Editor's Note: This paper explores the theoretical foundations of Connectivism and relates it to previous theories of learning. Its focus is on networks – neural, internal (conceptual) and external. It relates the role of teacher, learner and knowledge within a dynamically changing environment. The illustrations and examples clarify the position of the authors in asserting the relevance and importance of connectivity theory and practice to technology supported learning.

Understanding knowledge network, learning and connectivism

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Abstract

Behaviorism, Cognitivism, Constructivism and other growing theories such as Actor-Network and Connectivism are circulating in the educational field. For each, there are allies who stand behind research evidence and consistency of observation. Meantime, those existing theories dominate the field until the background is changed or new concrete evidence proves their insufficiencies. Connectivists claim that the background or the general climate has recently changed: a new generation of researchers, connectivists propose a new way of conceiving knowledge. According to them, knowledge is a network and learning is a process of exploring this network. Other researchers find this notion either not clear or not new and probably, with no effect in the education field. This paper addresses a foggy understanding of knowledge defined as a network and the lack of resources talking about this topic. Therefore, it tries to clarify what it means to define knowledge as a network and in what way it can affect teaching and learning.

Keywords: learning theory; constructivism; Connectivism; knowledge; network learning; e-learning, Massive Open Online Course; MOOC; epistemology; ontology; online learning; Artificial Intelligence; AI

Introduction

One may find it appropriate to resemble the education field as a melting pot: Philosophy, Technology, Science and Arts are some of the many disciplines that take part and intersect in this multidisciplinary field. Finding a tenable theory that combines and harmonizes this heterogeneous mixture is like playing an open-ended game. New discoveries and insights give place to changes in the background on which the current theories are based. Connectivism-a recent and growing learning theory-argues that there are tremendous changes happening in the learning processes and it is not possible to build on the previous theories. Instead, a new conceptual framework should be built in an attempt to explain the emerging phenomena. According to Connectivism, new theoretical trends are founded in different circumstances and Connectivism is founded in information age.

In this rapid change process, technology plays a leading role inside the classroom scenario. For instance, technology development is affecting, amongst others, in: (1) the tools developed around the classroom and (2) the curriculum development. Regarding the first one, tools development, the rapid development of technological tools such as the personal computer (PC), laptop, internet, smart phone, multi-media and web 2.0 has involved the educators in a battle of keeping pace with its speed. While educators were in debate about using or not using PCs in classroom, the internet emerged. When research started to embrace the internet, the smart phone was invented; and the cycle continues. Concerning the second one – curriculum development -, it has also been significantly affected (Cormier, 2008). For instance, consider a student of computer science at the university. In his first year, a new study plan was applied. During his 4-year program, he studied according to this plan. After graduation, what he studied was already outdated. In this new era, a

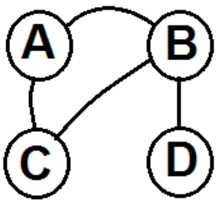
4-years period can involve significant technology changes; it all happens too fast and, in a short time, information can become obsolete!

Connectivism theory recognizes these issues along with an understanding of network sciences. According to Connectivism, it does not make sense to consider learning merely as an internal construction of knowledge. Rather, what learners can reach in the external network should be considered as learning. Moreover, the knowledge itself has a structure; it is not something fuzzy or mysterious. It is complex and chaotic, of course, but it has a structure. Connectivism uses what has been discovered so far in network analysis to interpret knowledge and assumes knowledge as a network (Siemens, 2008).

Meantime, defining knowledge as a network needs some clarification. In this paper, the authors propose to shed some light to this new framework adding some tangible examples of knowledge as a network. In other words, how network structure can represent the diversity and complexity of knowledge. From different disciplines, this paper moves step by step with simple examples to explain the complexity and chaotic characteristics of knowledge. Knowledge, however, is full of more sophisticated and complex examples.

Knowledge as a network

The network refers to a set of nodes connected with relationships. Therefore, the network consists of one or more nodes connected by one or more relationships. In the figure below, the network consists of four nodes (A, B, C, D) connected by four relationships.

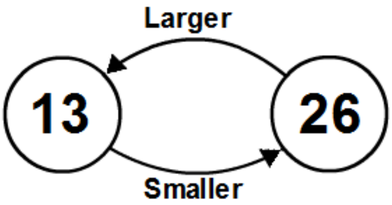


Network components

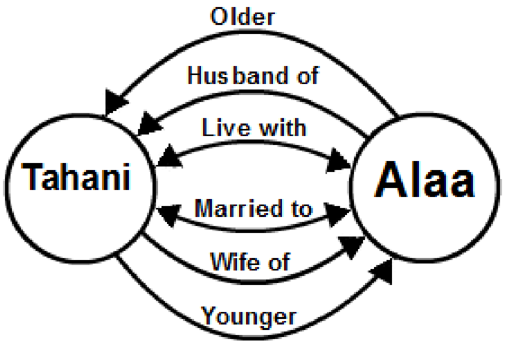
Node: The node refers to any objects that can be connected. Connectivism recognizes three node types: neural, conceptual (internal) and external (Siemens & Tittenberger, 2009). In the neural level, the network consists of neurons connected by neuron's axon and dendrites (Stufflebeam, 2008). In the conceptual level, the network consists of concepts, ideas and thoughts connected by conceptual links like similarity and positive correlation. In the external level, the network consists of people, books, websites, programs and databases connected by internet, intranet or direct contact.

Relationship: The relationship is a link between two objects. One or more relationships can be gathered in a tie. There are some special relationships or characteristics of network relationship.

> **Graded:** The relationship between nodes is not necessarily sharp. It is sometimes interpreted or graded. For example, consider a relation of 'friendship' between two persons. It is clear that the friendship is not a quantitative relationship. Instead, it is interpreted, graded or, even, contains sub-relationships. In this case, 'friendship' is considered as a 'tie'.
>
> **Direction:** The direction of the relationship makes a difference. Some relationship is reversed when you flow from one node to another. For instance, consider the relationship of 'smaller' that join a node of a number '13' and a node of '26'. The relation must be reversed to 'Larger' relationship when flowing from '26' to '13'.

