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DISCUSSION PAPER

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COMPLEX APPROACHES FOR EDUCATION IN BRAZIL

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DISCUSSION PAPER

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CONTENTS

ABSTRACT

Education systems can be viewed as complex systems, by considering that learning, teaching, cognition and education are phenomena resulting from interactions between the heterogeneous agents that compose such systems. Given the complex nature of education systems, new approaches seem relevant, and even necessary, if we consider that traditional methods are often not capable of capturing the dynamics of these systems.

This paper aims to identify what has been done in Brazil regarding the complex system approach in education, and to bring to discussion the potential benefits of this perspective to education in the country. The main concepts that have marked the theoretical thought of complexity are presented, as well as applications of complex systems' methods and methodologies in education in Brazil, such as Agent-Based Modeling, Network Analysis, Intelligent Tutoring Systems, Educational Data Mining, and Learning Analytics, among others. Finally, some insights of the complex system approach to education are discussed.

Keywords: complex systems; education; complexity; agent-based models; network analysis; intelligent tutoring systems; educational data mining; learning analytics; public policies.

1 INTRODUCTION

Education systems encompass a large number of heterogeneous agents, whose interactions give rise to learning, teaching, cognition and education. They are comprised of interconnected layers, each of which provides support and restraints to the others. Through mechanisms of feedback and adaptation, these systems and their agents co-evolve. All these features make education systems complex.

The heterogeneous agents in an education system are, for example, students, teachers, and parents. Every student learns in a different way, every teacher has his/her methods of teaching, and every parent raises his/her child in his/her distinct manner. Learning emerges not only from information passed from teachers, but as the result of interactions between students and other individuals, both in formal and informal environments.

Education systems are comprised of various interconnected layers. In a macro perspective, they involve government institutions, such as the Ministry of Education and the network of schools and universities. However, the ministries of Finance, Health and Transport, among others, can also be considered part of this system, as they influence the allocation of financial resources, the health conditions to the population, and the accessibility to schools, respectively.

In a lower level, schools cannot be separated from the context in which they exist. Out-of-school factors, such as the safety of the neighborhood or the social-economic standing of the community, impact the attendance of students and their academic performance. Similarly, higher education influences and is influenced by basic education.

At the interpersonal level, students interact with their peers, teachers, parents, school managers and the community as a whole, while at the intrapersonal level, learning results from mental processes influenced by personal interests, personal history, hormone levels, working memory and other specific features in response to stimuli from the environment.

Educational features in a society emerge thus from the interaction of all these different scales, which cannot be isolated from each other. Due to the complex nature of educational systems, traditional linear methodologies are not sufficient to capture their dynamics. The presence of multiple causalities and non-linearity might even put in doubt the external validity of results obtained in rigorous randomized controlled trials, as controlling for all key variables might be unattainable in educational research (Cohen; Manion; Morrison, 2003).

Given the complex nature of education, complex systems' methodologies can help analyze education in different ways. First, simply understanding the complex nature of educational systems might help researchers refrain from having a mechanistic view of education, governed by simple causalities and levers that lead to predictable results.

Second, modeling education can provide a better comprehension of the dynamics of the system. By trying to identify the key elements and rules within a system, one can little by little understand how the different agents interrelate as well as simulate possible outcomes of a given intervention, for instance. In this respect, the role of models as theory communicators should be emphasized (Heemskerk; Wilson; Pavao-Zuckerman, 2003). By means of collaborative research, models can be improved, at the same time enriching the understanding of the phenomena.

The availability of loads of data on education also makes viable association studies. Machine learning techniques and network analysis can provide valuable insights into general trends or specific aspects to be furthered studied. Besides, tackling the complexity of educational systems might be the way of finding simple solutions (Berlow et al., 2009). For example, by understanding the network of relationships involved in the system, one could identify the central nodes or leverage points through which changes could be brought upon.

It is important to mention that complex systems methodologies are not a substitute for traditional educational research methods, though, but a complement to them. Knowledge about educational systems might emerge from the combination of evidence-based research, traditional quantitative and qualitative methods, associative studies and modeling.

