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Building knowledge networks in STEAM teaching laboratories

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ABSTRACT

STEAM labs (Science, Technology, Engineering, Arts and Mathematics) are practical and interdisciplinary learning environments. When students are working in these labs, learning is built through multiple streams of information that span the entire environment. There is always a lot of collaboration between students, teachers and between them and devices, kits, and tools. To understand the construction process of this knowledge network, a methodology for mapping information flows was developed. Maps can provide important information for knowledge management in these environments. Our objective was to study how space shapes knowledge flows and how students can redesign these flows according to project needs. The professor presented a closed project on robotics to 16 students. The researchers used an ethnographic methodology, observing students in the environment and writing down their observations in a notebook. These data were entered into a software, which generated the interaction map. The network analysis pointed out 3 elements that should be highlighted: (a) isolation, (b) hubs, and (c) the role of the central bank. Each one was related to a feature of the space that contributed to the dynamics of information exchange in the environment.

KEYWORDS: Educational laboratories. Project-based Learning. STEAM. Robotic Labs. Makerspaces. Actor-Network Theory.

INTRODUCTION

STEAM learning environments have grown considerably in recent years across the world. Since the 19th century, laboratories were spaces focused on several basic sciences. The core of learning was the knowledge of a specific science (BRAGA, 2000). However, recently new types of laboratories have emerged for other purposes. The focus is on developing skills and competences, not only learning knowledge.

The rapid change in technologies has required an understanding of STEAM, centered on project development. More than content, it is important to learn how to think over problems, create solutions, make theoretical models, and prototype them. New environments are open spaces with non-specific devices and tools. In many places, these new labs have been given different names like Maker Spaces, Fablabs, Robotics Workshop, etc. Several countries have developed their own vision of these environments, depending on the regional technological culture (SANG; SIMPSON, 2019). As a result, the number of papers on the pedagogical role of these new environments has also grown (WANG *et al*., 2019). They are learning environments with a different dynamic from those used in old laboratories (BECKER; JACOBSEN, 2019). Activities tend to be more open, with a greater movement of students across na environment full of creative resources (BROWN, 2009). In the old laboratories, there was a greater number of closed activities, guided by scripts that explained the steps that should be followed. All artifacts were on the bench and students interacted only with their teammates.

The new labs are not static environments. When students are working on projects, learning is built through multiple streams of information that fill the entire space. There are always interactions between students, the teacher, devices, kits, and tools. These interactions are woven threads, forming a network during the learning process.

Information flows may carry different configurations depending on various factors. The architecture of the environment is one of them (IMMS; BYERS, 2017; CARDELLINO *et al*., 2018). Traditional science teaching labs tend to replicate the architecture of a traditional classroom, with desk arrangements being replaced by benches. The teacher is the center of the environment. Those students who sit with their backs to this center turn to watch the teachers speak, then return to their position around the bench to work with the teams. The tools or kits are placed on each bench, preventing the movement of students and the movement of people in the space. Collaboration is focused on each bench group, not the entire learning environment. In most activities, students stay in their places at all times. Doubts are addressed to the teacher, who is the one who circulates through the environment.

This type of configuration is a copy of the old factory system. People work all the time in a set position in an industry and performing a defined task over days, months and years. In the modern working world, it is still possible to find that. However, there have been several new functions in the world of work where people perform different tasks, collaborating with many colleagues from different sectors.

This article is part of a research on the dynamics of work in a STEAM learning environment during the development of a robotics project1. The concept of network (BARABÁSI, 2014) will be used to understand the interactions and some elements of the Actor-Network Theory (LATOUR, 2012). During an activity in a robotics class, several actors, such as students, teachers, devices, tools, and space characteristics, build a network where each one has an active participation in disseminating knowledge. In this article, we will focus only on the role of the space actor in building this network.

Observations on educational activities were recorded in the field diary for further analysis. There was no contact between researchers and students during this educational activity. No students were identified.

The question we will focus on will be how the characteristics of the environment, its design, and the layout of the furniture, can construct the learning process, opening new paths, or creating barriers for the dissemination of knowledge in this network. In this study, the teacher based the activity on the fundamentals of Project-Based Learning (PbL), which was being used for teaching (BELL, 2010; DYM *et al*., 2005). Students were working on developing a project whose essence of work is collaboration.

THEORETICAL REFERENCE

The construction of the analysis we intend to carry out is part of the confluence of several theories and concepts that, together, provide a powerful framework for understanding the dynamics that occur in modern STEAM learning environments. Here, we will try to take a brief look at each of them, knowing that the focus will not be on each one separately, but on their junction.

The first foundation on which the investigation was based is the Actor-Network Theory, whose vision of work in new laboratories led us to the interactions formed by both human and non-human actors. These actors can be students and teachers, as well as devices, tools, software and even architecture. Both have the ability to interact by exchanging information and actively participating in the learning process.

