# Teaching and Learning STEM disciplines: a Process Perspective

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**ABSTRACT:** STEM disciplines (science, technology, engineering, mathematics), have the particular feature of being based on theoretical and practical skills. Learning in the laboratory naturally focuses on the student who must do or create something, alone or in a small group, while benefiting from the teacher's supervision to gain good practices. In this context, the project's status at the end of the session enables the students to assess the quality of their works themselves. During the project's development process, they face the resistance of the problem that requires a solution. They use their know-how, mobilize the knowledge acquired in all areas of life, and solicit the resources of their group to optimize cognitive resources. Discoveries during the process and the project's completion, together with the repetition of the exercises, provide intense pleasure and boost self-esteem. The next challenge is to transpose the dynamics from the laboratory to the hall. This challenge is reinforced by the emergence of a new generation of students, for whom interacting with the Internet and virtual agents is a natural part of their lives. In this perspective, Whitehead's thinking remains a resource that reminds us of what is essential in the educational process. It allows us to preserve this essential in today's societal change. We show that the educational process has two important dimensions. The first relates to a crucial event in the individuation process, namely, the advent of a phenomenon of synesthesia in the subject, in the form of an acute awareness of what is important to her or him. This event is a turning point in the student's life. The second relates to the methodology, which, in Whitehead's case, takes the form of the ternary rhythm of education. We illustrate these two dimensions in a biology teaching project we call inverted funnel. Inspired by Whiteheadian pedagogy, the project takes advantage of the dynamics of romance-precision-generalization, and we hope that it will contribute to the emergence of the turning point in the student. This event is the very starting point of the educational process, the one that leads to the very nature of the learner. Such watershed not only purports to determine the direction of her or his educational process, but also that of his or her entire life.
**Keywords**: Active learning, Biology, Cooperative pedagogy, Knowledge, STEM disciplines, Synesthesia, Whitehead

## INTRODUCTION

Today, students go to university more mentally immature than in the past, but no less intelligent. The habit of video games and the way to communicate via social networks are very visual activities that require reactivity and involve being in a state of permanent excitement. These activities have the advantage of providing immediate satisfaction. In contrast, the educational process developed at the university in STEM disciplines (science, technology, engineering, mathematics) may appear slow, laborious and boring to them. Immediate satisfaction does not follow such endeavor, since this is a long-term one. It requires sustained attention and even some sacrifices, such as reducing the time dedicated to entertainment for a somewhat austere activity, which sometimes amounts to suffering. Sometimes we think the first hour of teaching should/could be a yoga class or a similar activity in order to help the student return to a basic state, and regain the listening and attention skills needed for his studies. But this is hardly conceivable. In addition, this solution could appear as an old-fashioned perspective that seeks to condition students to pursue the traditional teacher-centered curriculum. Instead of this regression, bringing the world of the younger generation into the classroom, and taking the most of it to turn it into an active, participatory style of learning seems to be the most energetically favorable parade.

From this perspective, at least three approaches can be identified in the spirit of the times. The first is the arrival of the video game in the educational institution because of its positive impact on learning (ADKINS, 2017; ALEVEN et al., 2004: BACKLUND and HENDRIX, 2013; BOYLE et al., 2016; KE, 2011), an approach known as game-informed learning (BEGG et al., 2005). However, this tool must be adequately designed to enter into real-world classrooms. This entails the imminent role of the teacher, whose task is to integrate it efficiently into the curriculum (ZHONGXIU et al., 2019).

Game-based learning has the potential to be used by numerous STEM users simultaneously; however, it has to face another hurdle in its expansion of learning practice, which is to find a sustainable business model (MAYO, 2009). Some authors advise as a cultural and educational tool, the strengths and weaknesses of games must be taken into account, so that the game increases the education of science. In this case, they propose the « gamification » of particular elements of science education (MORRIS et al., 2013), that is, using game elements in their environments to enhance the user's experience (KAPP, 2012).