A considerable amount of research has been done exploring the complex nature of educational systems, learning and teaching worldwide. In Brazil, however, this area is still incipient. The aim of this paper is to analyze what has been done in the area in the country so far and to explore how the complexity approach can help education in Brazil. Following this introduction, section 2 focuses on the use of complexity concepts to think education in a more theoretical sense. Section 3 presents applications of complex systems' methods and methodologies in the country. Finally, section 4 discusses why the complexity approach seems particularly suitable for analyzing and helping improve education in Brazil.

2 COMPLEX THINKING IN EDUCATION

The discussion of the complexity perspective in Brazil has particularly been marked by the contributions of the French philosopher and sociologist Edgar Morin. Many studies have been focused in discussing complexity concepts and the need to rethink education, with a special concern on reframing pedagogical practices. This new perspective challenges the traditional paradigm based on instructive theories, and proposes a new paradigm from the epistemological postulates formulated in the biological and quantum theories.

The traditional or Newtonian-Cartesian paradigm has as main postulates the fragmentation and the dualistic view of the universe. It has influenced the education, the schools and the pedagogical practices worldwide (Behrens; Oliari, 2007). The pedagogical practices have been built upon a Cartesian view of dichotomy of the dualities, such as subject-object, part-whole, rational-emotional, local-global, ignoring the interconnection between these binary pairs. What is seen is the subdivision of knowledge in areas, in institutes, and departments, which principles like fragmentation, division, simplification and reductionism are dominant, resulting in a de-contextualized pedagogical practice (Santos, 2008). These principles, brought about the disciplinary structure of knowledge, made knowledge lose its meaning (Petraglia, 1995).

According to Araújo (2007), the pedagogical practices have emphasized instructive aspects in the place of creative, reflexive, constructive and cooperative aspects, producing a (*i*) rigidity process, a transmission of content that favors the memorization of isolated information, and (*ii*) a process that ignores the context, the involvement of the students, and their heterogeneity.[1] The student is seen as a spectator; someone that must copy, memorize, and reproduce the information passed on by the teacher (Behrens, 1999).

1. Araújo (2007), particularly interested in the emergent challenges of the online education, notes that there are distance learning courses that still present a disciplinary structure, strongly marked by the instructive vision. For the author, instructive models are scientifically archaic, and they tend to simplify the process of knowledge construction. This implies the need to investigate the use of technologies in distance learning courses from an e-learning perspective, allowing the construction of an autonomous thought.

In general, most teachers tend to perceive and represent the world through the classical physics' lens, by which reality is seen as stable, predictable, and predetermined. In contrast with the traditional paradigm, the quantum and biological theories present some epistemological principles, such as the dialogical and uncertainty, which help us to rethink education and to reframe the pedagogical practices (Moraes, 2004a). Some of these principles are briefly presented below.

2.1 The dialogical principle

Morin (2011) points out the dialogical principle as an important complexity concept. This principle refers to the capacity of association between two items that are antagonistic and at the same time complements. For example, order and disorder are antagonistic, but they can be complements in some situations, by collaborating and producing organization and complexity, in such a way, that there is duality within the unity.

Considering the dialogical principle, Guimarães et al. (2009) argue that the involvement of opposites implies the valuing of pedagogical practices that take into account conflict; that observe the whole, the parts and interaction of the parts, instead of isolating them. By this view, the fragmented curriculum would be replaced by a curriculum that enables communication and dialogue among wisdoms, promoting the construction of the whole.

2.2 The complementarity of opposites

Related to the dialogical principle, there is the idea of complementarity of opposites.[2] In the educational context, Santos (2008) calls attention to the dichotomization and emphasis in only one attribute of the binary pairs, such as rationality, what contributes to an unilateral view and an incomprehension of the learning process. As a result, the students are not able to articulate the diverse individual dimensions. By this scenario, Santos (2008) proposes an articulation of the binary pairs, so as to obtain a more complete view of the phenomena being observed. For the author, "reason without emotion does not capture the human characteristic, while emotion without reason leads to nowhere" (p. 77).

2. The principle of complementary of opposites was proposed by the Danish physicist Niels Bohr, by which he argues that wave and particle composes the same reality (Santos,2008).

