Active Learning and Teaching Methodologies for Engineering

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Abstract. This paper presents the results of the implementation of a pilot project using active and collaborative teaching and learning methodologies such as Flipped Learning, Just-In-Time Teaching, Peer Instruction, Project Based Learning and Design Thinking in curriculum components of the civil engineering and production engineering matrix courses of at the Center for Science and Technology (CCT) Mackenzie Presbyterian University Campinas campus, state of Sao Paulo, Brazil. The efficiency of the use of active and collaborative teaching and learning methodologies was questionnaires and standardized tests for assessing cognitive skills and socio-emotional skills, such as the Force Concept Inventory (FCI) and Social Emotional Health Survey Higher Education (SEHS-HE), in different classes participating in the pilot project. Tests were applied before and after the use of active methodologies, where the control classes were evaluated from the perspective of the conventional lecture methodology and the so-called experimental classes were evaluated applying   different methodologies. Results indicated with the implementation of the pilot project in the curriculum components with the use of active and collaborative teaching and learning methodologies, students became more protagonists of their learning process, showing a teaching and learning approach, adding both theory and practice more effective, motivated and motivating the students of engineering courses.

Keywords: Cognitive skills, Socioemotional skills, Active methodologies.

1 Introduction

The demands of the 21st century are related to socially, politically and ideologically focused education which have driven research and the use of active and collaborative teaching and learning methodologies that seek to redefine the role of teacher and student in the process of knowledge construction in different educational contexts [01, 02 and 03]. In this context, the application of active teaching methodologies becomes in fundamental importance, especially in technology-based courses.

Among the most commonly used active teaching and learning methodologies, which is shown to be one of the alternatives to the formal model of merely expository classes, flipped learning / flipped classroom is one of the most prominent [04]. There are numerous other active and collaborative teaching and learning techniques developed in recent years that aim to enhance both the understanding of fundamental concepts and problem solving in the teaching-learning process, namely: just in time teaching, peer instruction, one-minute paper, think-pair-share, scale-up, team-based learning, problem-based learning, project-based learning, design thinking, among others [05, 06, 07 and 08].

Specifically, in the field of engineering, there is need for the cognitive and non-cognitive formation. The last one also called socioemotional skills. Both for understanding the fundamental concepts, which is the basis of intellectual and academic formation, and for problem solving, which is intrinsic to engineer in its different specialties, as emphasized in the National Curriculum Guidelines of the Engineering Undergraduate Course - Resolution CNE / CES 11 of 11 March 2002, specifically in Article 3, which states that "the Engineering Undergraduate Course has in its profile from the graduating graduate / professional the engineer [...] stimulating his critical and creative performance in identifying and solving problems [...] " [09].

2 Bibliographic Review

2.1 Cognitive Skills

Human intelligence has been modeled through three major streams: psychometric (or factorial), developmental, and the human information processing approach [10]. The psychometric approach defines intelligence structures and their organization. The developmentalist defines intelligence structures and their dynamics throughout development and information processing seeks to investigate in detail the cognitive processes involved in traditional test resolution, giving rise to the area of cognitive neuroscience [11]. The concept of competences would be in the plane of knowing how to know and is related to the ability to mobilize resources to solve complex situations. The skills would be in the plane of knowing how to do and are configured as tools that can generate the skills. A matrix of competencies and skills has been presented by the National Institute for Educational Studies and Research (INEP) for the government evaluation program of the National High School Examination (ENEM), proposing a matrix with 5 competencies and associated with each 21 skills [12]. In 2017 this proposal was revised and the Common National Curriculum Base (BNCC) started to present 10 general competences, as well as their related skills, also involving ethical, aesthetic, political principles and clearly presenting socio-emotional skills (Figure 01) [13, 14].

2.2 Socio-Emotional Skills

Socio-emotional skills are identified by the Organization for Economic Co-operation and Development (OECD) as essential to vocational training in order for young people to succeed in an increasingly dynamic and competitive labor market [15]. There is a large group of socio-emotional skills and competences, according to an OECD report [16], permeating the personality traits of individuals. Socio-emotional skills are configured as a set of skills inserted in a context to be worked. Below we can see, in figure 02, a list of socio-emotional skills that encompass the characteristics of individuals inserted in the 21st century [16].

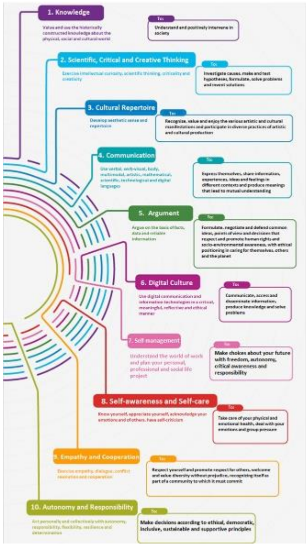


Fig. 1. BNCC Skills and Skills Matrix [13, 14]