Actor-Network Theory (ANT) was initially developed at the Center for Sociology of Innovation at the École des Mines de Paris (ParisTech). From the 1980s onwards, scholars from various countries began to base their studies on this theory to understand the role of social relations in science and technology projects. In Brazil, it is strongly identified with the work of Bruno Latour due to the translations of several of his books into Portuguese. But there are many other researchers like Michel Callon, John Law and Madelaine Akrich. In ART, not only humans are considered as “actors” of social relations. Many other elements, previously not considered by traditional sociology, came to play a preponderant role. In addition to humans, studies on project development began to consider the interactions between people, devices, tools, software, and other actors that can even be formed by other networks, such as research centers, equipment, and software manufacturers, as central, or business sectors (LATOUR, 1997; CALON, 1986; LAW, 2002; BIJKER, 1995). Each should be considered with the same level of importance when interactions are analyzed. Traditional studies have always considered only the interactions between human actors, giving the artifact a secondary role, as mediators between humans (LATOUR, 2012).

However, non-human actors can play a key role in these interactions. Since then, ART has become an important social theory that has expanded from scientific and technological laboratories to many other environments.

An artifact, previously considered only as a mediator in social relations, can change the structure of a community and become a relevant actor in social interactions. One of the examples used by Verbeek (2005) is the introduction of the microwave in North American homes. This artifact changed the eating habits of many cities and the structure of information exchange in communities. When it was released on the market, many people realized that they would find a new way to prepare food quickly. It is possible to prepare meals for the whole week at once, saving time, or even buying them ready-made in the market. However, it only allows you to prepare one meal at a time. It is almost impossible for a family to have a meal collectively, talking and exchanging ideas about their daily lives. This fact caused in the United States of America a break in the flow of information between families, who used to have dinner together and have conversations about how the day had been. More broadly, it impacted community life in neighborhoods by eliminating one of the important moments for exchanging information about the problems of these communities.

For ANT, human and non-human actors can come together to build hybrids as well. Humans do not fly. But it is possible to build a hybrid formed by an airplane + human. This hybrid can fly and has the power to change social interactions, creating possibilities for collaborative work for people from any country, anywhere in the world, or allowing the provision of global inputs for research and product development.

The knowledge network can be formed from several factors, from the relationship between students before the learning activity to the positioning of the benches chosen by students to sit (BRAGA; GUTTMANN, 2018). During activities in STEAM environments, students need to develop projects and create several interactions that involve the learning of knowledge and skills generating the development of competencies. This network can be composed of some human actors, non-human actors, and other networks that behave at that time as hybrid actors (CALON, 1986).

The first level of this network is formed only by human actors who work in the laboratory: the professor, all the students and sometimes a technician who keeps the laboratory usable. It is very common for the interaction between all these people to happen synchronously during the development of some activity. They can interact by asking each other something or watching something like assembling a kit. It is a face-to-face network and all interactions can be observed by researchers present in the laboratory or even recorded by a camera.

The second level involves interaction between students and devices, kits, or tools. From this interaction, a student-artifact hybrid emerges. Many students when they want to learn some assembly of an artifact they turn to Youtube, through a smartphone or computer. At that moment, the smartphone, which in some cases has the role of a non-human actor, assumes the role of mediator between two actors, the student, and the Youtube app. In a deeper analysis, it can be said that it is an asynchronous interaction between humans mediated by smartphone + Youtube. In modern STEAM laboratories, Youtube has played an important role as a repository of information. Students know this and use it a lot when they want to perform some operation they do not know about.

Thus, artifacts can take on different functions, either as actors or as mediators. But even in the mediation between humans, the artifact can be an actor if it shapes this interaction, depending on the possibilities it offers. For some, this mediation could prove to be passive, but it has a preponderant role because it is not static and is evolving, and may have the capacity to shape the interaction itself.

There is also a third level of the network. If we think about the networks of researchers and developers of artifacts (processors, circuits, screens, etc.) and software that made this action possible, the network ends up being perceived as even more complex (LATOUR, 2012). This is what Calon (1986) calls the Actor-World. When studying the creation of the first electric car in France, called VEL, Calon realized that the simple union of the various actors involved is not enough for the emergence of a network. Életricité de France (EDF) invited several companies to jointly design and develop this car in the 70s of the 20th century. Renault would be in charge of the chassis, CGE (Compagnie Générale d'Életricité) of the batteries and EDF itself, project coordinator, of the energy supply system. Bringing together the expertise of leading companies in their markets would ensure the project's success. However, it soon became clear that it would not be that simple. Each company had its own knowledge, objectives and language, different from the others. Each of them constituted a network in themselves. The construction of a network that would allow the flow of information between these companies would require a translation between objectives and expertise. There was a need to create translation mechanisms. Calon called the translators spokesperson. In this case, the synergy did not happen. This is a perceived reality for a network of actors to really be able to integrate. The flight of a single plane is the result of the interaction of several networks, from the sale of tickets to a fuel supplier, being much larger than the airline itself.