Another example is the binary order-disorder. For Santos (2008) there is a symbiotic relationship of interdependence between order and disorder. In relation to educational management, she argues that:

> order is represented by legislation and by the organization, legal and bureaucratic norms, curricular structure. In the management of this organization, the disorder and the ambiguity arise, introduced by the subjects that give dynamicity to the model of functionality and rationality of the system. Human beings, with their diversity, give support and functionality to the management of the organization. People's behavior in the institution is a mixture of dependence and autonomy (another binary pair). Order is desirable, but disorder, spontaneity, disobedience, provide vitality to the institution, although, in excess, lead to its disintegration (Santos, 2008 p. 78).[3]

2.3 Uncertainty and non-linearity

These ideas lead us to the importance of uncertainty and non-linearity. As pointed out by Santos (2008), the principle of complementarity of opposites argues for the articulation of dualities, such as certainty and uncertainty, denying a reductionist and deterministic view. The uncertainty concept goes against the dichotomized dualistic view, which emphasizes only order and certainty. The school maintains a scenario of certainty by repeating norms, values, and social sanctions, and by following the institutionalized rules, such as evaluation rules, in a way that the teacher's behavior becomes predictable. Most of the time, teachers disregard the uncertain and complex characteristics of the knowledge building process, depersonalizing and homogenizing the students. Santos (2008), by considering that the characteristics of the subject, of the knowledge and of the society are dynamic, argues that the articulation of certainty and uncertainty in the pedagogical practices is fundamental.

Besides, the uncertainty concept opposes the linear causality view grounded in the Cartesian rationality, by questioning the stability, the determination and foreseeability of the phenomena (Moraes, 2004a; 2004b). Non-linear dynamics counteracts the pedagogical practices based on instructive theories that comprehend the knowledge building process as linear, and that do not account for the collaborative and interactive learning (Araújo, 2007).

3. All quotes in this paper were translated by the authors.

2.4 Organizational recursion

Another important complexity concept is organizational recursion. According to Morin (2011, p. 74), a recursive process is "a process in which the outcomes and effects are at the same time causes and inputs of what had produced them". The recursive principle breaks up with the idea of cause and effect, by presenting the cyclic concept that everything that is produced returns on what had produced it.

This idea is congruent to the educational system if we consider it as a system that self-organizes; in the sense that a student is an outcome of a determined educational system, and at the same time the student influences the system. Therefore, the retroactive relations between the student and the system make the system evolve and develop (Moares, 2004a).

The same idea is seen when we talk about the construction of knowledge. According to Bonilla (2002), information and knowledge are related. But since meaning lays within the interpreter, information only gains meaning within a human context. Knowledge then would be the process of attributing meaning to information; and this would occur in the interactions among agents, and interactions between agents and the world. Therefore, the construction of knowledge comprehends a recursive organization, in which agents transform knowledge, and knowledge transforms the agents that had produced it.

2.5 The autopoiesis principle

Related to organizational recursion is the principle of autopoiesis formulated by the Chilean biologists and philosophers Maturana and Varela.[4] This principle refers to an autonomous unit that constitutes itself as a network of components production, in which each component participates recursively in the same network. That is, there is no separation between the product and the producer; in such a way that the autopoietic organization is itself the product of its operations (Varela et al., 1974; Maturana and Varela, 1995).[5]

4. Maturana and Varela, aiming at comprehending the living being organization, postulate the autopoietic principle, affirming that all living being is an autopoietic organization. The cell, for example, "is a network of chemical reactions which produce molecules such that *i*) through their interactions generate and participate recursively in the same network of reactions which produced them, and *ii*) realize the cell as a material unity" (Varela et al., 1974 p. 560).

5. The main difference between the former organizational recursion and the autopoiesis is how the authors understand autonomy per se. Morin (2011) considers a relative autonomy – the individual is indeed dependent on the environment –, while Maturana and Varela (1995) admit an absolute autonomy. For them, each autopoietic unit presents a particular structure, and when the autopoietic unit interacts with the environment, the structure of the environment does not determine; but it only unleashes structure changes of the unit. That is, due to the autopoiesis organization, the system is autonomous of the environment. The system and environment are interrelated but not dependent; each system operates independent from the other.

Based on this idea, Moraes and Torre (2006) argue that learning implies autopoietic processes, since knowledge and learning are interpretative and recursive processes, produced by the agent when he/she interacts with the environment. The authors call attention to the impossibility to predict what happens with the student only by observing the environment in which he/she is embedded, since the environment does not determine, but it can only unleash the changes on the cognitive-emotional structure of the student. This implies that a teacher's dynamics can work well with a specific group of students, but not with another group.