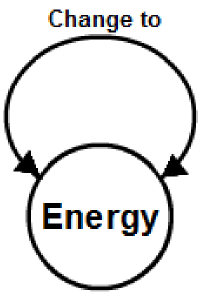


This is not a case with all relationships. Consider a tie that joins a couple, 'Alaa' and 'Tahani'. The relationship of 'Married to' and 'live with' are similar for both directions. However, the relations 'Husband of', 'Wife of', 'Younger' and 'Older' have different directions.



Other relationships go in one direction without inverse. For example, consider a relationship of 'subtract' between two numbers.

Self-join: The node can connect to itself. Consider, for instance, a person who blames himself. Another example of self-join relationship is the law of Conservation of Energy; energy cannot be created nor destroyed, but can change from one form to another (Planck, 2013, p. 40). Therefore, if the energy is represented by a node, then it should connect to itself with a relationship of 'changed to'.

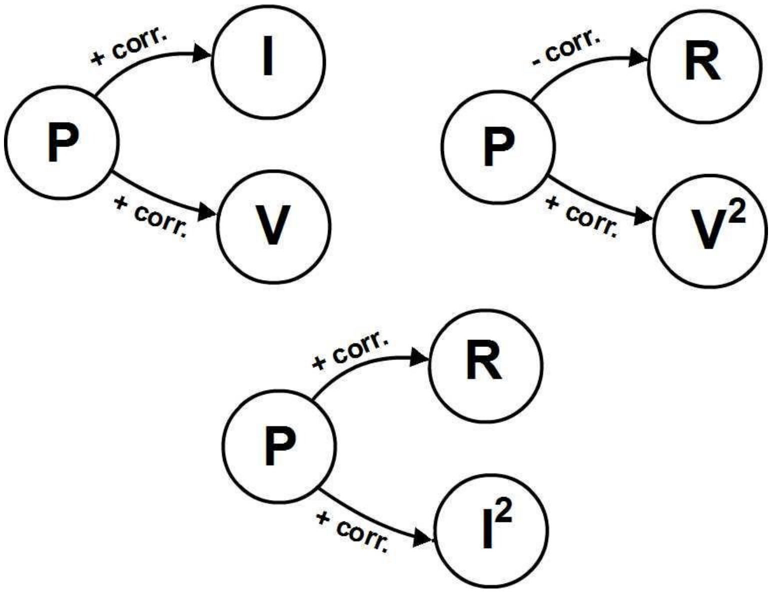


Pattern: The pattern refers to a set of connections appearing together as a single whole. This is one of the most important concepts of Connectivism. The examples given previously were talking about a simple relation that joins one or two nodes. Things go more complex when a relation cannot be seen between two nodes as an isolated relation. For instance, consider an electrical power formula in a Direct Current (DC) circuit.

$$P = IV = \frac{V^2}{R} = I^2R$$

Where: P = electrical power; I = electrical current; V = electrical voltage and R = resistance

The electrical power in DC circuit is recognized by one of the formulas listed above. The next figure represents the formulas as three separated networks:



The first formula states that 'P' is positively correlated with 'I' and 'V'. But is it true to say that 'P' is positively correlated with 'I' alone? To answer this question, let us move to the second and third formula and look at the relation between 'P' and 'R'. Unfortunately, the relation is negatively correlated in the second formula whereas it is positively correlated in the third formula! Therefore, it is not true to say that 'P' is positively correlated with 'R' and it is not true to say 'P' is negatively correlated with 'R'. Even more, it is not true to say 'P' is not correlated to 'R'. The notion is that a single relation between two nodes in this network does not make sense: it is a chain of relations that include the relationship between 'P', 'R', 'V' and 'I' all together or, in this case, subset group of them. These chains are called patterns. Therefore, the meaning is distributed among patterns of relations (Downes, 2007). The neural system presents another example of distributed knowledge. Researches in neuroscience suggest that a single neuron cell is not the holder of information; instead, it is patterns that connect a set of neurons (Siemens & Tittenberger, 2009).

Node formation

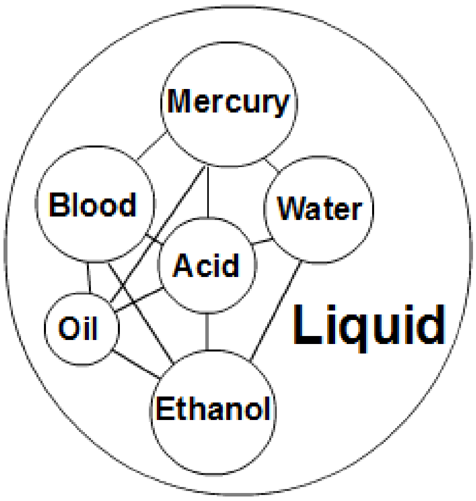
In the previous section, the node is described merely as a black box or an ambiguous object. Connectivism argues, however, that the node itself is a network. "Every entity is composed of additional entities" (Downes, 2007). The entity can be viewed in three separated levels:

Neural level

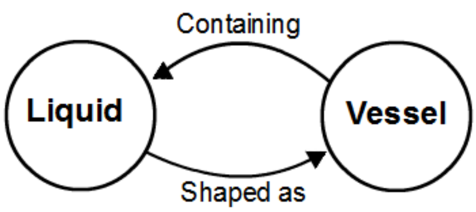
The network in neural level is a set of connected neurons; so, every neuron is connected to between 5,000 and 200,000 other neurons (Stufflebeam, 2008). But the neuron itself is a network. A typical neuron has a Soma in its center, which contains the nucleus of the cell. The cell is surrounded by plasma membrane. The nucleus and the membrane are connected to each other in dependency relationships to achieve the neuron function. The Soma itself is a network of protein synthesis and so forth (Lodish et al., 2000b). Neurons don't have the ability to divide. A damaged neuron, therefore, cannot be replaced, at least so far (Purves et al., 2001). Despite researchers' attempts to generate neurons from stem cells, the adult neural network does not grow; it is fixed.