A laboratory or STEAM environment is a convergence point (hub) between different networks. They are manufacturers of devices, software or even furniture that are in that environment. In each of these artifacts, there is a teaching concept. These conceptions do not always fit the pedagogical project that one wants to establish. Many applications offered to schools convey an idea of modernity because they are technological, but depart from a traditional educational vision, where the teacher presents the content and the students learn. They are poorly interactive or do not allow for collaboration. For networks to really work and for their mission to be fulfilled, it is necessary to create what became known as Collective Intelligence.

Collective Inteligence

Actions that connect multiple networks that are working or have worked with the same or a similar problem require meshing. Simple interaction does not guarantee that the objective will be achieved. In many cases, the translation between the networks defended by Callon (1986) is necessary, as each one of them may be seeing the problem in a different way. The electric car project united companies from different branches in the same project. If each one takes care of their part without understanding how the others are working, the experience will be a failure. When actions are brought together, what is known as collective intelligence is achieved. In this case, the whole is greater than the sum of the parts.

Levy (1999) believes that in collective intelligence, knowledge is spread among certain people and certain databases. Intelligence is a coordinated work function between people and between people and sources of knowledge. Therefore, people must have different ways of connecting and different sources of knowledge storage in easily accessible places. The great intellectual centers of antiquity such as Baghdad and Alexandria or Paris and Oxford in the Middle Ages produced a diverse network of thinkers, copyists, librarians, and large collections of parchments or books. Other networks, built throughout history, became even more complex. In the seventeenth-century, Holland saw a movement around an artifact, the lens, which involved philosophers (Descartes), physicists (Huygens), biologists (Leeuwenhoek), and artists (Vermeer), who exchanged ideas through letters (ALCÂNTARA *et al*., 2019). From it, works of art were produced with rich detail from the use of the darkroom, a scientific artifact. The telescope and the microscope were also perfected from this network, as well as philosophical currents that sought to understand the relationship between abstract knowledge and observation. These networks are studied today as a collective intelligence where humans and artifacts interacted through letters

Collective intelligence does not come naturally. It is essential to create a suitable environment where people can work together focusing on goals and sharing knowledge. Team members must have complementary skills and competencies and have a good interaction platform.

When teachers create teams for collaborative learning, it is not easy to predict what kind of collective intelligence will emerge from this activity. Collective intelligence may arise at different levels or not at all. Creating a suitable space in the STEAM environment is the platform for that creation, but what will happen from that point on cannot be predicted.

METHODOLOGY

The purpose of this research was to try to understand how the environment (non-human actor) interacted with the students and the teacher (human actors) while carrying on a STEAM project, shaping learning. Shaping means give it a form, facilitating or hindering the development of a collective intelligence.

Our investigation will be limited to the first two levels of the network, the interactions between humans and non-human actors, present in the furniture and architecture of the environment.

Students were free to create their own work process. They could form teams and choose their positions within the space. However, the space was previously defined by several characteristics, such as the position of the furniture, placed following the position of the teams' work benches, the teacher's desk, a blackboard and the existence of a central bench with many materials. The set of these elements formed part of the non-human actors that would format the network.

Students were able to build ways of exchanging knowledge during the development of the project, interacting with each other and with the elements of the environment according to the project's needs. In general terms, in the design language, we wanted to understand the user experience (UX) to design future configurations for STEAM environments.

The students were in the 9th grade of Elementary School in a public school, beginners in robotics. The activities were introductory, learning basic both coding and assembling artifacts. They performed different activities for each class. The goal was to introduce them to working with robotics, making them interact with the tools and parts through an introductory project. The professor proposed a closed project in which they were challenged to build a small car, programming it to complete an entire lap on a circuit. The project started with a classroom lecture on the basic elements of the project. There were 21 students at first.