In accordance with Moraes and Torre, Santos (2008) argues that for the pedagogical practice this implies that the professor should adopt a methodology that pushes the students to produce knowledge by their own. The professor would facilitate the dialogue among the wisdoms, respecting the heterogeneity of each student, since each student has his/her own way of learning and of solving problems. By considering that the environment influences the individual, Santos (2008) emphasizes that knowledge should be seen as a result of the entanglement of physical, biological and social aspects. For her this implies the need to reframe the perception´s concept.

2.6 Hologramatic principle

The last principle presented here is the hologramatic principle. Proposed by Edgar Morin (2011), the hologramatic principle refers to the idea that the part constitutes the whole, and the whole constitutes the part. The author uses the idea of the physical hologram to argue that the smallest image´s point of the hologram contains almost the whole information of the represented object.

This goes against the current disciplinary structure of knowledge, based on Cartesian orientations, in which it is believed that the sum of the parts listed in the curriculums is equal to the whole knowledge. This disciplinary structure hinders the student to establish relationships between the knowledge obtained (Santos, 2008). Considering that to understand the parts, one needs to understand the inter-relationships between the parts and the whole, Santos argues that in order to explain isolated phenomena, the context is essential. For the author there is the need to invert the binary part-whole, and to interconnect the fragmented totality.

One way to overcome the current fragmented disciplinary structure, and to articulate the opposites is transdisciplinarity. Transdisciplinarity points out that what seems contradictory in one level of reality, may be coherent in another level of reality; meaning that there is no absolute truth, but instead relative truths, subjects to constant changes. As such, transdisciplinarity offers a wider understanding of reality; reality assumes a wider meaning (Santos, 2008).

From the transdisciplinarity view, knowledge is seen as a web of connections, a network. Knowledge is multidimensional, given the different levels of reality in the cognitive process (Santos, 2008). For Santos, by following traditional pedagogical practices, teachers tend to disregard the hologramatic principle, and not to articulate the diverse wisdoms in the construction of a multidimensional knowledge. Given the complexity of the phenomena, understanding an object in its diverse dimensions, requires both transdisciplinary knowledge and transdisciplinary observers. As put by the author:

> Transdisciplinarity maximizes learning by working with images and concepts that mobilize mutually mental, emotional and body dimensions, intertwining horizontal and vertical relations of knowledge. It produces situations in which there is larger involvement of students in their own construction of meanings (Santos, 2008 p. 76).

3 COMPLEX SYSTEMS' METHODS AND METHODOLOGIES IN EDUCATION

The previous section presented a discussion on the use of theoretical concepts of complexity to think education in Brazil. This section focuses on the applications of complex systems' methods and methodologies in education in Brazil. These applications can be divided in two main groups: those predominantly related to modeling and those mostly related to data availability. The separation is mostly for analytical reasons, as these two groups are fundamentally intertwined and interconnected. Modeling encompasses Cellular Automata and Agent-Based Modeling; System Dynamics; Network Analysis; and Intelligent Tutoring Systems, while Educational Data Mining; Learning Analytics, and Data Visualization compose the second group.[6]

6. For more information on methods and methodologies of complex systems, see Fuentes (2015).

3.1 Agent-based models and cellular automata

In Brazil, agent-based models and cellular automata have been used mostly for teaching complexity concepts, Science and Maths at different educational levels. Xavier and Borges (2004), for instance, discuss the use of cellular automata for teaching about emerging patterns and complex behavior to students in the last year of basic education. Uehara and Silveira (2008) focus on the application of cellular automata for teaching Calculus in Computer Science undergraduate courses. Other examples include the use of computational modeling and simulation for teaching Physics (Gomes; Ferracioli, 2002), Chemistry (Recchi; Martins, 2013), Biology (Pereira; Sampaio, 2008), and Environmental education (Santos et al., 2001).[7]

The software Netlogo is popular in many of these applications. Recchi and Martins (2013), for example, used Netlogo to teach Chemistry and Science in an undergraduate course. In the course, the students were asked to develop projects using the Netlogo software. One interesting study conducted by one group of students simulated the diffusion of AIDS. By doing this, the students were able to better understand the concepts and mechanisms of infectious disease, as well as the factors that contribute to its proliferation. As such, the software promotes a dynamic learning process, in which the student is able to intervene and interact with the software, and to construct knowledge by him/herself.