Conceptual level

The node in this level is the concept. The concepts refer to ideas and thoughts that help human beings to interpret the world. The concepts are connected to each other in a network structure (Siemens & Tittenberger, 2009). For example, consider the 'liquid' concept. Actually, there is no physical instance named 'liquid'. The liquid is just a concept in human mind to gather relatively similar instances such as water, oil and ethanol. All these instances have something in common which makes them gather under one same concept: 'liquid'.



Therefore, the liquid is a concept that consists of a network of sub-nodes connected to each other with 'similar to' relationships. Creating a single node to represent an aggregation of different nodes simplifies human's network of concepts. The idea of aggregation returned to a philosophical idea of associationism: "two things that are relevantly similar become connected in the mind. This connection or association in turn allows knowledge about one to be inferred of the other" (Downes, 2007). Moreover, a liquid node can simply be connected to other conceptual nodes. For example, a 'liquid' connects to a 'vessel' node with a 'containing/shaped as' relationship.



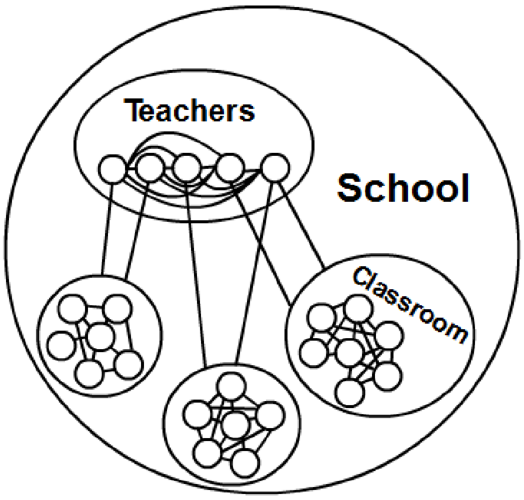
This also allows *density of liquid* to connect to *depth* and *gravity* to form a *hydrostatic pressure* formula. The differences between the inner nodes (water, oil, ...) are still recognized but, in such cases where their differences do not matter, a liquid concept comes as a black box. Thus, if one sees 'gasoline' for the first time, he/she will successfully treat it as liquid even without knowing its reality.

External level

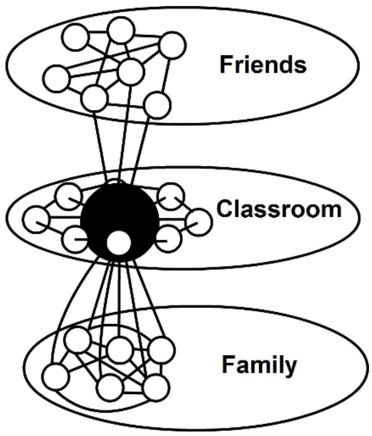
Unlike previous levels, the external network has a diversity of node types. Connectivism summarized all type of nodes by defining them as social or external nodes. Connectivism, in this level, built on Actor-Network Theory (ANT), which in turn, was built on Scientific Realism and

Social Constructivism (Frohmann, 1995). ANT realized that social environment is just a network of actors. Two main contributions are mentioned here: First, the topology or the structure that best describes environment is the network. Second, the actors of this process are not just human. Instead, humans and non-humans are all actors. The notion here is "in networks of humans, machines, animals and matter in general, humans are not the only beings with agency, not the only ones to act; matter matters" (Risan, 1997). Connectivism, however, puts more emphases on technology and assumes it as both, actor and connector. So, according to Connectivism, technology has actors such as Artificial Intelligence (AI) agents, smart phone devices, electronic books and websites; and connectors such as social network, internet and intranet.

Many different examples may be given for the formation of each node type in this level. In this section, some examples for human and non-human will be given. Consider, for example, a school as a node of a humanitarian network. The network consists of students, teachers and administrators. Within this network, sub-networks or clusters have emerged, such as classrooms and teachers' cluster. Clustering or dividing the network into sub-networks depends on the number of connections between elements. Therefore, it is heavily connected within a sub-network and loosely connected between sub-networks. The classroom itself can be divided into sub-networks of best friends and so forth.



It is important to know that the example above is just one sector of the real network. The real network is much more complex. For example, one student in the previous classrooms is connected to other networks such as friends and family.



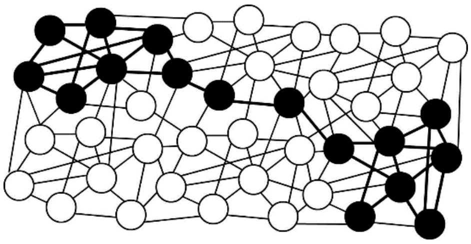
Similarly, non-human nodes participate in networks and consist of networks. A food chain is one of the famous examples. Considering the 'feed on/eaten by' relationship between humans, animals, plants and living things ends up in a food chain; and more precisely food network. One study in food network revealed an interesting finding which could be considered for other networks: Adding more parasites to food network increases connectance sometimes dramatically (Lafferty, Dobson & Kuris, 2006), where connectance is a key metric affecting the whole food web stability. In other words, small changes on a direct relation between two nodes, say 'A' and 'B', may have effects on the 'C' node, which does not have connection with either one.