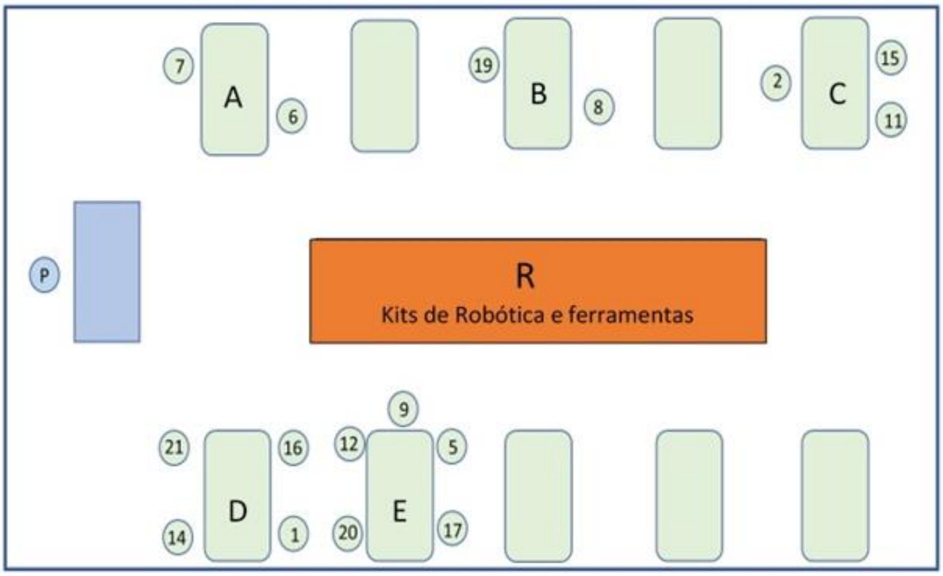
The researchers did not interfere in the educational process, using only observation and notes in a field diary. Each student was identified by a number (1 to 21), which was noted in the field diary on the day of the project presentation. After the initial presentation, only 16 students continued to participate in the workshop. Thus, the numbering established initially was maintained.

Students could freely choose their team with a maximum of 5 participants. However, 5 teams were created, being only one with 5 participants (Team E), one with 4 (Team D), one with 3 (Team C) and two with 2 participants (Team A and B). These teams were created based on empathy and prior knowledge. The teacher did not impose the need for each team to have 5 participants, nor for students to form groups with new colleagues. They freely chose their colleagues.

They had clear instructions for starting the process, but not to close it. There was a need to seek for information in the information sources.

Students entered the laboratory and chose their positions on the benches according to their preferences (Figure 1). The teacher did not indicate any positions.

Figure 1 – Initial lab setup



Source: Authors (2020).

The laboratory had a traditional work bench setup. In order to gain more space in the environment and to be able to count on nearby power outlets, the benches were placed against the wall (one face). Students were expected to sit around the other 3 sides of each bench. This expectation was confirmed.

The most important difference between the traditional setup and the ones we set up was the introduction of a central workbench. This bench had an important role in the development of the project. It was the focal point of all activities. All robotics tools and kits remained on this central bench. Therefore, students should leave the team bench and walk to the central bench to retrieve the materials needed for the work. At that time, we hoped that students could exchange information with colleagues from other teams and see the other projects that were being developed. In terms of knowledge management studies, the central bench played the role of an informal meeting place, where people can meet, talk about their problems. In terms of social networks, the central bench can be understood as a HUB, a connection point between all human and non-human actors. Therefore, it is a place designed to facilitate the emergence of collective intelligence. When people can exchange ideas and information, they improve their ability to understand problems by sharing views, and then new solutions can emerge.

In this article, we will not analyze all possible interactions between human and non-human actors. We will only consider the relations between students (human actors) and elements of space such as furniture (benches, chairs, blackboard) and architecture. In this sense, the entire central bench can be considered as a single non-human actor, independent of the objects that are on it. Although most of the encounters between human and non-human actors (hybrids) took place in this location, the work of the hybrids took place on the team benches. They will deserve special attention another time.

The researchers observed the entire activity and noted the students initial positions, displacements between the furniture, and their interactions with the central bench. From there, a spreadsheet was created. These data were entered into the Gephi software, which generated the interaction map.

In this article, we will not dwell on the number of interactions between two actors. We intend to create a map trying to identify the interaction paths in the environment. Comparing the laboratory with a city, we want to create a streets and highways map based on the information flow observation.

RESULTS AND ANALYSIS

The first observation made was about the position chosen by the students to organize their work. In the laboratory there were 10 benches with 40 positions. The teams had a total of only 16 students to fill these places. However, 11 students chose to sit on the benches next to the teacher. Only 5 students filled the benches farthest from the teacher's desk. Although in this type of environment nothing is static, from the position of the teacher who circulates between the benches and the students, who can also circulate throughout the space without restrictions, when entering the laboratory, the image of the classroom is still present. Two elements are fundamental for this recognition: the existence of a whiteboard and a larger table in front of it understood as “the teacher's desk”. These furniture elements are non-human actors who hierarchize and shape the space's dynamics.

