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JuxtaLearn Taxonomy: A Tool to Help Teachers to Identify and Understand the Causes of Student Misunderstandings

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ABSTRACT

Threshold concepts are key concepts, often troublesome and complex, that are vital to understanding a subject. Once understood, threshold concepts have been described as akin to a portal, opening up new and previously inaccessible way of thinking about the subject. This paper presents an exploratory study that explored the use of a digital tool entitled 'Juxta Learn taxonomy'. This tool was designed to support teachers in identifying threshold concepts their students have problems in overcoming and for what reason they have problems understanding these concepts. We interviewed math and physical chemistry teachers, and based on 'JuxtaLearntaxonomy' these teachers identified threshold concepts grounded on pedagogical practice, and the reason for their students have problems understanding these concepts. Results show that the taxonomy helped the teachers to identify threshold concepts and to break them down into smaller stumbling blocks illustrated by examples of student problems. So, we conclude that the tool allows teachers to reflect on the causes of these student misunderstandings and to think about appropriate pedagogical strategies to help the students overcome them.

Keywords: *threshold concepts, taxonomy, technology-enhanced learning, misconceptions.*

INTRODUCTION

Threshold Concepts are concepts that students have difficulty in understanding, so, sometimes the students take refuge in the memorization of these concepts without really understanding them (Meyer & Land, 2003; 2006). The misunderstandings presented by students in threshold concepts can cause students to fail. Also, sometimes students believe to understand the concept, but when proposed to them a task that demands knowledge of higher order (that involves for example to relate this concept), students fail and can give up a topic altogether.

This paper presents a study that explored the use of a tool entitled 'JuxtaLearn taxonomy' designed to support teachers in identifying threshold concepts in their students and for what reason have problems understanding these concepts. With the help of 'JuxtaLearn taxonomy' teachers identify, from their pedagogical experience with students, stumbling blocks (Clouth & Adams, 2013) for each threshold concept.

The aim of our exploratory study was to:

(i) apply the 'JuxtaLearn taxonomy' to math and physical chemistrythreshold concepts and, by doing that, teachers can acquire a deeper understanding of the problems that students encounter when working with these concepts;

(ii) Identify examples of threshold concepts in math and physical chemistry.

In section 2, we present a framing for threshold concepts and we introduce the 'JuxtaLearn taxonomy'. In section 3 we present the methods of the data collection process. On section 4, we present the content analysis of the interviews and the main results and considerations. In section 5, we conclude with a synthesis and some proposals for future work.

BACKGROUND

The threshold concept

In all subjects, there are some concepts that once they are known, become similar to passing through a portal, allowing the student to enter new conceptual territory in which things formerly not perceived are now brought into view (Land & Rattray, 2017). Meyer (2003) defined threshold concept as a barrier that, once surpassed, opens a new and previously inaccessible way of thinking about something, a transformed form of knowledge. They are said to be more than just key concepts (Harlow et al., 2011; Lucas and Mladenovic, 2007). Threshold concept represents a transformed way of understanding, a way interpreting something, or viewing something without which the student don't can to get continue your learning process (Meyer and Land, 2006). The learning thresholds are often the aspects where students have difficulty. It works as if it is a transforming space, which can open the way to a new area of knowledge, but which can also act as something that limits the construction of new knowledge if it is not solved (Land & Rattray, 2017).

The work done around threshold concepts can have a transformative influence on the development of student learning (Kinchin, 2010). When a student get understand a concept, the transformation in understanding involves the comprehension of a new concept, and its integration in set of existing concepts in a knowledge base to reconfigure the relations of already existing ideas. The successful integration of a concept results in the mental frame reformulation on the students (Land & Rat-tray, 2017). According to Meyer and Land (2003), a concept is likely to be a threshold if it has one or more of the following criteria:

- Transformative – once understood, it potentially causes a significant shift in the perception of a subject (or part thereof); sometimes it may even transform one's personal identity
- Irreversible – it is unlikely that a threshold concept is forgotten or unlearned once acquired due to transformation
- Integrative – a threshold concept is able to expose "the previously hidden interrelateness of something"
- Bounded – a threshold concept can have borders with other threshold concept which help to define disciplinary areas
- Troublesome – they may be counterintuitive (common sense understanding vs. Expert understanding)