Flow of information

In the previous section, the node is described as a network of related nodes. "Knowledge may reside in non-human appliances" (Siemens, 2006b, p. 31). However, knowledge is alive and the information is passed through the nodes. "Nodes that are no longer valued are weakened within this environment"(Siemens, 2006b, p. 30). In this section, the flow of information will be described partially in the three levels of networks:

Neural Level

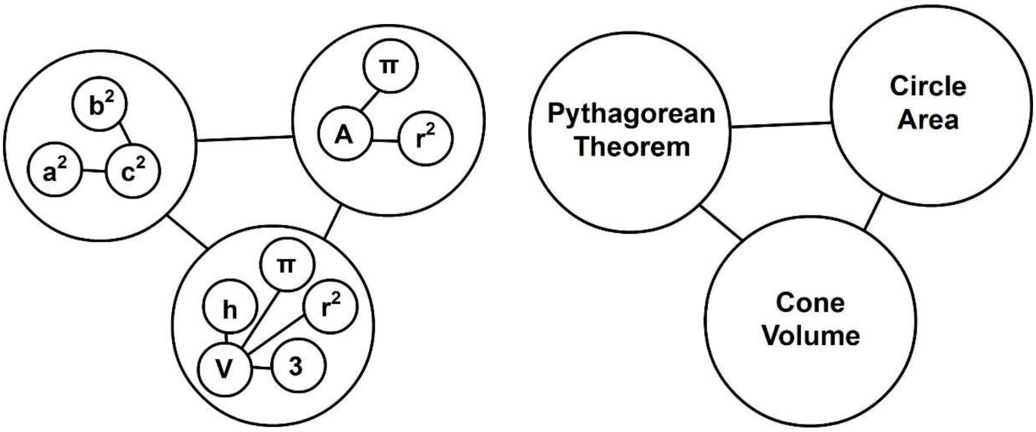
Neural network send messages back and forth using electrochemical nerve impulses. The neuron function is based on synaptic signaling, a pattern of connections or pathways that connects neurons and helps signals' transmission. This process is partly electrical and partly chemical (Lodish et al., 2000b). Each group of neurons is responsible for processing specific kinds of phenomena, for example; computing verticality and quantity. When two groups of neurons in the brain are activated together over and over again, they will find a short path that links them together. Therefore, they are becoming connected. Later, activating one group will activate the other (Lakoff, 2009a).



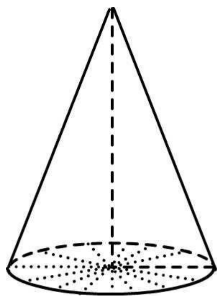
Each time the neuron is activated, the connection to the next neurons gets stronger. Without such signals, cells activate a so-called suicide program and eventually die (Lodish et al., 2000a). A child of 5 years old may get half of his neuron connections die off if they are not used (Lakoff, 2009b).

Conceptual level

Connectivism sees the node in conceptual network as ideas, thoughts and concepts. The information, events and experiences flow through one's ideas, thoughts and concepts in the process of thinking, dreaming, imagining and even while living and experiencing the real life. According to Connectivism, the conceptual network is working continuously and independently from the real world and the information flows either consciously or unconsciously, being, in most part (98%), an unconscious process(Lakoff, 2009a). The second assumption of Associationism says that "a certain amount of energy applied to a system will create a certain amount of kinetics- in other words, your brain goes on thinking even though it is not receiving input" (Downes, 2007, p. 5-6). The flow of information that passes through these ideas and concepts strengthen them, while the ideas and thoughts that are rarely visited by surrounding events, experiences and information slowly lose their connections to other nodes, and eventually are removed or forgotten. Consider for example a student who perfectly masters the Pythagorean Theorem of rectum triangle. By the time of studying the course, the student is fully aware of all details of this theory. She/he can calculate any given examples and can connect this theory to other broader areas and topics, such as circle’s area and cone’s volume. Over time, and if she/he doesn't face these concepts in real life, the first thing that may be forgotten is the inner connections of the Pythagorean Theorem, the circle area and cone volume concepts. Therefore, they become ambiguous entities. Finally, the connections between the broader areas may, gradually, be lost.



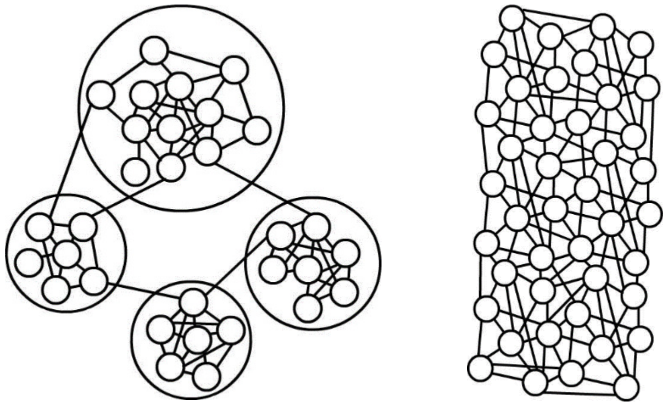
On the other hand, "a learner who continually encounters new information and events, will dynamically update and rewrite his/her network of learning and beliefs" (Siemens, 2006b, p. 30). Hereby, Connectivism applies the same concepts shown previously at the neural level. The flow of information between two conceptual nodes needs activating and extending both of them at the same time until the short path occurs. For example, in order to create a short path (connection) between Pythagorean Theorem, Circle Area and Cone Volume, each concept should be extended until the learner can see the relation that gathers them all.



External level

The flow of information at the external level comes as a form of social connection. The social studies of science and technology have revealed that the node (which may be human or non-human) is socially connected to its environment in a network based “topology”. The node has a unique position in the network. Hence, it can only see, perceive, send and receive information through this position. The position in the network (centrality), the number of direct connections (density), the importance, or the uniqueness, of a connection to other nodes (bridge) and the minimum number of connections needed to reach a target node (distance) are all subjects of analysis in Social Network Analysis (SNA). What really flows through these connections does not matter, from SNA's perspective, as the frequency, repetition and availability of messages. In other words, SNA does not usually analyze the content; it analyzes the maximum, the minimum, the average and the total number of messages between nodes.

Technology makes both the connections and the flow of information more feasible. In a broader view, technology has dragged the society from densely connected groups or communities to a loosely connected group but a more connected individual. In other words, it lead society to 'networked individualism' (Dirckinck-Holmfield, Jones & Lindström, 2009). It sounds contradictory, but it can easily be explained: the average number of connections per node has increased but those connections are no longer limited to a certain group of nodes. Instead, the connections spread out through the whole network.