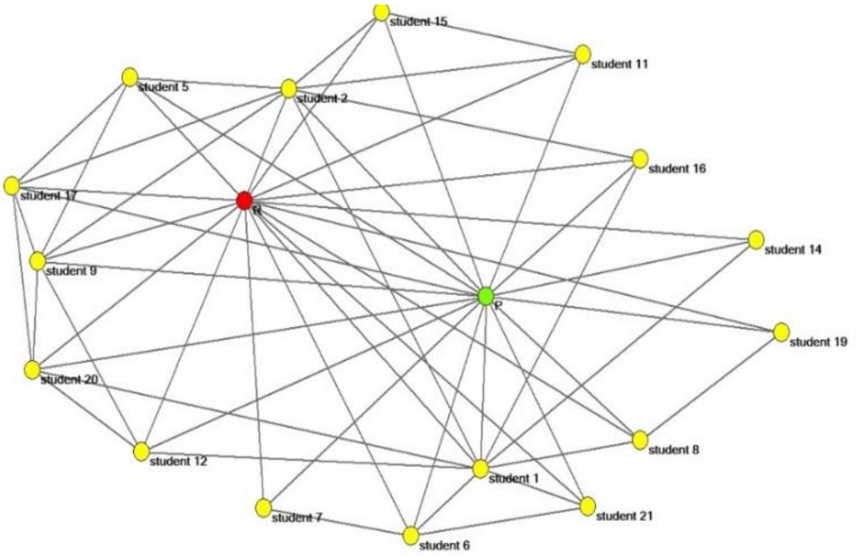
Today there are infinite sources of information beyond the teacher. But in the school game, they are the ones who hold the key to evaluation. Therefore, more than a source of information, the teachers have privileged information for being the ones who will produce the collection. So, almost instinctively, most students sit close to him.

Students, when working in a traditional laboratory, are isolated on their benches. Collaboration is allowed between colleagues on the same team. External shares can be understood as “cheat” between teams. The bench strategically placed in the center of the environment, with the materials that would be used in the activity, sought to break up this taboo. It required a constant commute from the team bench to the plant to pick up parts or tools. In some cases, it was necessary to move around the bench to find what you wanted. Braga and Guttmann (2019) argue that when there are meeting points in open learning environments, collaboration grows and there is greater interaction between all students, increasing the collective intelligence of the group. This movement would tend to induce the exchange of information and increase collaboration throughout the environment. In many cases, students take some material and do not return it to the central bench. This forces others to go from bench to bench looking for what they need.

The network topology, established in the laboratory during the activity, was composed of 18 actors. There were 17 human actors, 16 students and the teacher(P). In this first approach, we considered only 1 non-human actor, the R workbench.

The first topology extracted from the activity lasted 10 minutes at the beginning of the activity. The ideal interaction condition for the construction of a collective intelligence should be a set of interactions involving all actors, that is, each actor should interact with the other 17 actors. However, this did not happen. All interactions have not been completed.

Figure 2 – Interaction map between the studentss (student), teacher (P) and central bench (R)



Source: Authors (2020).

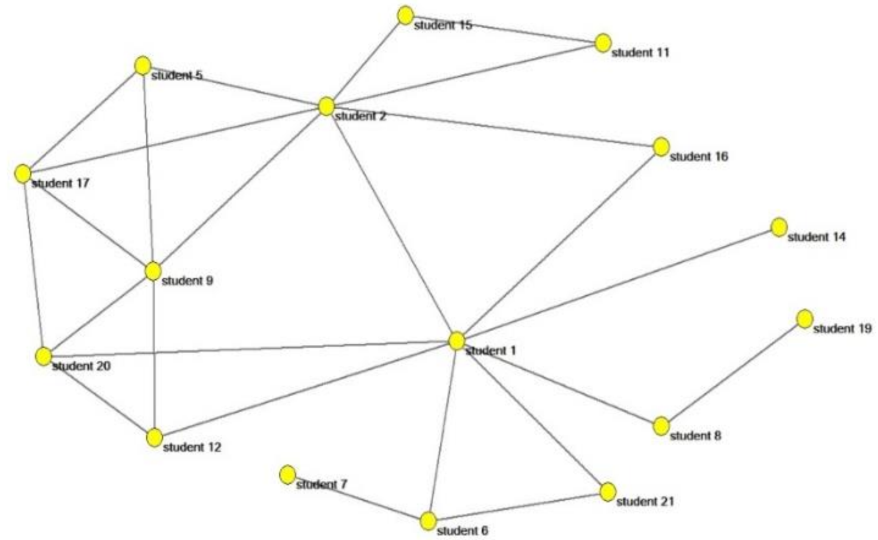
In network theory, there is a calculation for this condition, called Clustering Coefficient (CC). CC is the relationship between real interactions (RTI), that means the interactions that actually existed, and the total possible interactions (TPI) (BARABASI, 2014).

Data collected on the network indicate that only 35.8% of possible interactions happened. This number would be a good CC for a network with many actors. But for a network with few actors it is considered to have low interaction.