The Juxta Learn taxonomy

The process of identifying threshold concepts can make experts to reflection specific areas in a different way with the ultimate goal of improving learning students and teaching particularly (Green, Loertscher, Minderhoutb & Lewisc, 2017).Adams and Clough (2015) created 'Juxta Learn taxonomy' and presented a tool that allows the identification and deconstruction of difficulties usually found in students. Through examples of the problems usually identified, teachers reflection the difficulties of their students, which gives teachers confidence to act, guiding them helping students overcoming these difficulties. The identification of threshold concepts allows focusing on deeper students learning (Meyer & Land, 2005).

In the 'Juxta Learn taxonomy', by identifying the concept, the concept can be decomposed into stumbling blocks (simpler concepts, related to the previous concept), using examples from practice to illustrate the sort of problems students have. This tool helps teachers to grasp not only comprehension problems presented by their students (Cruz, Lencastre & Coutinho, 20018).

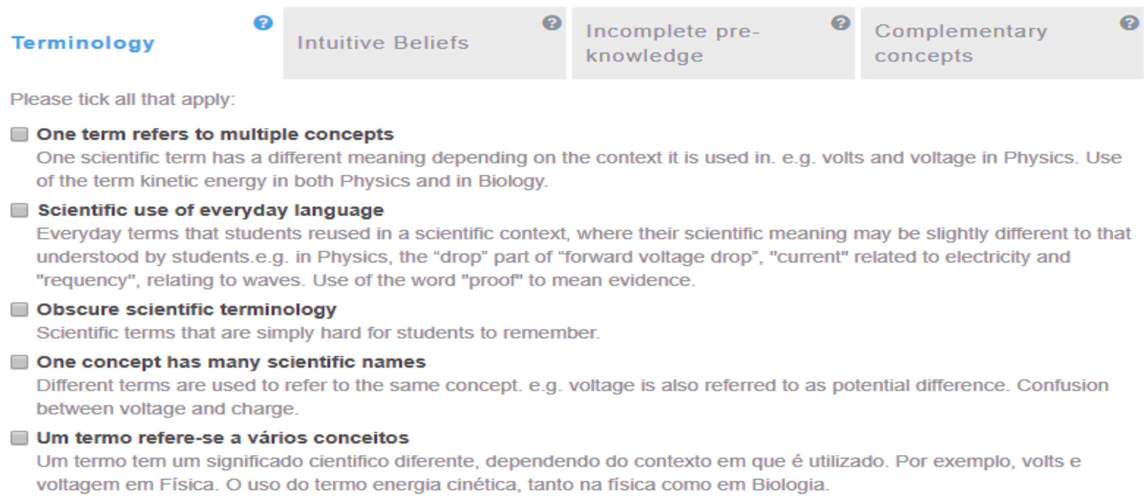

Figure 1: *The digital version of the 'Juxta Learn taxonomy'*

The digital version of the 'JuxtaLearn taxonomy' is divided into four reasons on students that do not understand the threshold concept. These reasons can be classified as:

terminology, incomplete pre-knowledge, essential concepts and intuitive beliefs; described below.

- The category – terminology - refers one term that often means different things in different contexts. This category is divided into three sub-categories in 'JuxtaLearn taxonomy':
  - (i) One term refers to multiple concepts, to occur when one scientific term has a different meaning depending on the context it is used in;
  - (ii) One concept has many scientific names, to occur when different terms are used to refer to the same concept; and
  - (iii) Scientific use of everyday language, occur when everyday terms are used in a scientific context.
- The category - incomplete pre-knowledge - refers previous understandings that need to be unlearned or modified. This category is divided into two sub-categories:
  - (i) Understanding of scientific method, process and practice (refers a simplistic understanding that may need to be unlearned or revised),
  - (ii) Underpinning understandings, refers an understanding or ability that the student is expected to have already but doesn't seem he has acquired it.
- The category - essential concepts - refers the key assumptions and knowledge that relate with concept, without which it is impossible for student to understand it. In 'JuxtaLearn taxonomy', these category are divided into only two sub-categories:
  - (i) Underpinning concepts, refers a knowledge that is required in order for student to understand the stumbling blocks related with threshold concept; and
  - (ii) Complementary concepts, refers to complementary knowledge that the student needs to learn, it is a concept related with the stumbling blocks that alongside it.
- The category - intuitive beliefs - refers informal, intuitive ways of thinking about the world that students have, normally strongly biased toward causal explanations. In 'Juxta Learn taxonomy', this category is divided into three sub categories:
  - (i) Weak human-like or world-like analogy, occur when student see scientific concepts in terms of everyday use that may be wrong;
  - (ii) key characteristic conveys group membership, refers one unobservable feature that involve the belief that if one condition is fulfilled for something, it is automatically a member of a group, and
  - (iii) Flawed causal reasoning, that involves a belief of the student based on the assumption of something that may be wrong.