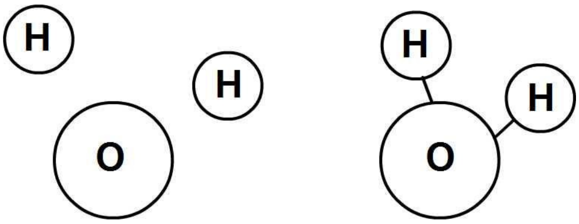
The relation between the connection and the flow of information is a unique relationship. The information needs a connection to reach the target and the connection needs the flow of information to stay alive. Therefore, no flow of information exists without connection and no connection remains without flow of information.

As an example of flow of information and the effect of technology in the creation of social connections, consider a software company, which imposes a hierarchical personnel structure with managers on the head and closed groups of programmers on the bottom. The Chief Executive Officer (CEO) has realized, after a while, that there are leaks of the codes that were developed inside the company. He hired a security company to track the flow of information and to insure no intruder can reach those codes. The first investigation revealed no security threats and the flow of information is secured. The second investigation, however, revealed that the closed groups of developers were not closed at all. Some employees were using virtual work websites and hiring other developers to get their jobs done. Some administrators have seen this as threat, others as an opportunity. The latter administrators have created many virtual companies, which gathered developers from all over the world. Similarly, educators may perhaps see these changes either as threats or as opportunities.

Known and unknown knowledge

Connectivism uses the network topology to represent the knowledge structure. One of Connectivism's questions is: 'does knowledge already exist – so the learner just has to explore, discover and aggregate it – or is it something 'in the open' and growing, so the learner can invent in addition?' Actually, Connectivism recognizes both scenarios but it concentrates more on known knowledge. Describing knowledge as abundant and easy to access, connectivists hold that adding something new to the existing knowledge is very complicated and requires the effort of others. Like Siemens (2006b) says, "Problems are becoming so complex that they cannot be contained in the mind of one individual — problems are held in a distributed manner across networks, with each node holding a part of the entire puzzle" (p. 44). Therefore, according to the connectivist's view, aggregating, exploring and discovering the known knowledge is more important than inventing new knowledge.

It is also important to know that the aggregation of existing knowledge is seen, by itself, as new knowledge. So, a compounded node is larger than the sum of its inner nodes. In other words, the compounded node has an emergent property where the node properties are not merely the collection of inner nodes properties (O'Connor & Wong, 2002). Actually, in some cases, they can be completely different. Consider, for example, the properties of oxygen and hydrogen atoms. Hydrogen gas is highly flammable and oxygen gas is necessary for combustion. If one oxygen and two hydrogen atoms are combined, the result is one water molecule (H_2O). It is a *liquid*, which is used for *extinguishing* fire! The emergent property resulting from this combination has nothing to do with any of these single atoms' properties.



Similarly, gathering one administrator, secretary and accountant does not mean a sum of them. Instead, it may mean tourism agency.

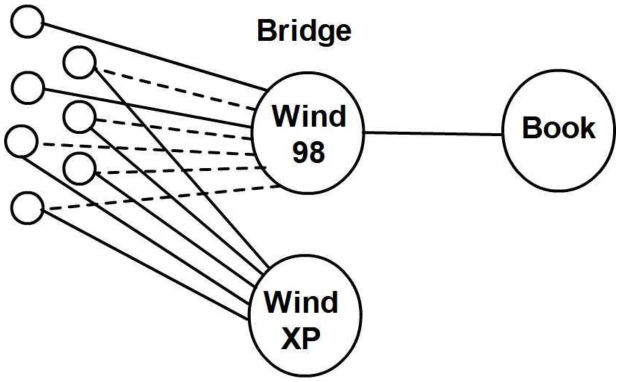
So, according to Connectivism, unknown knowledge will find its way to known knowledge when its surrounding nodes need it in their path. Electricity and gravity may have not been discovered without the preliminary discoveries. Those preliminary discoveries make it logical to think and find the pattern of relation between the fallen apple, the force and the acceleration.

What if the network was partially unknown, are we able to handle it? Are we able to use it? Observation emphasizes that human beings are able to deal with uncertainty, make use of complex objects and manipulate "black boxes": water has been used long before its synthesis was discovered; students use calculating machines without really knowing how they work. As Siemens (2006b) would say, that is the human's artistry: "The artist sees (and accepts) the beauty of uncertainty and values learning as both a process and a product... Tools are used like paint brushes to create the desired painting of learning" (p. 108).

Moving node

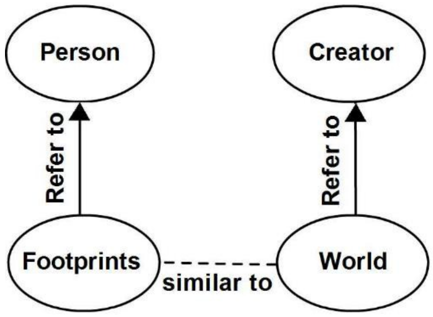
All previous theories recognize knowledge as an object or state to be acquired or built in the learner's mind. Connectivism, in contrast, conceives it as a process, which is alive and moving, a shifting reality. As seen in the previous sections, the flow of information from one node to another gives some vitality to the network. But, what about the nodes and the connections? Connectivism sees both of them as moving objects. In other words, time should be considered as a dimension of knowledge: in one moment some nodes appear, others disappear; some connections are strengthened, others are weakened. So, as Siemens (2005) says, "While there is a right answer now, it may be wrong tomorrow due to alterations in the information climate affecting the decision" (p. 4); the node itself may change its position by changing its connections and give place to another reality. To clarify this idea, consider a car driver who was driving a car in high speed. The road appeared to be empty and all coming information made him satisfied about his decision. Suddenly, a pedestrian jumped into the roadside and crossed the street. The car, at that moment, was about 50 meters away from the pedestrian. The right decision would to press the brake pedal. Unfortunately, the driver didn't take that decision. Two seconds later, the car was 10 meters away. The right decision, at that moment, was to steer the wheel. Pressing the brake pedal is no longer the right decision. In this example, there were three decisions (high speed, pressing the brake pedal and steering the wheel); each one was representing the best decision in a specific time fraction. However, when the incoming information is changing quickly, the best decision can suddenly become the worst. When things go faster, the lifetime of the decision gets shorter. That is exactly what is happening in the education scene: Sciences are developing very rapidly and the (reluctant) drivers' decisions are coming too late.

