelectual? Con la ayuda del programa ATLAS.ti podemos tratar datos cualitativos y obtener relaciones entre ellos ¿En qué medida el ser humano es marcado en el inicio? ¿qué factores pueden condicionar o revertir el proceso? Cientos de entrevistas a docentes y la opinión de algunos genetistas, parecen confirmar que el psiquismo humano se comporta como un sistema dinámico complejo. Un resultado esperanzador para el docente si esta dependencia va más allá del inicio y permite provocar un cambio significativo en la trayectoria educativa, incluso cuando ha sido marcada negativamente desde el principio.

Introduction

Traditionally we have spoken of complexity as a quality of the complex, in the sense of complicated; but there is another deeper definition that comes from epistemology and that, in the words of César Merea, E. (2013, p. 26) "corresponds to a reaction of the human sciences against the paradoxical simplification in which the hard sciences would have fallen, which, as they discovered the complexity of their objects of knowledge, became specialized and acquired a reductionist vision of the world". Complexity Sciences are now part of a multitude of research works in all fields in the last decades. In the Educational Sciences, several authors approach research considering the importance in education of taking into account the multitude of variables involved. Thus, it is said that education is a complex process, in the sense of *complicated*; but this is not the meaning considered here, but rather, the educational process is observed from the perspective, and taking into account the mathematical processes that underlie complex dynamic systems, with the purpose of better understanding human behavior, so often paradoxical, unpredictable, with growth or collapse marked by sudden and unexpected crises. Every teacher is puzzled by the unpredictability and surprise of human development. Paradoxically, this is encouraging. Understanding that the human being can surprise and resists being pigeonholed prevents any definitive diagnosis, no matter how complicated the circumstances; each crisis can lead to a discontinuity, increasing or decreasing, and the influence of the teacher can be key in this process. Although the mathematization of the problem is not yet realized in the strict sense (acceptable results have hardly been achieved in the physical sciences where, with the experiment of convection coils, a quite acceptable approximation of Feigembaum's constant was achieved $\delta \cong 4'6692 \ldots$ limit of the reasons for the amplitude of the intervals that follow one another on the way to chaos); parallels are sought between the mathematical aspects of complexity and the evolution in the development of the intellectual autonomy of the individual. Numerous authors include the word complexity in the field of Educational Sciences: Puente Vigiola, I. (2020), makes a historical tour from a philosophical point of view; Joaqui Robles, D. and Ortiz Granja, D. N. (2020), try to approach educational research from a holistic aspect; And in the same line González Carrasco, M. (2004); Fuentes Guevara, D. (2016), and many others. They all try to apply an eminently philosophical vision of complexity; in the same way that Morin, E. (2019), throughout his trajectory as a philosopher of complexity. Everyone looks at man as a complex being in whose behavior a multitude of interacting variables converge; but we are still a long way from transferring the mathematical results of complexity to the field of the human psyche. Trying to find the universal mathematical constants that govern the evolution of a complex dynamic system in the evolution of human behavior is, for now, a utopia.

However, some complexity scientists: David Feldman (Santa Fe Institute), Robert Bishop, Stephen H. Kellert, among others, affirm that we could dare to look for parallels even in the human sphere, although not with exact and precise results. This study analyzes similarities between the dynamics observed by educators and those of complex dynamic systems. As Feldman, D. (2023, Introduction to Dynamical Sistems and Chaos, Unit 3.5, min 4:21) says, one must contemplate the possible parallelism "in the same way we would contemplate a cartoon representing a real image". That is, looking for traits, patterns, similarities. Although this type of mathematical parallelism has not yet been established in the Educational Sciences, due to the difficulty of measuring human behavior mathematically, the present study tries to detect similarities between the topological

features of complex dynamics, the coincidences in other sciences, and the teachers' perception of their students' evolution. A single mathematical aspect among those characterizing complex dynamical systems that can have enormous repercussions on the educator's view is analyzed: the sensitive dependence on initial conditions (SDIC). A property that can be visualized in mathematical terms thanks to computer science. (Tables 1 and 2)

On the other hand, and very important for the subject of the research, Feldman, D. explains that this sensitivity is maintained throughout the recurrent succession that models the passage of time for a dynamic system, represented among other similar functions by the following function $x_{n+1} = r \cdot x_n \cdot (1 - x_n)$. Feldman states that a system that has sensitive dependence on initial conditions behaves as if every moment were a decisive moment:

> At every moment, the future trajectory is poised between those possible different futures, and the difference between those is a tiny little flap of gust of wind from a butterfly flapping its wings [...] so it's this continuous sensitivity where at every point along the journey a tiny change can make a big change later on and there is no way to know what those changes will be. (2023, Unit 3.3, V.5, min 3: 27)

Method

For the present research a mixed methodology is used, combining on the one hand hermeneutics in the analysis of the literature concerning the possible fields and modes of application of the complex perspective, to which is added, beyond the philosophical perspective, the application of the mathematical aspects of complexity. Computer modeling using software is used for this purpose: Bifurcation Diagram for the Logistic Map and Logistic Equation: Comparing Initial Conditions from ComplexityExplorer.org, in order to detect the mathematical significance of the property analyzed in the study: the sensitive dependence on initial conditions (SDIC).

Given the novelty of the extension of the mathematical aspects of complexity to the field of Educational Sciences, it is convenient to reinforce their approach to human behavior with a transdisciplinary analysis, typical of the complex perspective, of the same mathematical aspects in the field of physics and biology, looking for parallels that reinforce the hypothesis about the universality of the aspects of complex dynamics, in our case of a fundamental property: SDIC.