METHOD

Data collection involved interviews with two teachers from a secondary school in the north of Portugal. The first teacher (T1) is male, in his forties and teaches chemistry. The other teacher (T2) is female, in his fifties and teaches mathematic. Both teachers dedicated themselves to teaching for their entire working career.

The aim of the these research activities was to:

- Apply the 'JuxtaLearn taxonomy' to math and physical chemistry threshold concepts, and so teachers were able to acquire a deeper understanding of the problems that students encounter when working with these concepts;
- Identify exemplars of threshold concepts in math and physical chemistry.

Data was collected through structured interviews (20 minutes each) with the support of the 'JuxtaLearn taxonomy' and Think Aloud protocol (Van et al., 1994). During the interviews, we used a digital version of 'JuxtaLearn taxonomy' as a method to promote teachers' thinking. Based on their teaching practice they identified the threshold concepts and their Stumbling Blocks that are problematic for their students. During the interviews, paper versions of the 'JuxtaLearn taxonomy' were filled. The questions asked during the interviews were based upon the reflection on the threshold concepts and their Stumbling Blocks identified by the teachers. So, the questions were based on the following categories of the Taxonomy: incomplete pre-knowledge, essential concepts, Terminology, and intuitive beliefs. The interviews were transcribed and subjected to content analysis (Bardin, 1977). In this paper the chemistry teacher's answers were marked with the label "T1". The ones belonging to the mathematic teacher as "T2". Based on the data collected and the theoretical frameworks, we made a content analysis, which we will present in section 4.

Using the 'JuxtaLearn Taxonomy' as a Reflection Tool

In this topic we present

(i) The threshold concept,

(ii) The reason why it is a barrier for the student, and

(iii) The way teacher can help the student overcoming that obstacle.

Early in the interview with the chemistry teacher, we presented the 'JuxtaLearn taxonomy' in a paper printed format. During the interview we made direct questions to guide the filling of the taxonomy's with the stumbling blocks identified by the teacher. Initially the taxonomy appearance seemed to inhibit the teacher, but then we showed him a concrete example of how a stumbling block can influence the understanding of a threshold concept, and the way we wanted to fill the Taxonomy. After that, we noticed the teacher was getting more involved in the process.

This teacher identified the concept "mole" as a threshold concept, explaining it as follows: "*The student cannot disregard the very large, even huge numbers, to comprehend, for example, the Mole concept in Chemistry*" (T1). According to Gray and Tall (2007) when the student is unable to understand relevant issues for the production of his own knowledge, and just learn the essential for the realization of a specific task procedure, his brain has no structures of thought to process the concept. In this case, the student normally chooses to memorize the content. The process of abstraction is the key for developing an increasingly powerful thought. At this level, National Council of Teachers of Mathematics (NCTM, 2008) states that learning mathematical concepts requires the capacity to understand, develop and implement procedures, concepts and processes.

In order to overcome the difficulty detected in his students in understanding the threshold concept 'mole', this teacher usually uses examples with values closer to the students' reality. The teacher admits that students fail to understand the concept, but he cannot explain exactly why. After some reflection, using the 'JuxtaLearn taxonomy', this teacher has identified, as a possible cause some previously not acquired mathematical knowledge. In his own words:

> "*I usually give them the following example: you do not have to worry… a dozen is twelve. Here is Mole and represents a huge number. Twelve is one thing we can visualize, but not 6×10^{23}… The scientific notation is a prerequisite here. If they reveal difficulties at mathematical level it create us problems in Chemistry*. "(T1).