A second approach is to use the virtual pedagogical agent and intelligent tutoring systems (BELPAEME et al., 2018). Tablets and mobile devices are in every hand. Students can interact with a virtual environment via educational apps. Some researchers explore more advanced interaction from the tabletop to interactive robots (GIROTTO et al., 2016). These latters offer more advantages compared to virtual agents. Furthermore, they represent a step toward the personalization of curricula (BELPAEME et al., 2018).

A third approach comes from the hybridization of the neuroscience and the cognitive sciences. This paradigm is still in its infancy, but is likely to generate new models of learning. Science education will have to address these challenges.

The student-centered approach also requires developing research in the teaching of STEM disciplines. It involves rethinking the teacher's status and role within the scientific community. Indeed, we know the teacher's battleground and the administrative and economic barriers to educational change. In addition, there is reportedly an additional difficulty with the identity of the teacher (BROWNELL et al., 2012). They fear that they will be marginalized and discriminated. Apparently, there is a true problem of professional identities. Consequently, professors, researchers and teachers must be part of the same science community in which teachers are considered vital members, involved in the development of STEM education programs for teaching students who have grown up in the Internet era (SINGER, 2009).

In the rapidly changing techno scientific culture, how could Whitehead's thinking contribute to STEM education, and what would such contribution be? In this study, we show that Whitehead's thinking in this area is still relevant and helpful in that it has an approach to education that links two inseparable aspects. There is a vertical aspect, which the theory of knowledge represents, and a horizontal aspect figured in the rhythms of education. These two intertwined aspects remind us that we must constantly rethink the horizontal strategy in light of cultural evolution, and always keep in mind the vertical dimension. The latter has a decisive impact on the learner’s individuation process, and on what teachers do not master. They are privileged witnesses experiencing an adventure that exceeds them.

## 1 ACTIVE LEARNING

STEM disciplines have the particularity of having practical laboratory work that naturally fits into the active learning paradigm. Learning in the laboratory naturally focuses on the student who must do or create something, alone or in a small group, while enjoying the teacher's supervision to learn and gain good practices. In this context, the project’s status at the end of the session enables the student to self-assess the quality of his work.

During the project’s development process, he faces the resistance of the problem that requires a solution. He uses his know-how, mobilizes the knowledge gained in all areas of his life, and solicits the resources of his group to optimize cognitive resources. Discoveries during the process and the project’s completion provide intense pleasure and boost self-esteem, together with the repetition of the exercises. That is why cooperation and supervision are useful in the pedagogy of success.

From this point on, we realize that active learning is the educational approach that is ethically recommendable, and that we must find ways to transfer as much as possible the dynamics from the laboratory to the amphitheater, because there, the teacher must confront the inertia of the large group, compared to the dynamics of smaller groups and collaboration. Precisely, the teacher's experience is as follows. When you want to apply the dynamics of small groups in an amphitheater, the process then becomes very slow. It is impossible even to fly over the program defined by the academic authorities. The teacher also feels that the knowledge gained is superficial and unequal among students, as opposed to promoting deep learning.

In order to overcome these frustrations and to consider the appropriate strategy, some clarification of the objectives of the educational process is necessary. In this perspective, Whitehead's theory of knowledge can be a resource.

## 2 KNOWLEDGE AND STRATEGY

Knowledge is not only gained through the successful completion of some practical work done in an appropriate context, because in any case, what we can do is always very limited. Let's take a metaphor from impressionist painting. Each success and failure in the proposed exercises is like a trait on a surface destined to become an impressionist canvas.

In a "learner-centered" approach to teaching, only the student is able to know what painting he wants to become, while in the "teacher-centered" approach, the teacher knows what landscape the student has to paint. Generally, this strategy gives nothing valuable. This shows that knowledge relates to life, and more particularly, it is linked to the learner's trajectory. At this stage, we find some connivance with Whitehead's aesthetics (WHITEHEAD, 1967a). The process takes the form of an "adventure", and the final painting becomes an asymptote called "peace".

The role of education is not only to gain techniques, which anyway will be obsolete five years later. But, through the technique of the moment, the students will have to learn to draw their lines, above all and at the same time that their attention awakens to the painting or to the sketch of the canvas onto which they will have to project themselves.