There are two main factors that make the node unstable: (1) node emergence/volatilization and (2) the node autonomy. Consider, for example, a book talking about using Microsoft Windows 98 in education. The book took about one year to be written. Then it followed a regular process of validation and distribution. This means two additional years. The book reached library's shelves after 4 years. By that time, new Microsoft Windows version was released and the book's value is now questionable.



In this example, Windows 98 itself was a node in the network. As any other commercial product, this node follows a product lifecycle of introduction, growth, maturity and decline. This node emerged and declined within 4 years (Microsoft, 2014). In the meantime, people connected to this node. The book is another node added to the network, which is trying to use Windows 98 node as a 'bridge' or as a hub to reach the people. Suddenly, a new node has jumped to the scene: Windows XP. Because "currency (accurate, up-to-date knowledge) is the intent of all connectivist learning activities" (Siemens, 2005, p. 4), most people leave the old node (Windows 98) and connect to the new one (Windows XP). Of course, this is bad news for all nodes using Windows 98 as a hub: dealers, programmers, authors and educators.

Node autonomy is the second factor of network instability. This can happen in all kinds of nodes: neural, conceptual and external. Neural cells, for example, are different from each other. Each group of neurons is responsible for a specific task. Adjacent neurons resist the signal, at first, unless the power and repetitions compel them to connect. Otherwise, if activating one neuron can easily activate all adjacent neurons, then activating one neuron will activate all brain's neurons and that, of course, is not true. Similarly, the conceptual network of a person resists new ideas unless that person has allies of concepts in his/her mind. The concept grows gradually by connecting to other concepts. Again, the concept itself has its autonomy to "accept" or to "reject" the connections with other concepts. That is why, according to Connectivism, people have different ideas, opinions and reasoning; connection between two concepts is simply the path for reasoning. For example, someone who saw human's footprints on the ground, inferred that someone else had passed there. The relationship between the person (cause) and the footprint (effect) is a causal nexus. At the same time, he saw the world, which is perfectly harmonized, similar to the footprint (effect); can't come by chance and there is a cause for this effect. Therefore, this leads him to the Creator. Other people couldn't see the relationship between 'Footprint' and 'World'. Thus, they reached to other conclusions.

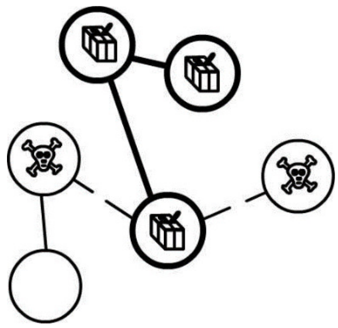


Learning as a Pattern Recognition

In Connectivism, the structure of the knowledge is described as a network. The network is a set of nodes connected to each other. These relationships/connections may not be seen as a singular link between two nodes. Instead, they are more like patterns: groups of relationships that come together as a single whole. The network is not static; it is dynamic and those patterns may change over time. Learning, according to Connectivism, is a continuous process of network exploration and patterns finding; it is a process of patterns' recognition. In the subsequent sections, the knowledge described as a network is explored in relation to the former theories. In other words, how the former theories act in a networked knowledge and how their proposed learning models are interpreted according to Connectivism. Finally, a Connectivism learning model is introduced as an alternative learning model, as connectivists say.

Former Theories

Behaviorism conceives knowledge as a physical object the learner should get and learning as a process of transferring facts to the learner's head through mechanisms of reward and punishment. According to Behaviorism, learning depends on the learner's innate like/dislike. It can be represented in a networked knowledge as the following: the teacher should put awards in the path, in which he/she think it is right and put obstacles in all other paths. Thus, the learner will find it interesting to follow the teacher's path. With repetition, the learner forgets all other paths.



Behaviorism is doing well in teaching animals such as dogs, monkeys and others. Some early school teachers still find this method useful once the awards and obstacles may speed up the process of transferring knowledge.

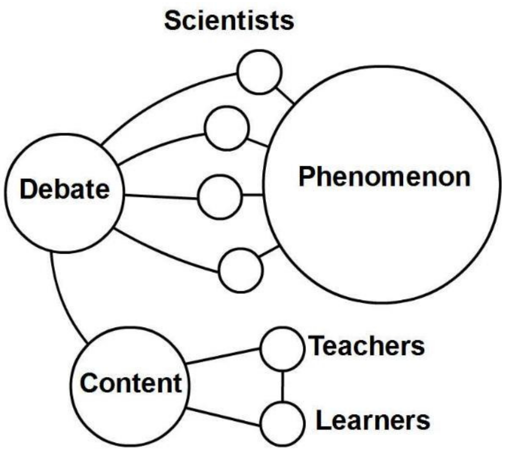
Cognitivism moved forward and says that the knowledge is not just as facts; it may include theories and opinions. Hence, learners should use their logical capacity to process information. The learning is negotiated through experience. In a networked knowledge perspective, the teacher should design for the learning experience in advance and prepare a narrow network where the learner has limited paths to try. Learners who follow the logical path will succeeded, the others may retry.

Constructivism, in specific, recognizes the complexity of the knowledge. "Constructivist principles acknowledge that real-life learning is messy and complex" (Siemens, 2005, p.2). The knowledge is inside the learner's mind built through the process of meaning-making. The teacher should design for learning experience to be rich and diverse. In networked knowledge perspective, the knowledge does not necessarily have one logical path to the right answer; there may be other paths. The learner should decide which path to follow.