Taking into account the many precautions necessary to transfer properties of physical or biological systems to the study of the individual, whose freedom calls into question any attempt at determinism, it is advisable to reinforce the hypothesis analyzed with contributions from teaching experience. For this purpose, the qualitative analysis based on teachers' perceptions is placed in front of the mathematical and transdisciplinary analysis, reinforcing the holistic perspective of the study. Using the qualitative data processing software ATLAS.ti, a sample of 600 interviews with teachers and internship students of the Faculty of Education of UNIR in the provinces of Alicante, Valencia and Murcia is processed; analyzing among the codes indicated, the experiences on the phenomenon of SDIC in the initial moment and throughout the educational process, as well as its relationship with the development of intellectual autonomy. The parallels found provide an interesting confirmation that opens the door to future research.

Mathematical Visualization of the Phenomenon of Sensitive Dependence through the Logistic Equation Program: Comparing Initial Conditions.

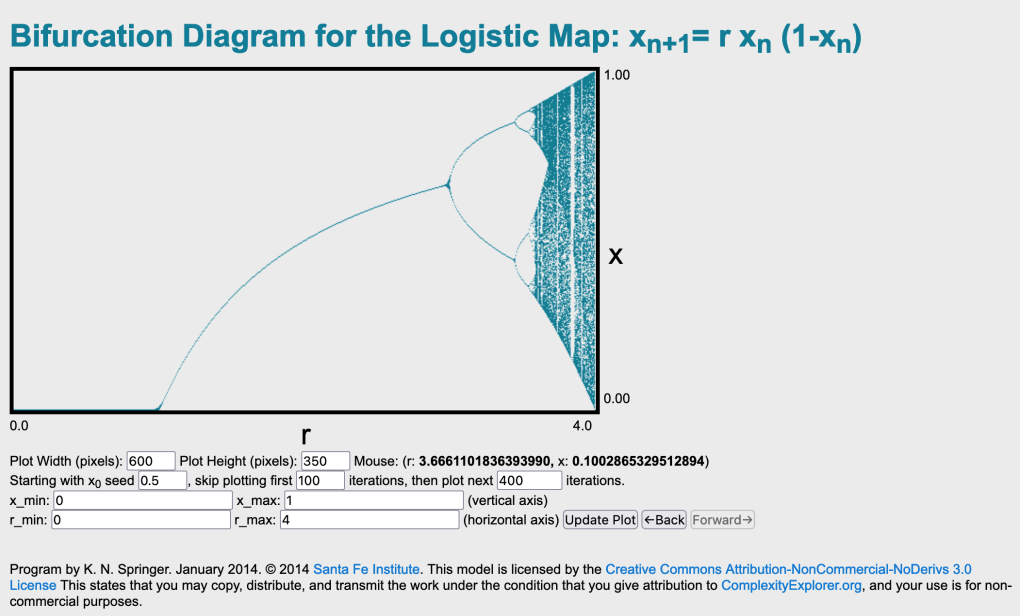
Feldman, D. makes available, from the SFI (ComplexityExplorer.org), in the course Introduction to Dynamical Systems and Chaos, the program to visualize the trajectories of the logistic function: $x_{n+1} = r \cdot x_n \cdot (1 - x_n)$ Logistic Equation: Comparing Initial Conditions.

At first we start by studying a particular function, later, as is often the case in mathematics, the results find a parallel in the physical and real world. Complexity scientists (Mitchell, M., Feldman, D., Krakauer, D., Bishop, R., and many others) have studied the *universality* principle that extends this result to a broad set of functions, which underlie the dynamic process of complex systems represented in time by a recurrent function.

The equation $x_{n+1} = r \cdot x_n \cdot (1 - x_n)$ models the growth of a population with a growth rate r. It is from it that the famous bifurcation diagram representing the trends (limit) of the recurrent function according to the values of r is discovered.

Figure 1

The bifurcation diagram or logistics map.



Note. Own elaboration based on the Bifurcation Diagram for the Logistic Map (SFI) program. For values of x, r: $0 \leq r \leq 4, 0 \leq x \leq 1$ For each r we represent the limit of the sequence with $x_0 = 0.5$. It is important to note that for almost all initial conditions the boundary values are similar until you reach the areas close to chaos, where high dependence on initial conditions begins $3.56994 \leq r \leq 4$ where high dependence on initial conditions begins.

The images in Tables 1 and 2 give an idea of the degree of sensitivity to initial values (or seeds). In the start boxes, the number of iterations can be chosen (n = 40), which is sufficient to observe the evolution. In the First Initial Condition and Second Initial Condition boxes, the two initial conditions are entered in each case. In the first table these are kept fixed to see how they vary with increasing values of r ($1 \leq r \leq 4$). In the second table, r is kept fixed in the chaos zone (r=4) to observe the evolution in time of the separation of the respective trajectories for each initial condition. It is a question of observing the behavior in a particular case (growth of a population) in order to transfer

by the principle of universality, first to a wide range of functions, and then to complex dynamic systems in general.

Figure 2

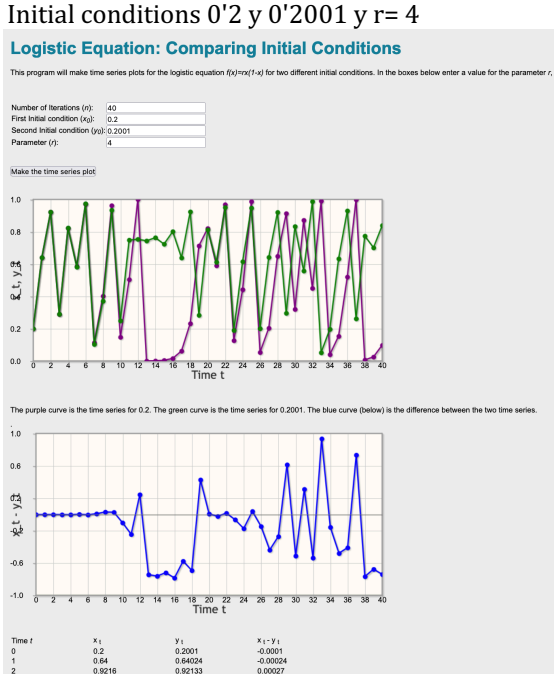
Increased sensitivity to initial conditions as r approaches 4

Note: Own elaboration using the Logistic Equation Comparing Initial Conditions program.
With increasing value of r, ($3.5 \leq r \leq 4$) the trajectories depicted at the top diverge earlier and earlier. The top graph shows the two overlapping trajectories. In the graph below, the differences between the two graphs can be seen in blue.