To support this perspective, we use what Whitehead identifies as the three factors of knowledge (WHITEHEAD, 1968): importance, expression and understanding.

### 2.1. Importance

Whitehead makes the difference between « importance » and « interest ». He says: 'Importance' relies more on the unity of the universe, and 'interest' more on the individuality of the universe".

Realizing that "something is important" is a moment of experience with its "affective tone" and "intrinsic value". That's why "this important thing" permeates reason and the emotional pole. It's like the sense of encounter that Martin Buber describes.

While « important » connects with the totality of the universe, Whitehead then adds, "Importance is what gives perspective" (WHITEHEAD, 1968, p. 1-19). Precisely, the totality of the universe is the person himself in the environment. What we discover as "important" is related to mathematics, physics, chemistry and the like. It uncovers something from the student's universe. At this moment, it does not only give perspectives, but it also puts him or her in motion towards the vision of the canvas that he or she is about to sketch.

### 2.2. Expression

With "expression," Whitehead states: "It is *the way* an individual conveys that perspective grasped by virtue of interest and importance". One could say that the importance of interaction with the universe, that is the learner, suggests an expression that always has to do with the final asymptotic painting (WHITEHEAD, 1968, p. 20-41).

### 2.3. Understanding

Finally, by « understanding » Whitehead means « an art of penetration » towards meaning. Indeed, meaning is infinite and we are finite beings. However, meaning is a creative advance as well, and it is part of the adventure. We could say that the quest for meaning feeds the "urge for", or fosters creativity. In sum, the process of learning has to enact a "concern" -another Whiteheadian terminology-, for the object of knowledge (WHITEHEAD, 1968, p.42-63).

### 2.4. The Turning-Point

In fact, this concern is a concern for oneself, a concern of the learner for himself or herself, via the object of study. When self-concerns arise, the student takes the lead of his or her educational process. This event is a major turning point in his or her life. If the educational experience does not lead to self-concern, then it is a dead process, or it generates dead knowledge.

The occurrence of this event, the turning point, is not solely the responsibility of the teacher or that of the educational team. The teacher is not almighty. The turning point depends on the student's structure, his or her history, what material he or she is made of.

We do not know the exact mechanism of this phenomenon, but there is certainly a process of coalescence of disjointed elements in the learner's mental process that leads to an acute awareness of his perspective about life. It is a phenomenon of synesthesia, when aesthetics and ethics converge in a perspective. It is about a moment of integration of the senses, the rational, intellectual and emotional dimensions of the subject toward a goal.

This coalescence entails the emergence of a style, the emergence of the student as a style, or at least as a proto-style, like a budding artist. There is no emergence of a style without an inner quest. Consequently, there is a spiritual dimension in this event that embeds all the dimensions of the person.

We can compare the Whiteheadian approach to life (creativity, aim, and self-enjoyment), his aesthetics (adventure, beauty, peace) with his approach to the educational process (importance, expression, and understanding). Each of the three sectors has interacting elements in a commutative logic, where there is an element that provides a driving force, an element that indicates a perspective, and an element that plays the role of the path to an asymptotic horizon. From this model, we can observe the relationship between life, aesthetics and knowledge (Figure 1). The repetition of the same pattern suggests the intrinsic link that Whitehead establishes between these aspects of the individual's existence.

## 3 FROM THEORY TO PRACTICE

With this model in mind, we realize that the educational process goes much further than the acquisition of particular knowledge. Nevertheless, it goes through these steps.

The student's turning point usually goes unnoticed by the teacher. The sign that the teacher may receive is the student's interest in a particular aspect of knowledge. This may indicate that the student has already a real perspective, i.e. one that comes from a personal experience.

Consequently, the primary purpose of the educational process is to put the student in a state of experience through exercises and through the acquisition of competence. It is obvious that one of the little-known roles of the educational institution is to trigger or at least contribute to the emergence of the turning point. Indeed, living knowledge really begins only after the experience of the turning point.