Learning model in former theories

All previous theories follow the same education process. The knowledge is inspected, negotiated, filtered and presented as useful books. Teachers handle these books and arrange learning experiences according to one of previous theories: behaviorism, cognitivism, or constructivism. The best analogy for this process is the story told by El-Gazaly (n. d., p. 1359), an ancient Arabic educator. El-Gazaly resembled the knowledge as an elephant entered a village for the first time. A group of blind people heard about that big animal, so they went to inspect it and said: we will do our best to know what that animal looks like. When they arrived, one of them touched the elephant's leg, another touched its tusk and the last one touched its ear. Thereafter, they returned to village and ran a debate; the first said: the elephant is like a big tough cylinder (the leg), the second said: it is like a small smooth pipe (the tusk) and the last one said: it is like a thin skin (the ear). All of them were honest, but none of them was true. In spite of the debate, they wrote books about the elephant. The books were used later by teachers and students. The blind people represent the scientists who go and inspect new phenomenon. Each one of them sees the phenomenon from one side. Constructivism recognizes this issue. It emphasizes a negotiation between scientists to construct a pattern that best resembles the phenomenon. It also recognizes that the final construction is not exactly the same as as the phenomenon.

In general, former theories follow the same education process: phenomenon, scientists, debate, content, teacher and learner. The teacher may work as a transferring agent (Behaviorism) or as facilitator (Cognitivism, Constructivism).



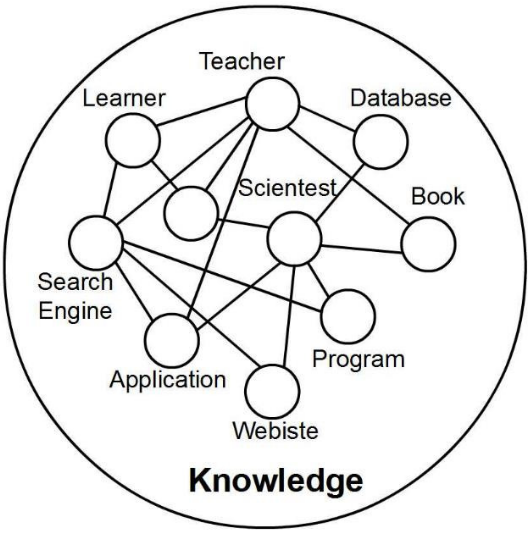
In this model, the content plays the central role: it is the aim the scientists generate; and it is the product the learners consume or put in their mind. **This model worked well for a long time, but not anymore, according to connectivism.**

Connectivism learning model

Connectivism simply adds two important notes to the elephant story: (1) the elephant is not an elephant, it is a jellied creature, which changes its shape much often and (2) the investigators, the teachers, the learners, along with non-human agents are within the knowledge; they are partners not counterparts. Taking into account the Connectivist's conceptual proposal and anticipating its implications on the educational processes, many critical changes can be foreseen. First, if we consider the quick and numerous changes that sciences and society are witnessing, we can say that the methods and processes that we are using today, in teaching, take too long, i.e.; while the scientists inspect, run debate and write books, knowledge rapidly and significantly changes and soon expires. Second, the current educational approaches try to keep teachers and learners away from the controversy and the debate amongst scientists. The idea is to provide teachers and learners with a ready-for-use material but this, somehow, keeps teachers and learners as mere knowledge consumers, as passive agents.

As we could see throughout the author’s attempts to clarify the Connectivist proposal, this new conceptual framework has a unique vision regarding the interaction between learners and content. The content is just a node in the network and learners are mainly not interested in putting it inside their minds. In contrast, learners are interested in using, copying and pasting this content to reach their aims. In Siemen’s (2006b) words "We off-load many cognitive capabilities onto the network, so that our focus as learners shifts from processing to pattern recognition" (p. 43). Besides, learners are autonomous nodes in the network and they are different from each other in their aims and, therefore, in the way they use contents. According to Connectivism, the educational system should foster the learners' diversity and not their similarity.

Additionally, it proposes that learners are put in the same place as researchers: in front of the recent knowledge. That way, learners become content generators and not content consumers. Therefore, instead of giving learners a stable, ready-for-use and solved problem, Connectivism proposes giving them unstable, controversial, unsolved and real-life problems. That may increase students’ tension and uncertainty, and maybe, the feeling of 'chaos'. The uncertainty will force them to search for answers, to ask help, to seek for patterns and, in other words, to form connections, in an attempt to solve the problem ahead. Here comes the role of the teacher, a mature learner, or a specialized node, someone who has already connected to a very good network in the field: other researchers, books, journals, websites, databases, mobile applications and others. Instead of being a bridge node to this network, the teacher should help new learners to plant themselves in the network, to be connected to its nodes and to be part of it.



In this process, technology represents the main connector in the network. Either by phone, e-mail, search engine or social network; technology makes it easier to reach the current, up-to-date information. However, "whether online, face-to-face or blended, learning and knowledge environments need to be democratic and diverse" (Siemens, 2006b, p. 47).

Discussion

Connectivism has been drawn from a long history of Artificial Intelligence findings. The idea of representing the knowledge as a network has been extensively used in AI research. Russell and Norvig (2010, p. 290) summarize, in a table, the languages used in AI along with their ontology (what the world contains) and epistemology (what the agent believes about ontology):

Table 1
AI languages and agent epistemology (Russell & Norvig, 2010)

Language	Ontology	Epistemology
Propositional Logic	facts	true/false/unknown
First-Order Logic	facts, objects, relations	true/false/unknown
Temporal Logic	facts, objects, relations, time	true/false/unknown
Probability theory	facts	degree of belief E(0-1)
Fussy Logic	facts with degree of truth E(0-1)	known interval value

The first time the ontology presented as a network was in a First-Order Logic. Temporal Logic adds time to the network. Connectivism, at least in its first version, corresponds to Temporal Logic where the ontology is a network that consists of objects and relations. In addition to them, the network has facts and time. The facts or the rules govern the network. The time makes difference in validating the facts. The agents in AI correspond to the learners in Connectivism. The learners have an epistemology that consists of the network in which they believe, disbelieve or do not know. This epistemology does not belong to one learner; instead, it is distributed among learners and things. This paper adds the degree of truth to Connectivism's ontology and epistemology.