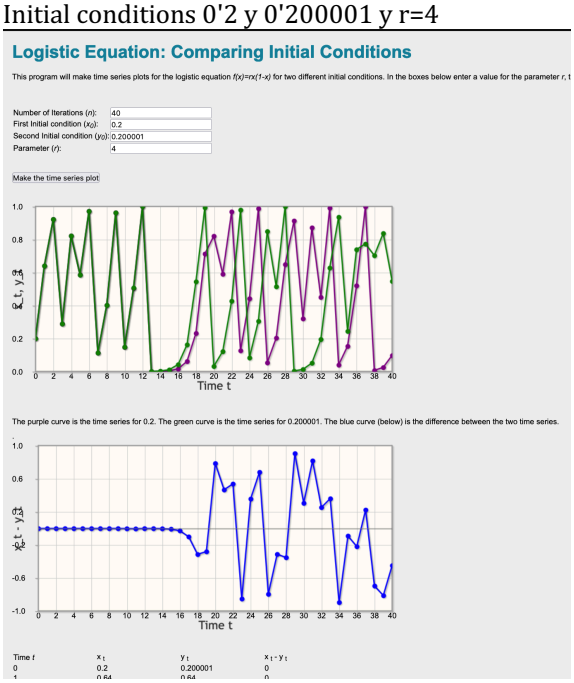
Figure 3

Strong sensitivity to initial conditions when r=4

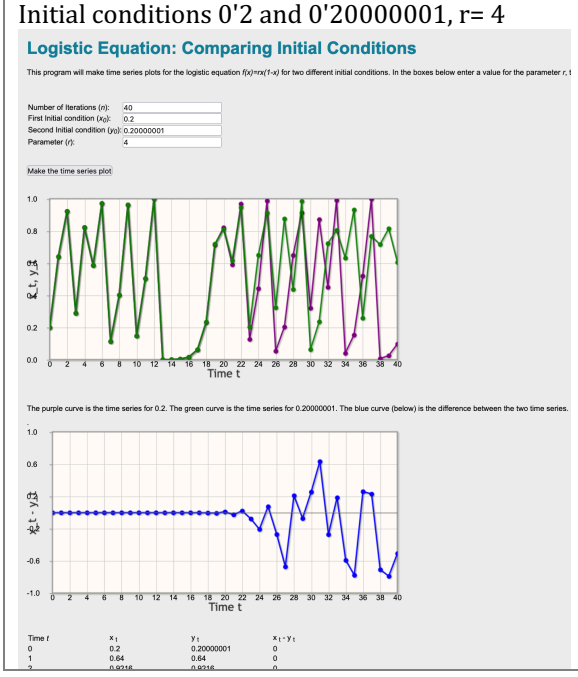
Initial conditions 0'2 y 0'2001 y r= 4



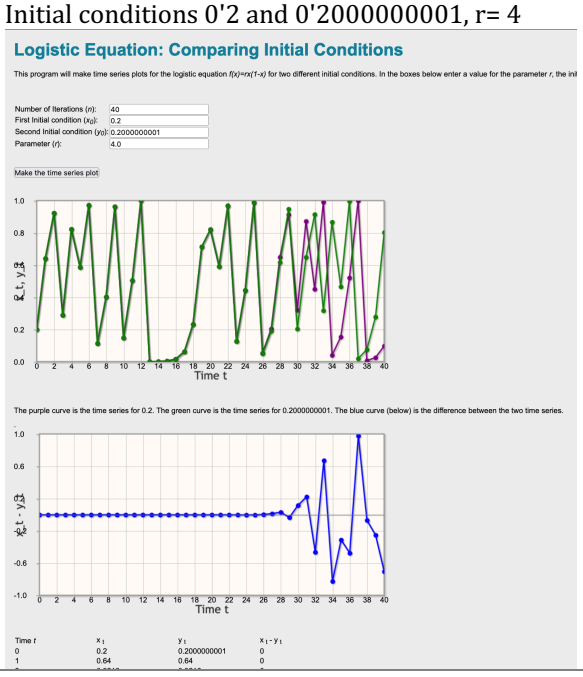
Initial conditions 0'2 y 0'200001 y r=4



Initial conditions 0'2 and 0'20000001, r= 4



Initial conditions 0'2 and 0'2000000001, r= 4



Note: Own elaboration using the Logistic Equation Comparing Initial Conditions program.
With the value r=4 we are in the chaos zone, where the sensitivity to initial conditions is very strong. The initial conditions are approached until they differ by just 10^{-10}. It can be seen how, although with a few more units of time, the graphs soon differ completely despite starting at practically identical values.

In principle, this is a property of a very simple recurrent mathematical function that would seem to have nothing to do with reality, much less with human behavior. However, the complexity sciences reveal many surprises: as Feldman, D. (2023, Unit 6.5), what happens with this function happens with a very large set of functions (this phenomenon is repeated with all functions with a single quadratic maximum that map an

interval in itself); moreover, it is a universal phenomenon that underlies transversely all dynamical systems that have aperiodic behavior in the zones close to chaos (when r approaches 4); not only physical systems, but also biological, sociological... It is inevitable to ask whether the phenomenon of universality can also be extended to the field of psychology. It is still an open question because human freedom seems to reject any kind of systematization; and philosophers and psychologists debate between freedom and determinism. But chaos researchers are continually expanding the scope of application of this new science. Morin, E. (2019), from the philosophical field, introduces the ideas of complexity making it clear that complexity is not opposed to determinism and is present in all fields; something very familiar, on the other hand, to mathematicians investigating chaos, since it is generated by deterministic mathematical functions. Not only from philosophy; from the field of psychiatry, Caparrós, N. and Cruz Roche, R. in their work Journey to Complexity (2012-13) make a journey through the different levels in which it is present, from the physical to the psychological. But also from physics and mathematics, scientists of complexity see the horizon of application extending more and more: Feldman, D. (2023), in his course Introduction to Dynamical Systems and Chaos reflects on the implications in everyday life of chaos studies and comments:

> "I think this is important for any area of science [...] the world follows rules, but these rules need not be ordered or allow predictions; this is one of the twists that chaos and sensitivity to initial conditions gives us [...] Some argue that phenomena that are sensitive to initial conditions move us away from determinism and give us a space where free will has room again. Personally, I'm not so sure. It may take us away from the gloom of determinism, but it's not clear how the butterfly effect, which is in essence unpredictable, leaves room for freedom, although I'm not quite sure how to think about it" (Feldman, 2023, Unit 3.8 Summary, part 2, min 7:41-8:55)

Although Feldman is silent, his reflection on complexity even in the realm of personal freedom is very important. The simple fact of analyzing the question of free will versus determinism, from its eminently mathematical perspective, is already very significant. Like him, other complexity scientists such as. Kellert, S.H., Bishop, R. (2017), and more recently Hoefer, C. study how chaos affects all fields of study, including philosophy and psychology. Thus, Hoefer, C, in his book Causal Determinism, states:

> "The popularization of chaos theory in the relatively recent past perhaps made it seem self-evident that nature is full of genuinely chaotic systems. In fact, it is far from self-evident that such systems exist, other than in an approximate sense. Nevertheless, the mathematical exploration of chaos in dynamical systems helps us to understand some of the pitfalls that may attend our efforts to know whether our world is genuinely deterministic or not" (2023, p. 20)

More recently, Van der Maas, H.L.J. (2023), has dealt with the subject in greater depth in his book: *Complex-Systems Research in Psychology*, in which he states in his foreword: "We, with our complex brains embedded in various hierarchies of social systems, are the ultimate complex systems" (p. xv) and in which he quotes Doyne Farmer, J. (2017) as an introductory sentence: "We have an increasing need to model ourselves" (p. vii).

The fact of asking about determinism in all fields (including human behavior) from the perspective of mathematics that analyzes chaos is already surprising. Without resolving the question of freedom, we try to analyze the experience of sensitive dependence on initial conditions; something that is known as a determining characteristic of the complexity of a system. As Hoefer states:

> A deterministic chaotic system has, roughly speaking, two salient features: (i) the evolution of the system over a long time period effectively mimics a random or

> stochastic process - it lacks predictability or computability in some appropriate sense; (ii) two systems with nearly identical initial states will have radically divergent future developments, within a finite (and typically short) timespan. We will use "randomness" to denote the first feature, and "sensitive dependence on initial conditions" (SDIC) for the latter. Definitions of chaos may focus on either or both of these properties; Batterman (1993) argues that only (ii) provides an appropriate basis for defining chaotic systems. (2023, pp. 16-17)

Thus, for some authors, detecting evidence of SDIC in human behavior would confirm its complex behavior and would allow us to deduce the set of properties of complex dynamic systems. To situate the freedom of human behavior as the limit in the scale of complex organisms and their levels of complexity would be one of the aspects in which the present research could have an impact: having a small margin of choice would be sufficient for the management of significant changes. This is a mathematical visualization of freedom that is also crucial for the teacher's vision and prevents a frequent defect: pigeonholing students.

Does human behavior belong to this type of systems highly sensitive to initial conditions?

The above graphs provide a visual image of the significance of the SDIC phenomenon. It differs greatly from the separation of two linear paths that start with different inclinations. This is another level: infinitesimal variations produce, extraordinarily quickly, totally different paths. This is how Bishop, R. relates it in his book Chaos: "Many authors consider an important mark of chaos to be trajectories issuing from nearby points diverging from one another exponentially quickly. However, it is also possible for trajectory divergence to be faster than exponential". (2017, p. 6)

Some authors visualize a sphere in equilibrium on the vertex of a cone understanding the sensitivity to fall in one direction at the slightest influences. As Bishop expresses quoting Poincaré: "A man walking on a Street on his way to his business. He start out a particular time. Meanwhile unknown to him, there is a tiler working on the roof. The tiler accidentally drops a tile, killing the business man. Had the business man started out at a slightly earlier or later time, the outcome of his trajectory would have been vastly different!" (2017, p. 6). As Yorke, J.A. says. (2015, min. 3): "Everybody knows about chaos. In fact, you may not know you know about chaos, but you live chaos"

Contributions from Physics.

There is a striking parallelism between SDIC and the theories that have been developed in the last decades (1960-2020) on the *anthropic principle* or *the fine tuning of the universe* (Dicke, Carter, Feynman, Barrow, Tipler, Penrose...). In recent years, many scientists have worked on this sensitivity in the initial conditions that seems to mark all natural processes, both physical and biological. Thus Smoot, G. (Nobel Laureate in Physics) states in Bollorée, M. & Bonassies, O: "The Big Bang, the most cataclysm-like event we can imagine, if you look at it closely, appears as finely orchestrated" (2023, p. 279). From the initial instant, there are about twenty numerical values invariant in time and space. The following list shows the extreme sensitivity of the most important values:

Table 1

The main constants of the universe and the accuracy of their fit.