The use of a calculator and computer enables to support working with simulated situations or verification of conjectures and alternatives to a given situation (Martins, Maia, Menino, Rocha, & Pires, 2002). In order to overcome the difficulty in teaching the Threshold Concept Derivative, which is a barrier because students fail to graphically visualize it, the Mathematics teacher uses the calculator and PowerPoint materials that make available to students through the school's webpage: "*I started many years ago working with PowerPoint resources, and I have lots of work done. These are the features I use in the class, and they are in the school webpage* "(T2). The fact that students can "*check it and see all this features again at home*" (T2) is seen as an important support to student's work.

Incomplete Pre-knowledge

Shulman (1986) emphasizes the need to establish a connection between the teacher's knowledge of the content he is trying to teach, his pedagogical practice, and the different ways of learning that content. The teacher recognizes that in order to understand the threshold concept 'mole', students need previous knowledge. When the teacher detects problems in understanding the concept, for example lack of mathematical background, the teacher chooses to draw students' attention to this situation through concrete examples. The difficulty in using the «Exponent» in the use of moles, in achieving reductions in the context of the discipline of chemistry, and motivation for learning, are possible causes for students to misunderstand the threshold concept 'mole'. The chemistry teacher associated the obstacles in understanding the threshold concept mole as a psychological block that prevents the student to progress:

> "*My believe as a teacher is that this creates psychological barriers to the student, and then he thinks he is not able to understand the concept, and does not even try it. And we have to work on a psychological level, because there are*

> *many students who give up easily. So there's a mental block in which the student simply says: I do not understand, then I'll just give up!"* (T1)

The acquisition of concepts occurs through student reflection about what is presented to him. The math teacher states that "*the student has difficulty in recognizing the Threshold Concept, and therefore he does not apply it. As simple as that!*" (T2). The difficulty in the study of 'derivatives' results from the difficulty in using letters to symbolize 'variables', and also the diversity of interpretations (or graphical representations) of a function (Saraiva, Teixeira, and Andrade, 2010). This is considered as Incomplete Pre-knowledge of the notion of 'variable', necessary to realize the concept of 'derivative'.

Essential Concepts

According to Arends (2015) learning a concept is more than just the classification of objects, categorizing something, memorizing labels or a determined vocabulary. For this author, learning concepts implies a process of construction of knowledge and the organization of information into broad cognitive structures. The failure to comprehend a concept that is essential to **underpin** or support a threshold concept, is seen by the teacher as a factor that promotes the student demotivation for the discipline, his willingness to learn and to overcome his difficulties:

> "*They do not understand, and they let go. They demotivate themselves. When they realize that they do not understand a lot of things, and much time has passed since then, the questions are many and they are too embarrassed to ask for help. We ask the student: What questions do you have? He responds: all! Then there are some students with more courage and they say that is all… that is everything, that they don't understand anything at all. And I think what can I do?"* (T1)

The lack of essential concepts such as "the basics functions in mathematics" can limit the understanding of other concepts such as "derivative". The math teacher said that students "*have to know the minimum to realize what we are working with marks*"(T2). When asked if the knowledge of threshold concept 'mole' requires the understanding of essential concepts to support the teaching of chemistry, the teacher hesitated for a while and replied:

> *"Only if it is about the concept of «Quantity». Because the example I give when starting the Mole concept «how much is a dozen». The Threshold Concept Mole has to do with «Quantity». What I tell them is that 12 eggs are a dozen eggs. If it were a Mole of eggs it would be a huge amount of eggs, such as $6x10^{23}$. And sometimes I tell them that is $6 \times 10 \times 10 \times 10 \times 10 \times 10$ ... And then I say: I will not draw here twenty six zeros, please (!), but for them to realize that is a huge amount. Sometimes they are... but then they stay... it seems that not even realize that there's such number."* (T1)".