We draw inspiration from the ternary rhythm of education, Romance (R), Precision (P) and Generalization (G), to implement the horizontal or methodological aspect of the teaching of integrative biology. According to Whitehead, the adventure of romance is the first stage of apprehension, characterized by discovery, curiosity and wonder. It requires guidance, discipline and an adequate environment (WHITEHEAD, 1967b, p. 32). The author warns about the importance of this first stage. If the latter is ignored/overlooked, the learner will have to find satisfaction at best with inert knowledge, or at worst, with ideas without knowledge (WHITEHEAD, 1967b, p. 33).

With this stage in the background, the learner can move to the stage of precision or to the understanding of principles through the acquisition of precise knowledge of details. The third stage aims at applying the acquired knowledge to new fields. From this, the educational process becomes a continual repetition of such cycles, integrating and overcoming the past, in line with the meaning of the German verb *aufheben*, as used by philosopher Hegel (CAZALIS, 2016, p. 230).

In the teaching of integrative biology, as we practice it, we reverse the classical pattern. In other words, we propose a path that goes from practice to theory, metaphorically, as one would use an inverted funnel, i.e. by pouring the liquid through the small opening to make it go and leave through the large one.

The metaphor of the inverted funnel suggests taking the opposite view from the idea of filling students' heads with data. On the contrary, it is an invitation to expand knowledge, from simple to complex, or from local to global.

We start the course with laboratory practices in plant biology. This is typically a practical supervised laboratory exercise that is a hands-on experience, and which provides guidance. This serves as a grounding to represent and understand the reality we want to grasp.

The second step in the progression aims at an extension of the first. It comprises supervised exercises from scientific papers. Groups work on the exercises, and each group presents the results to all students. The possibilities of laboratory work are always limited, because they are time-consuming and expensive. This is why they must be extended by the paper's analysis in the same spirit and with the same aim, i.e. to grasp the object in a concrete way.

The third step aims at the maximum extension, which is the theoretical course that is online and available for consultation. It aims to ensure that students take into account the entire landscape from the foundations laid out in the previous practices.

In this approach called inverted funnel, each step corresponds to a complete R-P-G cycle insofar as each one includes several progressive exercises that enable students to discover, engage their curiosity, learn and apply this knowledge to the next exercise.

The transition from step 1 to step 2, which consists in passing from practical exercises to theoretical exercises, while remaining within the experimentation paradigm, can be regarded as similar to the fact of passing from R to P, and even to the first phase of generalization. But it is above all the transition from step 2 to step 3 that aims to move from case studies to the first outline of a model capable of integrating these cases.

The study of the new chapters of the course brings us back to the starting point with a new step-1, and so on. The project we have developed in plant biology can be virtually implemented in all STEM disciplines.

The three steps help the student to interact with various clusters in a cooperative learning context.

According to Leo Tan and Subramaniam (2001), cooperative learning:

Exposes pupils to problem-solving skills
Expands pupils' cognitive spectrum

Forces pupils to think out of the box
Encourages pupils to appreciate the realities of group dynamics
Allows pupils to engage in collaborative inquiry
Allows pupils to work in a networked community
Helps pupils develop higher order thinking skills
Introduces pupils to research skills
Gives pupils experience in multitasking

Indeed, in cooperative learning, the students have to work together to perform tasks in a small group. Each student in the group has a specific role to play. The group can only reach the end goal when it works effectively. Because each cooperative learning group has a heterogeneous structure, each student bring his or her strengths to the group effort and seeks outcomes that are beneficial to himself or herself and to all other group members. In this approach, the students take part in creating knowledge and are accountable for it. Therefore, this strategy aims at both increasing their performance in biology and at improving their attitudes.

With regards to the turning point, it is only the birth of oneself as a style. Then, it is necessary to develop a long-term task that evolves over time. Consequently, the R-P-G cycle takes place throughout life, because as soon as the turning point occurs, we realize that we will have to study all our lives. The school and university periods only represent the apprenticeship of the art of learning. As a result, the cycle never stops, because what we learn is a never-ending process. As for the techniques, they quickly become obsolete, which means that new ones have to be acquired.

## CONCLUSION

STEM disciplines have the specificity of integrating laboratory work, which is a starting point for setting up an active pedagogy. There are different ways of approaching active pedagogy according to the reality of the institution in which we operate.