The use of cellular automata and agent based modeling for teaching is also thorough abroad. A research project at Stanford University, for instance, promotes the use of computational models to link physical and virtual experiments in Science classes (Blikstein, 2012). In contrast to Brazil, agent-based models have been more directly applied to analyze educational policy abroad. Maroulis, Bakshy, Gomes and Wilensky (2010) simulate an agent-based model in order to investigate the impact of choice-based reforms in Chicago public schools, while Millington, Butler and Hamnett (2014) use an agent-based model to analyze the impact of distance-based school-place allocation policies in the United Kingdom. Similar kinds of study have not been found in the country.

7. The use of games in education can also be considered a simulation based approach and is gaining popularity in Brazil (Borges et al., 2013).

3.2 System dynamics

As OECD (2009, p. 10) puts it,

> Dynamical systems models are generally sets of differential equations or iterative discrete equations, used to describe the behavior of interacting parts in a complex system, often including positive and negative feedback loops. They are used to enable simulation of, among other things, the results of alternative system interventions (for example, which incentives are most likely to yield adoption of alternative energies by consumers and power companies). They have also been used to anticipate unintended consequences of policies (for example, the impact of increased availability of health insurance on decreases in preventive health behaviors).

Only one application of System Dynamics to educational policy was found in Brazil. Concerned about a possible failure of reaching the enrollment goal established in the National Education Plan (NEP)[8], Strauss and Borenstein (2014) applied the dynamic systems methodology to better analyze and understand the dynamics of the higher educational system in Brazil. They developed a model that allowed them to simulate the behavior of many variables, such as government regulation, demand and supply, and the private and public sector, in order to analyze the effects of different policies. The scenario analysis enabled a better understanding of the dynamic behavior of the higher educational system in Brazil, giving support to the development of effective strategies and the improvement of educational policies.

One similar example abroad is the work by Murthy et al. (2010) who use a system dynamics simulation model to analyze and plan future investments of a distance education program at a leading engineering institute in India. Other related papers (Al Hallak et al., 2009; Dahlan et al., 2010; Rodrigues et al., 2012) use the system dynamics approach as decision support systems for higher education management.

3.3 Network analysis

Different examples of network analysis applied to education were found in Brazil. Mesquita et al. (2008) apply the methodology of network analysis to investigate the

8.The NEP (2011/2020) establishes the goal of increasing the liquid enrollment rate of higher education to 33% of the population between 18-24 years-old (Ministério da Educação, 2011).

organization and potential action of a group of teachers, technicians, coordinators and schools directors from the municipal schools of the city of Fortaleza, who have as common goal the socio-educational inclusion of individuals with special needs. By identifying each actor's role, the size and density of the network, and the key actors that sustain and may expand the network, the analysis supports the construction of effective actions that can foster a better functioning of the group. This involves stimulating the sharing of information and experiences in order to promote the inclusion of individuals with special needs.

Aquino Guimarães et al. (2009) apply network analysis in order to examine the network of graduate programs in management in Brazil. Given the lack of academic research tradition in the area, the authors consider that articulation among the graduate programs would increase national publications in management and consolidate this scientific field in the country. That is, a strong and dense network, regarding the diversity of grounded edges and the number of actors (programs) involved respectively, tend to promote an increase in the amount and quality of scientific production.

Therefore, a better understanding of the graduate programs' network allows that each program identifies its role in the network and its potential contributions for the strengthening and expansion of the network. Besides, it contributes to the formulation of more adequate public policies, by providing important information to the development of graduate programs in the country (Aquino Guimarães et al., 2009).

The study shows that the network of graduate programs in management in Brazil is weak and diffuse, what indicates that there are few partnerships and shared activities among the programs. Besides, the nature of the institution, whether public or private, seems not to be an important factor for the constitution of the network. Based on these results, Guimarães et al (2009) argue that institutional policies that may foster the practice of joint researches and the exchange of professors and students should be taken into account as a way to increase cooperation and the strength of the graduate programs' network.

A similar study investigates the network of research institutes of public and social management in Brazil (Rossoni et al., 2008). The analysis demonstrates a diffuse network, in which the stronger links lie between institutions within the same state. Besides, the structure of the network is related to the scientific production index of each research institution. In the same line, Silva et al. (2006) use the network analysis method to examine the co-authorship network of professors in the postgraduate program of information science.