The chemistry teacher recognized that the difficulty of the threshold concept mole can arise from **complementary** concepts which were related to the threshold concept 'mole', without which it is impossible to understand it:

> *"The Threshold Concept Mole entails knowing other concepts. Is like climbing a set of stairs. We have to introduce a lot of concepts that are essential, and the ones that are above need the ones that are in the bottom. The first steps are essential, and, at a certain time, they do not have strides and then they fail... it is very complicated"*(T1).

Terminology

The concepts have names, labels, and definitions that allow a mutual understanding. Names or labels also represent themselves a prerequisite for the teaching and learning processes. However, the fact that a student recognizes a name or a label of a concept does not mean that he understands the concept (Arends, 2015). Sometimes students have problems with the use of **language and scientific terms, and inconsistent and overlapping terminologies.** When asked if it would be possible that **the term 'mole' may refer to multiple concepts**, the chemistry teacher said: "*No! It is fixed. One 'mole' is an exact value*". (T1). The teacher admits that some difficulties may arise from the **use of scientific terms and terminologies associated with the concept**:

> "*Oddly, the students have many difficulties in dealing with numbers when making reductions. For example, simple things like moving from kilograms to grams or vice versa, sometimes causes them a lot of confusion because we use associations to that the scientific notation*

> *and then... seems that it spoils everything*"(T1)

However, according to this teacher, the term ‘mole’ cannot be used with **different scientific meaning**: "A *mole is a Mole. Like a dozen is twelve*." (T1).

Similarly, with regard to its use in **everyday language**, the Chemistry teacher states "*this mole concept is not something that you hear at home, almost certainly*" (T1). Nevertheless, the teacher admits that the threshold concept ‘mole’ can be used more than once in the student's curriculum, in subjects such biology and mathematics. The teacher admits that the lack of understanding the concept of ‘mole’ is also a barrier in these two subjects. And when asked if there is any additional knowledge about the threshold concept ‘mole’ that the student should have and that will help overcome this difficulty, the teacher hesitated and replied: "*Only if the question for them to realize what are quantities. (...) And know and distinguish quantities of different materials. Because this quantity… a dozen can be of eggs, potatoes or atoms”.* (T1)

Issues with the use of **language, scientific terms and terminologies** in different subjects are also one of the aspects mentioned by the mathematics teacher who said: "*students always use other terms and other terminologies for everything*" (T2). Stating that "*when it comes to «Derivatives» they are talking about «Speed», «Acceleration»*" (T2). Students “*represent these concepts in different ways”* (T2), and sometimes "*the terminologies are different as well*" (T2) depending on the subject in which they are included. For this teacher, the scientific concept of «derivative» can have different meanings, overhanging the context in which it is used. Also says "*none of these things should be taught in Physics without having been taught in Mathematics*" (T2). However, he assumes that it is exactly the opposite that usually occurs. For the comprehension of the threshold concept «derivative»," *can have multiple scientific names depending on the applications*" (T2), and the use of scientific terms can confuse the student.

Intuitive Beliefs

Questioned about the use of mathematical concepts in the student’s daily life, the mathematics teacher showed some hesitancy: “*outside of the school maybe not, but inside the school it should be a part of the student’s daily routine*" (T2). Similarly, the threshold concept ‘mole’ to the chemistry teacher is not commonly used in daily life. This teacher stated that the difficulty might be in the interpretation of the ‘mole’ value:

> "*Because it is a huge quantity, if they memorize it they know. If they don’t memorize it, because it is a tabulated value, it is a matter of going to the table and find what a Mole corresponds to… Then, they have to understand if that is what they are talking about.* "(T1)

The Mathematics teacher says that "*one of the problems we have in mathematics is that the students don’t realize its use in daily life*" (T2). The applicability of the concepts learned is seen as a way to motivate the student for a subject: "*if we could really tell the concrete use of the concepts, it could motivate some students*" (T2). Performing tasks with an exploratory dimension takes a reflective character in classroom work, which can lead to more meaningful experiences for students. Additionally, this type of investigative tasks fosters a greater reliance on work undertaken and consequently a greater emotional involvement by the students, which have positive consequences on the process of learning mathematics (Martins et al., 2002).