The process perspective in STEM disciplines presented in this paper is based on two dimensions of education. The former or vertical aspect is related to the emergence of a turning point, or to an experience of synesthesia that leads to the integration of the subject. The latter concerns the acquisition of knowledge and skills. Whitehead's thought is a resource for two aspects, his theory of knowledge and the rhythm of education, respectively.

Education is generally related to the second aspect, and we illustrate it in a plant biology project. However, we believe that the first aspect is more fundamental or at least comes first, because active pedagogy really does bear fruit when it stops generating dead knowledge, that is, when the student has experienced his or her turning point and takes the lead of his or her own educational adventure.

What the teacher can do is to create a favorable context to awaken this desire, this "concern", as Whitehead puts it, for himself. Probably, a favorable context, which is the purpose of active pedagogy, is certainly more propitious to this event than a context where stress, boredom or suffering reign. Our approach with the inverted funnel technique has such aim. But no one controls a student's turning point event; it is part of his or her uniqueness as an individual.

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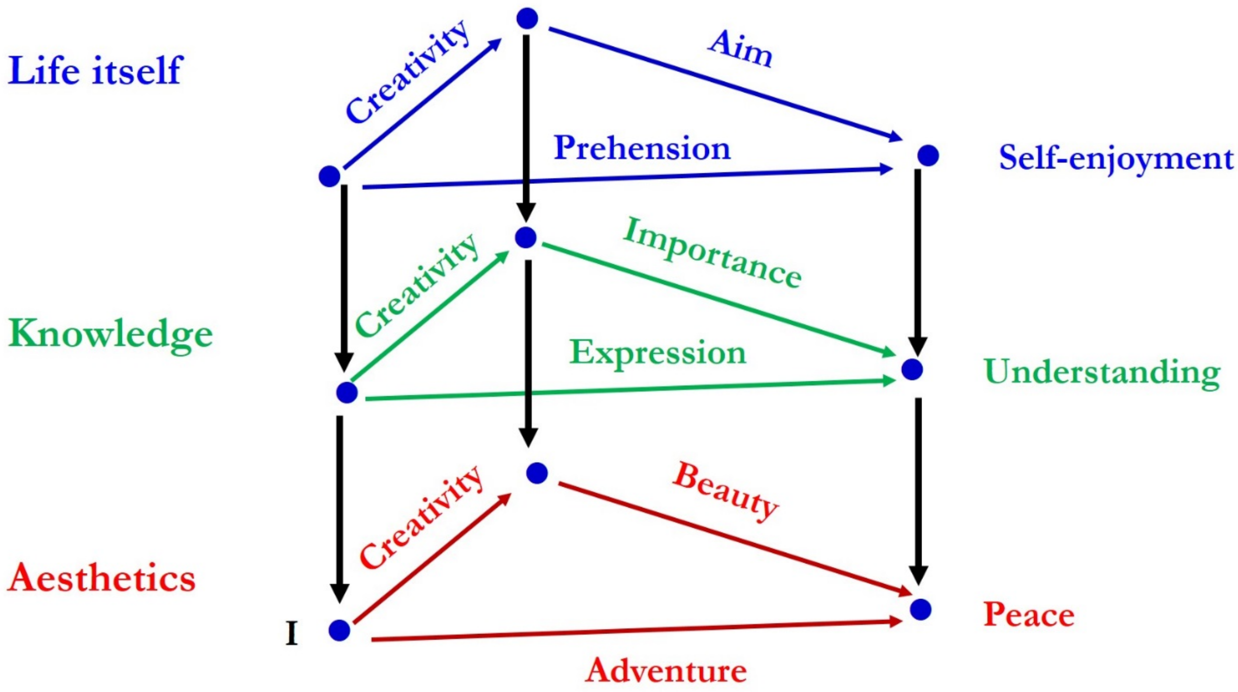
**Figure caption**

**Figure 1.**

Schematic representation of the relationship between Whitehead's conceptions of life, knowledge and aesthetics.

**Figure 1.**

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