The situation can be considered more critical if the teacher and the bench are excluded from the network (Figure 3). The CC drops from 35.8% to 20%, showing that the teacher and the central bench have enormous power to connect to the network. During a traditional class, the teacher speaks to all students. Therefore, the information is generated globally, but we do not know if it is received by everyone, as some may be distracted. In laboratory activities, it tends to convey information to students individually or to groups of students. But still, it is a source of reception of problems and guidance of solutions through the transmission of information. In both cases, collective intelligence is not formed or is formed in a precarious way.

Actually, the human actors of a knowledge network tend to form different groups (Clusters), which can be on the same bench or be from different benches. If each of these clusters is connected to others, there is a huge possibility that information will circulate. Therefore, the network can be formed from smaller groupings, as long as they are interconnected.

Figure 3 – Network formed by the students (not considering the interactions with the teacher and the central bench)



Source: Authors (2020).

DATA ANALYSIS

Following, we analyze the network from three structural aspects.

Hub

Hubs are fundamental elements used in the management of different types of networks. The networks formed by airlines in international traffic are an example of this. Each company has its own network in its country. There is only one national hub connected to the main hubs in other countries so that anyone from a small town in country A can reach another small town in country B. Hubs allow you to optimize this traffic. In studies on hubs, researchers noticed that information to circulate throughout the network does not require each element of the network to be connected to the others (high CC clustering index). It is enough that there are connected hubs and that the information is inserted in one of them so that it can reach all the actors in the network (BARABASI, 2014).

STEAM environments produce networks with similar characteristics. All it takes is for a student-hub to connect two clusters for knowledge to spread across both. Therefore, we must identify the hubs in the laboratory's network. A hub should have some external connections and be fully connected to its own teammates. He is the one who looks for information in the external environment and takes it inside the group. At the same time, it has the ability to take part of the knowledge developed in the team, spreading it to others.

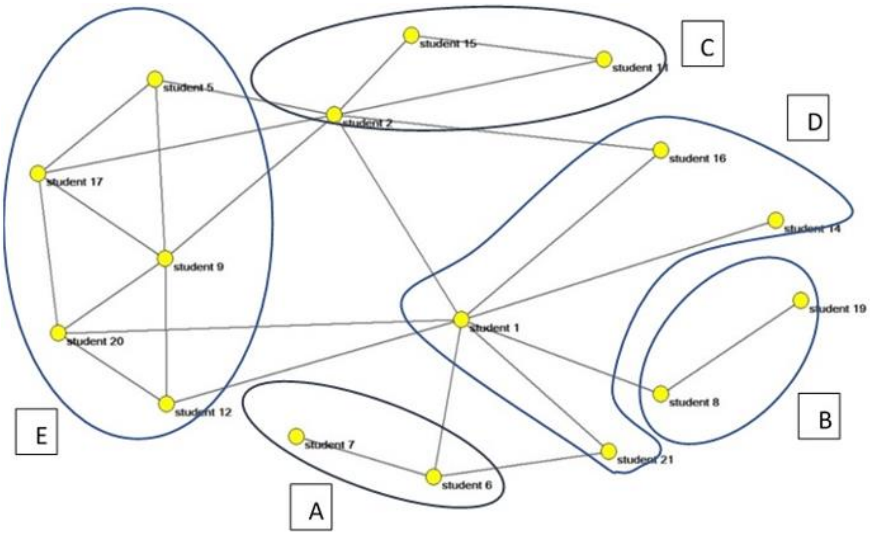
In the network of this activity, you can identify students 1, 2 and 9 with more internal and external links.

Student 9 had connections with five colleagues (5, 17, 20, 12 and 2). Four of them were in the team itself (E) and student 2 was on the other side of the laboratory in team C.

Student 2 kept interaction with six colleagues (1, 5, 9, 11, 15 and 17). Two of them were from team C itself and four from outside. Therefore, this student had a more important set of external interactions than student 9, feeding the work of his entire team.

Student 1 was the best in terms of connections, keeping them with eight colleagues (2, 6, 8, 12, 14, 16, 20, 21), being three on the team and five external. There are students in these connections on all teams. We can conclude that this student was the great Hub of the entire network in this activity. There was the fact that student 1 was in the center of the most important grouping in the laboratory, formed by 9 students from teams D and E. However, he had the necessary movement to maintain interactions with all the other teams.

Figure 4 – Interaction between teams via student 1 (main hub)



Source: Authors (2020).

Student 1's clustering coefficient (CC) was CC = 0.53, which means he had connections with more than half of the students in the lab. Even students who remained with a greater degree of isolation, such as 7, 14 and 19, had some connection with student 1, directly or indirectly. Student 14 was directly linked because he worked on the same team. Student 7 through the intermediation of student 6, and student 19 was linked through student 8.

Hubs are critical to creating collective intelligence. Even though there are no direct connections between all students, it can occur through student hubs. They act as connectors and make knowledge spread across the entire network.