Universal Gravitation Constant	$G = 6'67418 \cdot 10^{-11} m^3 Kg^{-1} s^{-2}$
Coupling constant	$\propto -g = 10^{-39}$
Electromagnetic force. Cte of fine structure.	$\propto = 0'0072973525376$
Strong interaction (cohesion of atomic nuclei).	$\propto -s = 1$
Weak interaction	$\propto -w = 10^{-6}$
Speed of light	$c = 299792458\, m \cdot s^{-1}$
Planck's constant	$h = 6'626070040 \cdot 10^{-34} J \cdot s$
Boltzmann's constant	$k = 1'380649 \cdot 10^{-23}$
Proton charge (+) and electron charge (-)	$1'6021766208 \cdot 10^{-19}$
Proton mass	$1'6726219 \cdot 10^{-27}$
Neutron mass	$1'674927471 \cdot 10^{-27}$
Electron mass	$9'10938356 \cdot 10^{-31}$
Cosmological cte fixing the initial curvature of the universe	$1'289 \cdot 10^{-52} \cdot m^{-2}$

Note. Source: Bolloreé & Bonnassies (2023)

Lennox, J. (quoted by Bolloreé, M. & Bonnassies, 2023), Professor of Mathematics at Oxford, explains: "At the beginning of the Universe, in order for life-enabling chemistry to exist, the relationship between the electromagnetic force and the gravitational force must have been tuned to a precision of $1{\cdot}10^{-40}$." (pp. 184-185)

Bolloreé, M. & Bonnassies, O. cite in their book a long list of scientists who, since the end of the 20th century, have been working in the field of biotechnology. XX to the present day support the fine-tuning theory. A single variation in one of these decimal places would have prevented the appearance of life; a variation in the expansion velocity in decimal 15, according to Robert Dicke, and the Universe would have been scattered. In decimal 60 according to Planck (2023, p. 192)

why for example does G have exactly that value? Demaret, J. (1994, p. 2) admits that this value cannot be explained by any existing theory. But if its ratio to the strong nuclear force were not exactly 10^{39}, there could be no life in the universe. The same is true for the other 20 constants as Geraint, F. and Barnes, L. A. (2016, pp 108-109) explain

Cosmologist Trint Xuam Thuan went even further by demonstrating that, for the Universe to lack curvature, the primordial density had to have been determined with a precision of the order of one part over 10^{60}. (Barros, 2019, p. 9)

Some complexity scientists have already related the dynamics of the universe and its origin to the human psyche. Thus, César Merea, E., in his reflection on *Complexity and Psychism*, after detailing the process of the origin of the universe, states categorically: "It corresponds to say that the complexity of the psyche is the complexity of the Big Bang and that this is its essence." (2013, p. 24)

Complexity that refers to the deployment of energy as a central element in expansion, but also to the fine-tuning of its beginnings.

From the field of physics come the first intuitions about chaos. Feigenbaum began by reflecting on the passing of time, periodicity, the observation of cumulus clouds and their seemingly random shapes. Little by little, the chaos has spread to all processes. Is it possible to consider human processes as well? We are not yet in a position to apply mathematical formulas to human behavior, but something hints that perhaps freedom itself can be explained from the perspective of chaos. In fact, some physicists during the last decades have wondered about it. Barros, P., in his comments to Gleick's work (1987): "Believers in chaos [...] speculate about determinism and free will, evolution and the nature of conscious intelligence. They feel that they interrupt a certain tendency of the

scientific to reductionism, to the analysis of systems in terms of their constituent parts [...] they believe that they are looking for the totality." (2019, pp. 11-12)

Erwin Schrödinger published in 1944 his book *What is life?* on the question of life. In it, he contemplates living organisms as, in the words of Cruz Roche (2013, p.16), *neguentropic islets*. Schrödinger reflects on the behavior of atoms and molecules in inert matter: curiously, at the macroscopic level they follow the laws of physics, but when we approach each particular molecule and atom, erratic behavior is observed. Only when considering the statistical average of their positions do they respond exactly to the laws of physics. However, in living organisms this is not the case: each molecule perfectly follows the complex laws of genetics and life. Schrödinger, apologizing for his opinion on biology, a subject in which he is not an expert, is surprised at the precision and organization of each organic molecule (bearing in mind that he published his book in 1944 when much was still unknown about the organization of the DNA molecule). In this line, a deeper question is asked, which is still topical and timely for the present reflection: *Why are atoms so small? Why is each neuron so small compared to the size of the brain? In what way does each tiny unit contribute in order to an overall thought produced in the brain?* This physicist, Nobel Prize winner for his work on the equation that bears his name and his contributions to quantum physics, gives an answer that anticipates later research on complex dynamical systems and their sensitive dependence on initial conditions:

> *Why should an organ like our brain, with the sensory system attached to it, of necessity consist of an enormous number of atoms, in order that its physically changing state should be in close and intimate correspondence with a highly developed thought? On what grounds is the latter task of the said organ incompatible with being, as a whole or in some of its peripheral parts which interact directly with the environment, a mechanism sufficiently refined and sensitive to respond to and register the impact of a single atom from outside?* (p.3)

On the one hand, the precision and stability of the operation is surprising, despite the vulnerability of the physical matter and the variations of the environment; and on the other hand, the delicate sensitivity to capture the changes in it and respond or adapt to them.

Some Ideas that Illuminate from Genetics

It is impossible not to draw a parallel between the fine-tuning of the universe at the initial instant and the beginning of human life and the circumstances surrounding it. As Lejèune, J. says "Life has a very long history, but each one has a very precise beginning: the moment of conception". (2009, p. 35)

In the Educational Sciences, the repercussions of the first stages of life, their permanent and obstinate incidence in the processes of autonomy development, are well known. How far back do we need to go to assess the influence of the environment on subsequent development - is the initial instant of the human being as important as the big-bang for the universe? does the new creature possess that sensitive dependence on initial conditions characteristic of complex dynamic systems? Psychological studies on *early adversity,* as shown by the Spanish Association for Mutual Aid in Cases of Early Adversity and Attachment, reveal interesting data on the persistence throughout development of the influence of negative factors in early childhood, including at the time of gestation. Although it is difficult to go back to the initial instant to reveal whether there is a sensitive dependence on the initial conditions at the beginning of human life, there are some texts that illuminate the present investigation in a special way: In 1989, Jerôme Lejèune, the French geneticist who discovered the trisomy 21 characteristic of Down

syndrome, traveled from France to attend the Maryville, Tennessee, courthouse to assist in the difficult decision to consider the legal status of seven frozen human embryos. In his statement he gave a detailed account of the process of formation of the new individual in which he referred to the first moments in these terms:

> The very young human being, just after fertilization, after having divided into two cells, divides into three. Because, curiously, we did not divide ourselves into two, four, eight... no; at the beginning we did not do it that way. After division into two approximately equal cells, only one of the cells divides into two. There is then a moment when, within the zona pellucida, we pass through a three-cell stage. This has been known for fifty or sixty years, but it remains an embryological enigma since, after this three-cell stage, it starts again, goes to four, and continues with multiples of two. What does it all mean? We don't know exactly, but it is of great importance: we can manipulate mouse embryos and separate the cells inside the zona pellucida of a sixteen-cell embryo and take some of them. We can take another few cells from another embryo, and put them all together inside a new zona pellucida from which the rightful occupant is expelled. Most of the time it fails, but sometimes a chimera emerges. If a black and a white embryo have been chosen, we will have a mouse with mottled fur. This can be done with a very small number of cells. We have tried three different alignments and have obtained mice with characteristics of all three. It has been tried with four and it doesn't work, five, and it doesn't work either. This reminds us that when we divide at the beginning of our life we go through a three-cell stage. Perhaps, at that moment, one of the cells sends a message to the other two [...] to suddenly understand: We are not a population of cells, we are united to form an individual! That is, individualization, what establishes the difference between a population of cells in a culture and an individual is established at the three-cell stage, i.e. very soon after fertilization. (2009, pp. 45-46)

The entire design of the new being takes place at the initial instant. Any slight modification in the individual's global project at that moment will have long-term repercussions. Lejèune summarized in his lecture *The Incarnation of Intelligence* collected in *In the Beginning, Life*: “In the beginning there is a message, and that message is life” (2019, p. 79). The extraordinary sensitivity of the maternal uterus and its response to negative emotions in the face of conception is a sign that nature is working in the direction of searching for optimal conditions at the moment of fertilization. Along these lines, Dr. Ruiz Zambrana (2024) points out that stress as a lifestyle complicates female and male fertility, not only from the perspective of the greater good for the mother. As Lejèune explains, from conception, it is the embryo that directs all the changes that occur in the mother's body, for its own benefit. Everything points to the fact that optimal conditions are directed to the importance of the environment surrounding the initial instant of life.

After reading Lejéune's statement before the Maryville Court of Justice, it does not seem irrelevant that nature foresees for the instant of conception the psychological atmosphere that accompanies an act of love. It is difficult to go back to the first instant to see the repercussions of the conditions at the instant of conception and differentiate them as a key instant beyond the total process of gestation and early childhood, but complexity theory reveals that every complex dynamic system has a strong dependence on initial conditions. In our case, as stated by Caparrós (2013) and as reflected in the title of his work: The psyche (is) a hypercomplex process, or as we have stated: the complex system par excellence.

In the same vein, Lejèune talks about sensitivity in the transmission of information for the creation of the new being:

> To transmit information from parent to child, nature uses the smallest possible language. And this is very necessary, because life takes advantage of the movement of molecules to put order in the erratic movements of the particles themselves, so that this randomness is transformed according to the need of the new being [...] With life we find ourselves at the very limits of matter, energy and information. (2009, p. 37)

Complexity Sciences and Psychology

Teachers' experience of sensitive dependence at the initial moment and throughout the educational process

To complete the present research, the experience of education professionals gathered during visits and interviews with teachers in about 600 schools in Spain (Alicante, Murcia and Valencia) will be taken into account when monitoring the internship students of the Faculty of Education of UNIR.

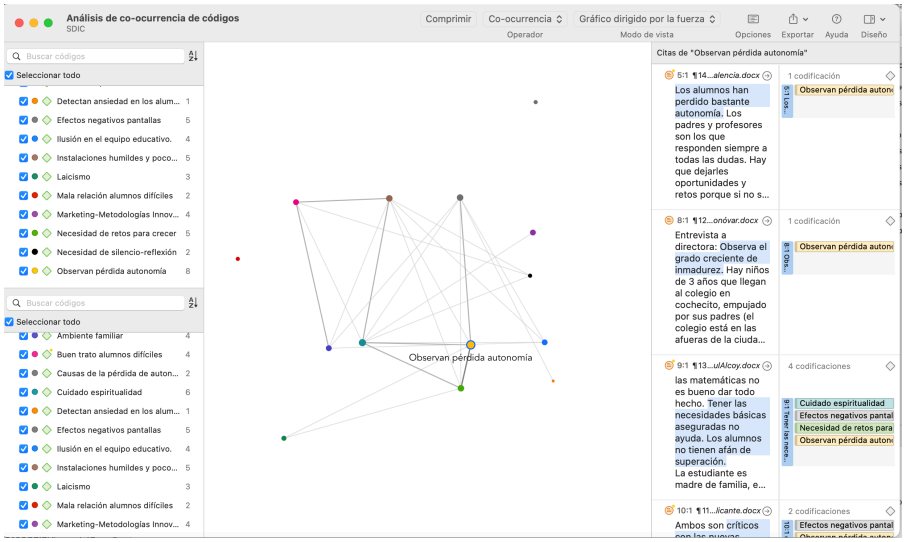
The interviews include conversations with teachers and trainees, as well as members of the management staff of educational centers and psychology offices. The interviews are processed with ATLAS.ti software for qualitative data processing. Not all interviews are of equal quality. A distinction is made between those carried out in psychology offices and those carried out in schools. The first ones collect diagnosed students and have relevant information on the circumstances surrounding the conception and gestation process, getting closer to the initial moment. Under the label of *Special Interviews*, conversations with teachers of long experience are gathered, who have witnessed the evolution through the years dedicated to teaching, together with other younger, but reflective, with true vocation and intuition; interested in analyzing the causes of the decline in the maturity of students. All with a desire to share it for research and deepening the knowledge of the evolution of the intellectual autonomy of students.