Students have different ways of processing the information they receive. So, it is important that teachers are aware of it and adapt their teaching methods (Arends, 2015). The fact that the student is not familiarized to deal with very large quantities; **the threshold concept ‘mole’ presents a weak analogy with the student’s daily life**, which causes difficulties. A kind of difficulty that the teacher does not comprehend:

> "*It is hard for me to realize that they do not understand, and how they have trouble understanding something that in practice is very simple, because it is a tabulated value. If a dozen is twelve, Mole is just a number that is huge, and nothing more. When you want to say that number, it is easier to say the name «Mole», than* $6{\times}10^{23}$"(T1)

This teacher is able to identify limitations in students thinking. He realizes that at a certain moment, students block on their own learning process, but has difficulty understanding exactly where the student’s problem is. This chemistry teacher is able to identify problems in understanding mathematical procedures in the construction of the threshold concept Mole, but then he experiences difficulty on identifying which stage of the mathematical process is being blocked on students. He starts by identifying the student's difficulty to use very big numbers, and the use of these values in the calculator. But only through a few directed questions he identifies the association between the number of zeros of a huge number, and the value the exponent of this written in scientific notation, and that might be the reason why some students are confused: "*Because they repeatedly make mistakes when counting, and dealing the decimal places ... I think that causes them some problems ... It is a huge number, it's complicated, it always aground there*" (T1).

Each person has a set of knowledge and mental schemes that uses daily and constantly adapt to its surroundings. Therefore, teaching concepts is a way to build ideas based upon knowledge and pre-existing mental schemes (Arends, 2015). When asked about the possibility of the difficulty in comprehending the threshold concept 'mole' can be related with **intuitive ways of the student to think the world around**, and sometimes students understand a part of the concept and not its whole, the T1, after some reflection, answers:

> "*It is a good question. I think there ... Well, I don't know in which point they collide with that concept. Perhaps it is the representation of the number that has no scientific notation, but a hundred, two hundred, a thousand, ten thousand, and then starts to get very huge numbers. And because the number is to big, it is represented as 1x10^{a}*"(T1).

When the difficulty is a result of the student's imperfect or casual reasoning, the chemistry teacher states that "as *the threshold concept mole is a fixed number, doesn't seem to be something like «now it's this… but later it can be something else»*" (T1). When we tried to make the chemistry teacher think about the causes that lead to a misunderstanding of the threshold concept 'mole' by the student, we realize that the teacher isn't able to place himself as a student:

> "*The problem for me is trying to put myself in student situation, and what I can remember as a student when learning that concept. The issue is that it is a very big number. It was easier to say: a dozen are twelve but a Mole is that strange number*" (T1).

Conclusion

This paper presents a study developed with 'JuxtaLerantaxonomy'. In this study, we interviewed teachers of math and physical chemistry of a secondary school in Portugal. Teachers identifying complex concepts, having as its starting point the own experience with students. Based on digital version of the 'JuxtaLearn taxonomy', teachers explained why students have problems understanding some concepts. Is an essential tool o helped the teachers to reflect on the stumbling blocks starting from similar examples already identified by other teachers (Cruz, Lencastre, Coutinho, Clough & Adams, 2016).

The four categories of analysis - incomplete pre-knowledge, essential concepts, terminology, and intuitive beliefs – designed in the 'JuxtaLearn taxonomy', served to guide the teachers reasoning in order to reflect upon the difficulties identified in the threshold concepts, and the stumbling block. The most mentioned categories in the interviews were the first two: incomplete pre-knowledge and essential concepts. We noticed through the interviewees' answers that the taxonomy helped the teachers reflect on themselves, the methodology adopted, and helped frame the stumbling block of a certain threshold concept that can help students overcoming difficulties. We also noticed that teachers were able to easily reflect on the difficulties of their students, it was easy for them to identify these difficulties. However, the teachers presented some difficulties in presenting the reasons for the students to have the difficulties in these concepts. These results are the same as those found in a study made by Santos, Silva, Andrade, and Lima (2013) conducted among 95 high school students, where the authors tried to identify the difficulties and motivation to learn chemistry. The students presented difficulties in learning due to lack of essential mathematical knowledge, the content complexity, the methodology adopted by teachers, attention deficit, and difficulties in comprehending statements. Also the Mathematics teacher identifies the incomplete previous knowledge that need to be improved to enable an understanding of the threshold concept derivative.

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