Isolation

The first observation is that all students interacted with the teacher and with the central bench (Figure 1). However, when the network is observed without the teacher and the central bench, we can conclude that the development of teamwork projects can induce students to work only within their teams. The extreme case was that students 7, 14 and 19 were left out of the interaction between the other students. Many hypotheses can be proposed.

The first hypothesis comes from a characteristic of all collaborative projects. We can often find people who take on the role of team leaders and become group spokespersons. For convenience or laziness, students 7, 14 and 19 could have transferred responsibility for the interaction to their team leaders. The observation developed by the researchers in the field indicated that this was a good answer, but not the only possible one.

The second hypothesis is the position of these students in the laboratory. They were at points in the lab that didn't allow for great movement or easy interaction with other colleagues. Students ages 7 and 19 worked in small teams with 2 students. They could transfer group leadership to students 6 and 8, but they were in distant positions from other peers. Student 14 was in the same position as student 7, on the other side of the class; but this student had too many teammates on the bench for interaction and was isolated. Clearly, this student transferred the lead to number 1. However, the case of students 7 and 9 is different and could be solved by another lab setup.

The only exception in terms of interaction of these students is with the teacher, something natural since they were participating in the orientation given by him, and in the central bench.

The role of the central bench

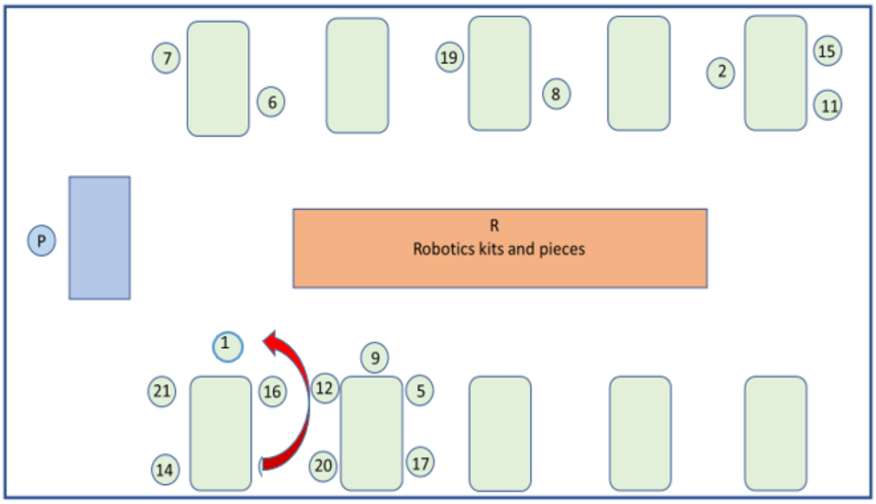
The central bench played a key role because it was a natural hub. She characterized herself as the most important non-human actor. In Figure 1, it is possible to see that all students were there for some time. Most interactions took place around it. Therefore, it was the laboratory's most important hub.

The difference between the teacher and the central bench was the fact that most of the teacher's interaction with the students was a one-way interaction. Much information was transmitted from the students to the teacher and part of it was returned to the students through him. However, the role of the bench was the meeting point for direct interaction between students. Some of them just looked at the tools and robotic kits and parts, but others were able to exchange information about their designs.

Students 1 and 2 started the project in locations far from the laboratory. Student 1 was closed in on his position, but he had socio-emotional skills, such as leadership, that propelled him out of his environmental isolation. So he changed his position at his team's bench and started walking around the lab. His meeting with his colleagues took place around the central bench.

If student 1 remained in his first position, several connections would disappear during the activity, drastically decreasing the CC. Therefore, the change in position was the key factor in improving collective intelligence in the laboratory.

Figure 5 – Student 1 change after the start of activities



Source: Authors (2020).

Student 1 had greater interaction than student 15. It can be seen that the second was closed between walls and student 11. Other closed students (20 and 17) remained in their benches, but had bigger teams.

Table 1 – Cluster coefficient (CC) for some students

Student	Cluster Coefficient (CC)
1	0.53
15	0.13
17	0.26
20	0.26

Source: Authors (2020).

The clustering coefficient, by itself, may not reveal nuances of the activity dynamics that the laboratory architecture reveals. Students 17 and 20 had the same clustering coefficient. They belonged to the same team and had links with three students from the team itself, one of which was between themselves. They also had interactions with 1 student from an external team. But student 20 (team E) was in a position close to student 1 (team D) at the beginning of the activity. The interaction took place at that moment, in the closed space they were in and before student 1 started to move. Student 17 (team E), on the other hand, had to walk to the central bench to find student 2 (team C), who belonged to a team located on the opposite side of the room. It was a different interaction from an architectural point of view.