Another interesting application examines interactive systems and Learning Objects (LOs) in the teaching and learning process. Rossi et al. (2013) use the network analysis method to evaluate learning from the use of a game that exercises mathematical operations with fractions. The method allowed the authors to analyze students' participation in the game and their performance, and to identify learning deficiencies within a group of students.

Further studies using network analysis could encompass the use of contagion and opinion formation[9] models to analyze how education propagates in society[10].

3.4 Intelligent tutoring systems

Intelligent tutoring systems are linked to the application of artificial intelligence to education and can be described as "computer software designed to simulate a human tutor's behavior and guidance" (Educause, 2013, p. 1).[11] Intelligent tutoring systems differ from other computer-aided instruction, in that they are able to interpret complex student responses and they learn as they operate. This means these systems do not merely check whether an answer is right or wrong, but identify where in that response the student has gone wrong. Also, they can adjust their knowledge base using data generated by students using the system, and alter their tutoring behavior in real time to be more effective (Educause, 2013). Massive online courses (MOOCS), such as Coursera and Edx are examples of computer-aided instruction, as they do not adapt according to student's behavior. They consist mostly of pre-recorded videos and exercises whose content does not change based on how students respond. They do have the potential to turn into intelligent tutoring systems though.

9. See Tessone (2015) on the complex nature of social systems.
10.For a more general overview of the use of network analysis on educational research, see Alan, J. Daly (2010) and Brian, V. Carolan (2013).
11. More information on intelligent tutoring systems can be found in Koedinger et al. (2013).

The best example for intelligent tutoring systems in Brazil is arguably "Geekie".[12] Geekie is an intelligent tutoring system developed in the country, which offers computer-aided tutoring for students connected to the internet. In 2014, Geekie partnered with the Secretariat of Education of different states in Brazil to offer its intelligent tutoring system for free for students to prepare for Enem, a national exam taken by students to enter university. When the student first logs into the system, he or she takes a diagnosis test, based on which the system identifies the student's difficulties and proficiency level in different content areas and builds a personalized study plan. The students' progress reports are sent to teachers and managers, so that they can adapt their lesson plan accordingly. In its website, Geekie states that the system has had an impact on 13 thousand public schools and over 2 million students.

Research on intelligent tutoring systems is plentiful in Brazil and tends to be concentrated in Computer Science Departments. The Brazilian Symposium and the Brazilian Congress on Informatics in Education (SBIE and CBIE), for instance, bring together much of the research in the area. Bittencourt et al. (2009) and Brusilovsky and Peylo (2003), for example, build adaptive learning platforms, which use data from the student to provide a customized learning experience.

Müller and Silveira (2013) use a recommendation technique - analogous to the ones employed to suggest products to consumers - in order to suggest users in a system that might help others in solving a particular problem. In other words, the system uses social matching to support the formation of pairs. The system is aimed at teachers that might be having difficulties using a computer-teaching platform. When a teacher has a doubt, the system helps finding a person with a similar system configuration and skill level to help solve the first teachers' question.

3.5 Learning analytics and educational data mining

All these intelligent tutoring systems, MOOCs, and other educational technologies are producing vast amounts of data, that can help understand how students learn and, by doing this, enable more intelligent, interactive, engaging and effective education (Koedinger et al. 2013).

12. <www.geekie.com.br>.

Data mining and analytics refer to "methodologies that extract useful and actionable information from large datasets", such as the aforementioned ones. When these methodologies are applied to education, they are referred to as educational data mining and learning analytics (Baker and Siemens, 2014).[13]

Baker and Siemens (2014)[14] categorize the key methodologies in the field in five main groups: prediction methods, structure discovery, relationship mining, distillation of data for human judgment and discovery with models. The main models for prediction are classifiers, regressors and latent knowledge estimation. For example, by studying students' data, one can try to identify students with a higher risk of dropping out; and by analyzing students' answers, one can estimate latent knowledge. Structure discovery encompasses clustering, factor analysis, social network analysis, and domain structure discovery. In an exercise to which students answer in different ways, clustering techniques can help identifying a cluster of wrong answers and detecting concepts that are being misunderstood, so that videos can be sent to students to clarify such points. Relationship mining involves four main groups: association rule mining, correlation mining, sequential pattern mining, and causal data mining. Distillation of data for human judgment is related to visualization[15] strategies to present data to educators in a timely fashion, such as heat maps, learning curves and learnograms. Finally, discovery with models involves the use of a prediction model inside another prediction model, or within a relationship mining analysis, for example.