It seems that most current researchers have realized that technology has impacted the way we understand knowledge and learning. However, they differ in their visions of this impact; some are still seeing previous learning theories valid and technology as another way in which a person stores his/her knowledge; like books, like databases. For them, "modern cognitive tools are nothing but an extension of the toolkit" (Verhagen, 2006, p. 4). Therefore, "we should forget about Connectivism" (Verhagen, 2006, p. 5). Others see technology impacts significant but they argue that Connectivism theory is not the right approach: naming Connectivism as learning theory "is a tall order for so young a theory" (Bell, 2011, p. 104) and "it does not seem that Connectivism's contributions to the new paradigm warrant it being treated as a separate learning theory in and of its own right" (Kop & Hill, 2008, p. 11). Therefore, they suggested alternatives: for example, Actor-Network Theory (Bell, 2011) and Cultural Psychology (Clarà & Barberà, 2013). Some other researchers see the value of Connectivism Theory and use it (Garcia, Brown & Elbeltagi, 2013; Barnett, McPherson & Sandieson, 2013; Blot & Saurel, 2014; Denzil, 2013; Dunaway, 2011) or try to integrate it with other theories such as Community of Practice, Design-Based Research and Activity-Theory (Boitshwarelo, 2011).

Among other things, Connectivism has been criticized:

- It does not address how learning take place; it is concerned about what is learned and why (Verhagen, 2006).
- It does not present new ideas; all of its principles have circulated somehow in Education literature (Verhagen, 2006).

- The ideas and principles used in AI and machine learning are-in no means-applicable to human learning as the human learning is not applicable for machine learning (Verhagen, 2006).
- Connectivism principles lack rigor and are not written in such way that can be tested (Bell, 2011; Verhagen, 2006).
- Connectivism's exponents do not provide a coherent view of the theory; some wrote ideas that are different from others (Bell, 2011).
- Any new theory should be built on older theories not discarding them; Connectivism does not (Kop & Hill, 2008).
- Connectivism is lacking sufficient empirical research (Kop & Hill, 2008).
- Connectivism does not present a solution for a learning paradox (Clarà & Barberà, 2014).
- Connectivism under-conceptualizes interaction. For example, the relationship between a teacher and two different students would be represented by just two connections. This oversimplifies a human relationship where the teacher may connect to one with a completely different relationship than the other (Clarà & Barberà, 2014).
- It can't explain concept development (Clarà & Barberà, 2014).

Downs and Siemens already discussed some of the issues listed above (Kop & Hill, 2008; Siemens, 2006a). This paper also tries to make things clearer and it may answer some of these issues. For example, we think that under-conceptualizing interaction can be explained by defining a relationship as graded. In addition, this paper may contribute in explaining the concept development using the principles of "every entity is composed of additional entities" (Downes, 2007) and flow of information.

One interesting issue from the list is that connectivists provide inconsistence in their view of Connectivism. In our opinion, this is a natural phenomenon, especially for a growing theory. Moreover, this paper may introduce a slightly different presentation than that presented by other connectivists.

Regarding the lack of empirical studies in supporting of Connectivism Theory, we can see that the process started and the results showed some positive feedback (Barnett, McPherson & Sandieson, 2013; Blot & Saurel, 2014; Dunaway, 2011). However, we notice that most of these empirical studies were done using online courses. This indicates that the researchers may find Connectivism suitable only for e-learning settings. Even though Connectivism is presented as a learning theory in educational settings and not exclusively for e-learning settings (Kop & Hill, 2008). Therefore, it is imperative to continue the process of validating Connectivism in all educational settings including school classrooms.

Conclusion

Conceiving knowledge using a network topology is ambiguous for some researchers. Even though this paper is not the first to talk about connective knowledge (Downes, 2007; Siemens, 2006b), it certainly adds a concrete sense of some abstract words. It moves step-by-step so a newcomer to the field of networks can easily understand what is really meant to define epistemology's structure as a network. The study shows how knowledge may be represented in a network consisting of nodes and relationships. The node can be neural, conceptual and external. The relationship has a direction and in most part is graded or interpreted. The relationship may not be seen as a single connection between two nodes; instead, it should be seen as a part of other connections, a pattern. Knowledge network is not static; it is alive and moving. In other words, time is considered as one of knowledge dimensions: the flow of information plays a role to retain or drop down the connections; new nodes are added and others disappeared. Even though the former learning theories do not hold the notion of knowledge as a network, this paper tries to explain how their assumptions reflect on a network. Finally, the paper presents a Connectivism learning model which asserts on considering the rapid changes of knowledge and a new relation between all learners: students, teachers and researchers.

However, this paper does not claim that it covers all networked knowledge aspects. For example, distributed cognition and collective knowledge are not covered, but they still can be interpreted. In addition, this paper builds mainly on George Siemens and Stephen Downes works, but it sometimes borrows ideas from Artificial Intelligence.

After reviewing Connectivism interpretation of knowledge, we hold that a network is a fixable structure; it is dynamic and can cope with complicity and diversity of knowledge. However, defining learning as pattern recognition is not enough to interpret learning. The second step for Connectivism, we think, is to interpret 'how the pattern recognition is done? What are the mechanisms used for pattern recognition?' Even in AI research, it is not possible to build an agent by stopping in this stage. For example, in order for AI agent to recognize the pattern, it should be equipped with searching mechanisms (Breath-first, Depth-first, Greedy best-first and A* search), a store of axioms (knowledge base), logic and inference rules, learning algorithms and many others. Only then, educators can build learning networks that can make learners grow easily and very fast.

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