The ATLAS.ti software makes it possible to visualize the relationships between the different codes marked in the different texts and the frequency of their occurrence.

Results

Figure 4

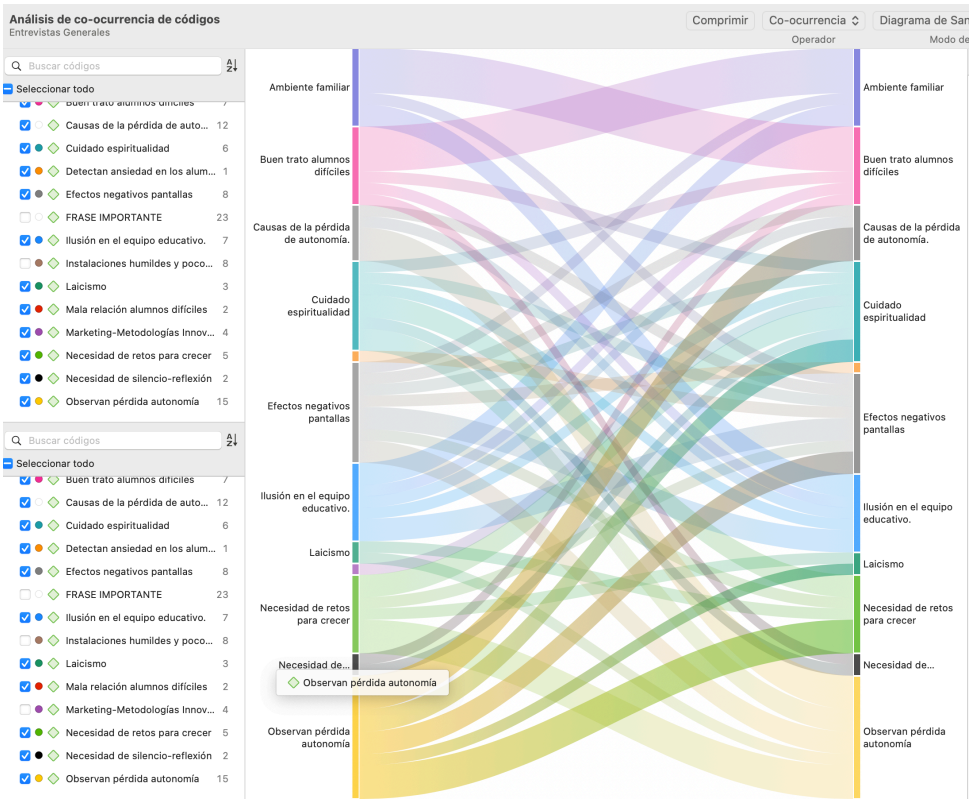
Loss of autonomy a cause for concern among teachers



Teachers note the fact of the loss of autonomy in general, despite the efforts of teachers and the continuous involvement of parents in the educational process. the great involvement of parents and teachers generates confusion; it seems to act in the opposite direction.

Figure 5

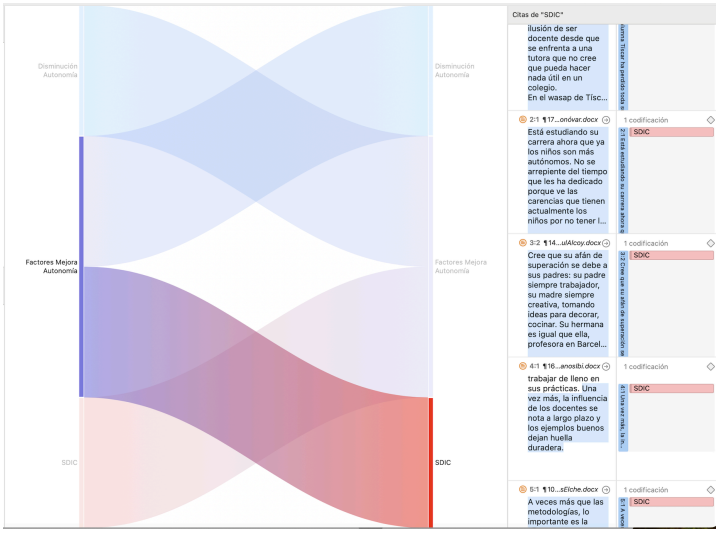
Code co-occurrence graph: Loss of autonomy is a multi-causal phenomenon.



There is no single cause identified by teachers as fundamental in explaining the loss of skills that contribute to intellectual autonomy.

Figure 6

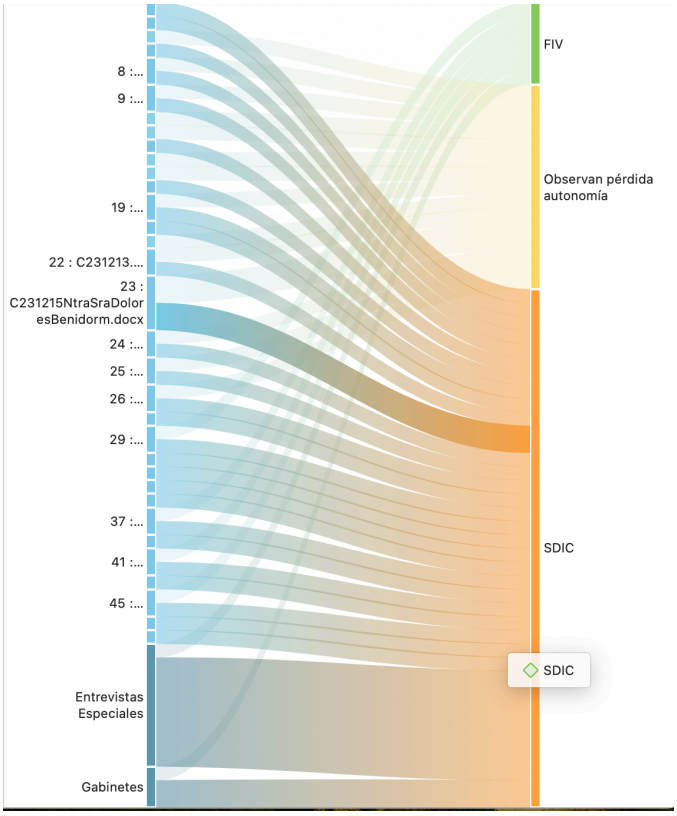
Co-occurrence of codes related to SDIC and Autonomy improvement



Sensitive dependence is observed and it presents a significant relationship with the factors that improve the development of autonomy in the students.