Big data in education seems to be the area which has advanced the most. In the world, Learning Analytics and Educational Data Mining have been used, for example, to study online courses, to support the development of more effective e-learning systems, and to explore how children 'game the system' (Baker; Yacef, 2009; Kotsiantis, 2012; Siemens; Baker, 2012). Eye tracking data and movement sensors have been used to give insights into the very learning process taking place when a child is doing an assignment (Blikstein, 2011); and machine learning has been used to help predict when a student will drop-out or fail school (Bayer et al., 2012; Márquez-Vera et al., 2013).

13. For more on the development of the two communities – Learning Analytics and Educational Data Mining – and their differences, see Siemens and Baker (2012) and Baker and Siemens (2014).

14. The paper provides detailed explanations and examples of applications of these methodologies.

15. The issue of visualization is discussed in more details in the following section.

In Brazil, though, such applications are scarcer, although still plentiful. Kampff (2009) tried to identify characteristics and behavior of students who had a higher risk of failing in a virtual learning environment. The system then alerted the teacher that the student might need some special attention and suggested what the teacher could do based on previous experiences. Pimentel and Omar (2006) used students' data to identify the relationship between cognitive and metacognitive skills, that is: does what we believe to know relate to what we actually know? Finally, Rigo et al. (2014) discuss improvements needed in the application of educational data mining, such as the implementation of interactive solutions, so that results can effectively support the detection of behavior linked to dropping out of school.

3.6 Visualization

Loads of data on education might be available, and powerful models might help simulate policy interventions and understand education mechanisms better. These efforts will have minor contributions though, if stakeholders cannot understand what all these data and models are saying. This is why the distillation of data for human judgment mentioned in the previous section is crucial.

As Rand (2015) puts it, stakeholders and decision makers need to understand the analyses in order to make appropriate decisions. "In some cases, they do not have the complex systems *literacy* necessary to understand the results. Education (about complex systems) will help this, but so will increased efforts in visualization, since visualization can make results and models easier to understand."

Gentille also emphasizes the importance of visualization and interactivity: "Thought must be given to how simulation results are presented to stakeholders, minding their interests, salience and experience. Promote ad-hoc data exploration because it facilitates model verification, validation and knowledge discovery." (Gentile, 2014).

One of the most prominent examples in Brazil regarding visualization is the site Qedu.[16] Qedu is a free open-access portal, which presents information on school quality for the federal, state, municipal and school level. Basically, it brings together all data that

16. <www.qedu.org.br>.

are being generated by different learning assessments conducted in Brazil, and presents them in an easier and more manageable way for the ample public to understand.

The portal shows, for example, that only 12% of children in the last year of basic school in Brazil reached adequate learning in Maths in 2011. It also allows the user to see how this percentage varies per state. In Alagoas and Amapá, for instance, this percentage (3%) is the lowest in the country, while the states of Minas Gerais (22%) and Santa Catarina (17%) show the best results. When zooming in the state of Minas Gerais, though, the results per city are very heterogenous. In Gameleiras, also in the North of the state, this percentage is 3%, while in Coronel Xavier Chaves, in the North, this percentage is 85%. Besides the site allows the user to see the result as far as the level of the school. This can be an important instrument for parents and the population in general to accompany the performance of students, to help them choose schools and demand from them, and to be an active agent who can try to influence the educational system.

4 DISCUSSION

This paper provided an overview of the application of the complex systems' approach to education in Brazil. The first part explored the use of complexity concepts and views to think education in a theoretical sense, while the second focused on applications of methods and methodologies. This analysis brought up a couple of insights for teaching, learning and for educational policy in Brazil, which are discussed in this section.

First, teaching students and stakeholders complexity concepts might be relevant. As Rand (2015) puts it, from a young age, people tend to develop a deterministic and centralized mindset. That is, they expect systems to have deterministic rules that govern their behavior and that there is a central controller in most system. However, most complex systems show the opposite. Therefore exposing students to complexity concepts might help counteract this tendency.