On the other hand, student 19 remained isolated, despite not having been spatially blocked. This case was different because it was a refusal to participate. Choosing to use a distant workbench was part of the problem. The chosen bench had two other sides that isolated this student from his mates.

There is a direct relationship between the architecture of STEAM environments and the building of collective intelligence. The pedagogical project of the activity in an environment focused on STEAM education must be considered in the laboratory's architecture. Several elements are important in this relationship.

CONCLUSIONS

Building a collective intelligence must be an open process in all dimensions. First, students must be open to exchange, in a psychosocial relationship with their peers. The feeling of belonging to a team is an important construction to enhance collective intelligence. However, if all paths are not open for them to meet with their peers, the maximum levels of collective intelligence cannot be reached. For this reason, the architecture factor is an important element to be considered.

The architecture factor is closely related to the type of furniture used in the laboratory. The role of the furniture must be clear in terms of its functionality and distribution within the space. The creation of the central bench in the laboratory and the positioning of almost all the tools and parts to be used in the work was of fundamental importance. In STEAM environments it is very important to create meeting points for students to exchange information (Hubs), even when outside, such as relaxation zones or coffee machines when students are university-level students. These meeting points play an extremely important role in providing opportunities for the exchange of ideas or for generic conversations that enhance the team's integration, a key element in the construction of collective intelligence. The center bench played that role, almost forcing students to leave their workstations and walk downtown to pick up tools or parts for their project. In this short walk, they were able to open up exchange possibilities, whether looking at the other benches or talking to colleagues. It was important not to put all the tools and materials on each team's workstation. All students remained around the central bench at some point. Even if this moment failed to produce any interaction for any reason, as our data showed, it is important to create this possibility. Hubs are fundamental in the creation of collective intelligence, they are the ones that allow for greater collaboration because they connect actors, becoming bridges through which knowledge flows.

The second is about the position of workstations in the space. In the case presented in this research, a traditional laboratory setup was used, with benches against the wall. This is a situation that exists in most laboratories because it allows easy access to electrical power outlets and the internet, placed on the walls. If it is not possible to create a configuration where these points reach from above, through ducts that descend on the bench, or from below, through a slightly suspended floor, the solution would be to work with a smaller team, with three students, one for each face of the bench. In the case of the laboratory used in this research, the professor had five empty benches. These benches could be removed temporarily, or teams could be distributed across all benches with 3 students each.

The analysis applied to STEAM environments presented in this work does not exhaust the theme. We could use it for other non-human actors who serve as a source of knowledge or simply as pollinators, as they induce the movement of students throughout the environment, allowing them to interact more with colleagues and artifacts (BRAGA; GUTTMANN, 2019). In the opposite sense of a virus, in search of isolation to prevent its dissemination, knowledge needs agglomerations (clusters) and spaces that allow for exchange, collaboration and the creation of collective intelligence.

A CONSTRUÇÃO DE REDES DE CONHECIMENTO EM LABORATÓRIOS DIDÁTICOS STEAM

RESUMO

Os laboratórios STEAM (Ciência, Tecnologia, Engenharia, Artes e Matemática) são ambientes de aprendizagem práticos e interdisciplinares. Quando os alunos estão trabalhando nesses laboratórios, o aprendizado é construído por meio de vários fluxos de informações que se espalham por todo o ambiente. Sempre há uma grande colaboração entre alunos, professores e entre eles e dispositivos, kits e ferramentas. Para entender o processo de construção dessa rede de conhecimentos, foi elaborada uma metodologia de mapeamento dos fluxos de informação. Os mapas podem fornecer informações importantes para a gestão do conhecimento nesses ambientes. Nosso objetivo foi estudar como o espaço molda os fluxos de conhecimento e como os alunos podem redesenhar esses fluxos de acordo com as necessidades do projeto. O professor apresentou um projeto fechado sobre robótica para 16 alunos. Os pesquisadores utilizaram uma metodologia etnográfica, observando os alunos no ambiente e anotando suas observações em um caderno de campo. Esses dados foram inseridos em um software, que gerou o mapa de interação. A análise da rede apontou 3 elementos que devem ser destacados: (a) isolamento, (b) hubs e, (c) o papel do banco central. Cada um estava relacionado a uma característica do espaço que contribuía para a dinâmica da troca de informações no ambiente.

PALAVRAS-CHAVE: Laboratórios Educacionais. Aprendizagem Baseada em Projetos. STEAM. Robótica Educacional. Espaços Maker. Teoria Ator-Rede.

NOTES

1 This work was supported by CNPq and CAPES.

2 As there was no visual or nominal identification of the students, and the research was carried out through observation of an educational practice without a digital record or contact between researchers and students, we considered by article 1, sole paragraph, item VII of Resolution 510 of 07-04- 2016 of the National Health Council it is not necessary to request approval in the Ethics Committee system.

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