Figure 7

Frequency of perception of the phenomenon of sensitive dependence



The SDIC code captures aspects of the interviews that allude to the observation of an unexpected response to difficult situations.

Discussion and Conclusions

A transdisciplinary analysis highlights the parallelism between the mathematical results of Complexity Sciences, Physics, Genetics and Psychology. The significance of the initial instant is revealed in all of them, conforming to the mathematical modeling observed in the graphs of Tables 1 and 2. A process, which, as Feldman points out, generalizes to a broad set of functions underlying all systems with complex dynamics. There are levels of complexity that in the logistic map of Fig. 1 increase when r approaches 4.

Complexity Sciences have been extending their fields of application to Biology, Economics, Sociology. Behavioral Sciences are presented as the most delicate field for its introduction since any science that has the human being as its object must deal with the pitfall of a unique phenomenon: freedom. However, in complex thinking, freedom itself can become an object of study.

Some complexity scientists such as Caparrós and Cruz Roche (2013) point to the human being as the hypercomplex organism par excellence. Although, as Feldman points out, mathematical parallels must be understood in a metaphorical sense or in a topological sense, mathematically speaking. Detecting some features can be very revealing given the importance of their application.

The parallels found in the analysis of an essential feature, according to Karl Hoefer, such as the phenomenon of sensitive dependence on initial conditions in physical and biological systems, are illuminating. In the field of physics, they go back to the initial instant of the universe, revealing themselves as an essential character, present in all dynamics as they are located in the adjustment and equilibrium of all essential physical constants. Although without mathematical treatment, it appears in the field of genetics, pointing to a key importance of the initial instant.

Figures 2 and 3 respectively reveal autonomy as a central concern and as a multicausal phenomenon. On the other hand (Fig. 4), the phenomenon of sensitive dependence on the initial conditions is pointed out among the possible causes of loss of intellectual autonomy by psychology professionals, who, with the consequent reservations, point out the importance of the circumstances surrounding the first moments and focus on the different fertilization techniques as an element that could be at the origin of later diagnoses. (IVF Code Figure 5). The results are incipient and still confusing due to the number of variables involved, but they point in the same direction: the crucial importance of the initial moment.

What Feldman already pointed out about the SDIC phenomenon is a constant in the conversations with teachers at different stages (Figure 5): *It seems as if every instant is crucial*; the sensitive dependence is maintained throughout the whole process, since the evolution of the dynamic system is mathematically modeled by a recurrent function: $x_{n+1} = F(x_n)$ the degree of complexity of the trajectory means that the slightest variations at a point along the trajectory have the same sensitivity as that observed at the initial instant. Each instant acts as an initial instant.

This phenomenon is widely noted by most teachers, especially the EE group, who almost unanimously point out the experience of disproportion between the level of dedication and attention to students with special difficulties and the results obtained, not immediately, but in the short or medium term. Meeting with alumni is revealing for them of the influence that is sometimes not possible to detect in the short term.

The results can be summarized in some key ideas for the teaching task: The human being is strongly affected at the beginning and maintains, to some extent, this sensitive dependence throughout its evolutionary process, behaving as, what several complexity

scientists call, the hypercomplex organism par excellence. This strong sensitivity implies the indeterminism that is inherent to all complex dynamics, which is good news for teaching practice: no one is irretrievably lost. The influences at the beginning, despite being strongly conditioning, do not irremediably determine the human being, since this sensitivity is maintained throughout the process. This allows the educator to work with hope in situations in which it is apparently too late, either because of the magnitude of the circumstances or because of the prolonged effects, knowing that small influences in the right direction can trigger significant changes. Therefore, and opening another line of research, the phenomenon of sensitive dependence points towards an increasing personalization in the educational field. Only from a personal point of view can we activate the appropriate springs and fine-tune the necessary changes, both in the didactics of knowledge and its assimilation processes, as well as in the influence exerted on the learning process by the environment: affective relationships, behavioral models, vocation, meaning and transcendence of life processes.

The confluence of the different fields and the harmony in the teachers' perceptions point to the affirmation of the human being as a hypercomplex organism, strongly affected by the conditions surrounding the moment of its conception; that maintains sensitive dependence throughout its development, showing itself highly receptive to the gaze and expectations of its educators, so that small gestures can be transcendental in the process of the development of its intellectual autonomy.

It is a great responsibility for teachers, but also a cause for hope in difficult cases where it seems difficult to channel trajectories strongly affected by an adverse environment. The Complexity Sciences begin their journey in the field of Educational Sciences by providing mathematical tools for a deeper understanding of the person and what chaos can say about their disconcerting reactions, which escape determinism or prediction, but which are therefore also revealing of the surprising possibilities of change hidden in human beings at any moment of their evolutionary trajectory.

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To all the teachers who offered their time and experience in the interviews, sharing their discouragement at the disproportion between their efforts and the results. It is for them that the present research work is carried out, with the desire to deepen the knowledge of the processes of development and the disconcerting reactions of the human being, on the one hand revealing its complexity and resistance to determination, but also the hope that arises from the strong dependence (SDIC), which makes possible what we have called *freedom*, that is, the possibility of the human being to break any conditioning to change his destiny.

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