Also, complex systems methods can be considered relatively new in educational research in Brazil. Researchers with a thorough knowledge of the theme are relatively scarce and there is less tradition of quantitative or computationally intensive approaches in education research. Actually, most of the applications tend to come from computer science rather than education departments. Teaching educators complex systems concepts and familiarizing stakeholders with its terms and methodologies might thus be an important step towards improving educational research, which can bring important insights to educational policy.

Second, promoting a transdiscilipinary curriculum at the student level and conducting interdisciplinary analysis at the policy-research level might be crucial to promote effective learning and to tackle the complex nature of educational systems.

As Carter and Reardon (2014, p.16, our griffon) comment on educational inequality:

> The multidimensional problems of inequality require multidimensional solutions, perhaps developed through innovative, interdisciplinary collaborations between seasoned researchers and the next generation of researchers. As we move forward, tackling inequality through research, policy, and practice mandates an ecological approach that attends to the multiple, interlocking domains of inequality. Mixed-method research projects, in particular, may be necessary to produce both generalizable findings and deeper insight into the subtle, often invisible social mechanisms that shape individuals' lived experiences.

Third, it seems important to recognize and incorporate students' heterogeneity in educational practice and research. Given the high levels of inequality in Brazil, taking students' heterogeneity in account is critical.

Forth, computational modeling and simulation are powerful tools to teach complex concepts at the student level, and to analyze complex problems at the research and policy level. Models can help understand underlying mechanisms and be used as decision support tools.

Fifth, network analysis can be employed for promoting system's resilience, identifying key nodes, and promoting information flow.

On the data side, data are precious resource to improve knowledge about learning and to validate and improve models. Visualization efforts are crucial though to promote information flow and learning within the educational system and the emergence of bottom-up solutions.

Finally, gearing education policy and practice towards personalized learning, that is “instruction that is tailored to learning needs, tailored to learning preferences, and tailored to the specific interests of different learners” (Pea et al., 2014, p. 13), might be an interesting path to follow. Personalized learning supports learning for all students and is argued to improve educational performance, to promote cost efficiencies through educational productivity and organizational optimization, and to accelerate educational innovation (Pea et al., 2014, p. 13).

This seems to make particular sense in Brazil, given the mentioned heterogeneity of students, that encompasses different aspects, such as socio-economic background and intrinsic individual characteristics. One aspect worth pointing out is the heterogeneity present within classes in Brazil, given the high school year distortion in the country. In 2011, 15% of students from the 1st to 5th grade (primary school) were two or more years behind the appropriate grade; 28% of students from the 6th to 9th grade (middle school); and 30% of high school students (Qedu). This scenario results from both failing school years and dropping out.

A continuous progression policy was adopted in some states in Brazil to improve this situation. After evaluating the program, Menezes-Filho et al. (2008) find a higher promotion rate and a lower dropout rate at the urban state schools that adopted the program. The school performance impact estimates point to a significant reduction in proficiency of 8th grade secondary education students, whereas the impact for 4th grade students was not significant.

This suggests that the continuous progression policy might be important towards promoting attendance and avoiding dropout, but that it is insufficient. In this sense, personalized learning could be complementary towards learning and proficiency, by incorporating students’ heterogeneity; and by being scalable if implemented by means of intelligent tutoring systems.

Acemoglu et al (2014) argue that “web-based education will have broadly equalizing effects. Not only will human capital around the globe be enhanced,[17] but human

17. For the impact of the internet on the concentration of economic activity, see Forman et al. (2014) and Sakowski (2014). Forman et al. (2014) argue that "The rate of patent growth was faster among counties who were not leaders in patenting in the early 1990s but were leaders in internet adoption by 2000, suggesting that the internet helped stem the trend towards more geographic concentration "and that"…the internet could act as a broad force for weakening the links between the geography of inventive activity and spatial patterns of downstream use of it."

capital inequalities may also decrease." We think that personalized learning is a good opportunity to help develop human capital and diminish educational inequalities in Brazil. At the same time, it is important to point out that it is also a risk. If we do not keep up with the new developments in education and do not work on the infrastructure issued for this view to develop for the population at large, these advances could have the very opposite effect.

Finally, it is important to highlight that the aforementioned insights are possible paths derived from the complex systems' approach to education. Further investigation is warranted to confirm the validity of these aspects.

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