Ability to quickly acquire and apply new knowledge	Diligence	Integrity	Reverence
Abnegation	Discipline	Interconnectedness	Risk taking
Abstract problem solving	Diversity	Interdependency	Self-actualization
Acceptance	Efficiency	Justice	Self-awareness
Accountability	Effort	Kindness	Self-care
Adaptability	Empathy	Leadership	Self-compassion
Altruism	Energy	Leading by example	Self-control at school
Applying technology	Engagement	Learning from mistakes and failures	Self-control in relationships
Appreciation	Enthusiasm	Listening to others	Self-direction
Appreciating beauty in the world	Equanimity	Living in harmony with nature	Self-discipline
Appreciating others	Equity	Living in harmony with others	Self-esteem
Appreciating what I have	Ethics	Load management	Self-kindness
Assertiveness	Excitement of creating something new	Love	Self-reflection
Authenticity	Executing plans, follow through	Loyalty	Self-respect
Balance	Existentiality	Mental flexibility	Selflessness
Belonging	Exploration	Mentorship	Sensibility
Benevolence	Fairness	Mercy	Sharing
Bravery	Feedback	Mindfulness	Social awareness
Camaraderie	Feeling awe	Modesty	Social intelligence
Care	Flexibility	Motivation	Social perspective
Charisma	Focus	Negotiation	Socialization
Charity	Followership	Observation	Speaking out, taking a stand
Cheerfulness	Following	Oneness	Spirituality
Citizenship	Forgiveness	Open-mindedness	Spontaneity
Civic-mindedness	Fortitude	Optimism	Sportsmanship
Commitment	Generosity	Organization	Spunk
Common humanity	Genuineness	Passion	Stability
Compassion	Goal orientation	Patience	Tackling tough problems
Confidence	Grace	Perseverance	Teamwork
Conscientiousness	Gratitude	Persistence	Tenacity
Consciousness	Grit	Playfulness	Timeliness
Consideration	Growth	Precision	Tinkering / inventing
Consistency	Happiness	Presence	Tolerance
Cooperation	Helpfulness	Problem solving	Toughness
Courage	Heroism	Productivity	Tranquility
Critical thinking	Honesty	Professionalism	Trustworthiness
Cross-cultural awareness	Honor	Project management	Truthfulness
Curiosity	Humaneness	Prudence	Verve
Dealing with ambiguity	Humbleness / humility	Public speaking	Vigor
Decency	Humor	Receptivity	Virtue
Decisiveness	Inclusiveness	Reliability	Vision
Decorum	Initiative	Resilience	Willingness to try new ideas
Delegation	Innovation	Resourcefulness	Wonder
Dependability	Inquisitiveness	Respect for others	Work ethic
Determination	Insight	Responsibility	Zeal
Devotion	Inspiration	Results orientation	Zest

Fig. 2. OECD Socio-Emotional Skills [16]

2.3 Cognitive and Socio-Emotional Skills Assessment Tools

In the case of cognitive skills assessment there is a large amount of standardized tests validated in various areas of knowledge for all levels of education, such as tests for higher education in the area of physics called Force Concept Inventory (FCI). , which seeks to evaluate the basic concepts of Newtonian mechanics, trying to highlight the alternative conceptions related to these concepts [17]. The concept of force in FCI is widely evaluated and is decomposed into six conceptual dimensions: (i) kinematics, (ii) Newton's First Law, (iii) Newton's Second Law, (iv) Newton's Third Law, (v) Principle of Overlap and (vi) Types of Force [18]. The original test consists of 29 questions, presenting 5 alternatives where only one refers to the scientifically correct concept. The official translated and validated version of the FCI consists of 30 multiple choice questions, presenting for each question the scientifically correct alternative and the distractors [18 and 19]. To measure socio-emotional skills and competences in the sphere of higher education, we have the instrument of Furlong et al. 20], which developed and validated, over an 18-month period, an instrument for assessing socio-emotional health in higher education individuals called the Social Emotional Health Survey Higher Education (SEHS-HE). Based on the concept of co-vitality, which describes the empirical observation that positive human traits tend to be found together, the scale was developed with 72 pilot items that, in a new version, were reduced to 48 items across four distinct cores: belief in itself; belief in others; emotional competence and engaged life [20].

3 Methodology

The implementation of the methodology and active teaching and learning techniques was done gradually, selecting the main fundamental concepts that integrate the contents of some curriculum components of the matrix of the civil engineering and production engineering courses of the Center of Science and Technology. Two classes were chosen from each curriculum component of the matrices of the two engineering courses to carry out the project, where one class was the experimental one, using the new active learning methodology, such as Flipped Learning, Just in Time Teaching, Peer Instruction, Project Based Learning or Design Thinking, and the other class was the control class, where the conventional methodology of lectures was used. The curricular components chosen were: General Physics, Differential and Integral Calculus, Innovation and Product Development, Urbanism and Architectural Design and Technical Design and CAD. For General Physics curriculum content, for example, students in both the Control (Civil Engineering) and Test (Production Engineering) classes answered the FCI Cognitive Skills questionnaire before and after the content of the Three Laws of Newton so that it could calculate the normalized percentage gain [21]

$$G = \frac{S_{pos} - S_{pre}}{100\% - S_{pre}}$$

Where

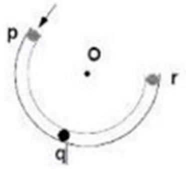
S_{pre} is the percentage of correct answers before the study of the theme;
S_{pos} is the percentage of success after studying the theme.

In the case of the curricular component of differential and integral calculus, students answered questionnaires on cognitive skills prepared by the teacher himself and in the specific curriculum components of engineering courses students developed projects using the techniques of PBL and Design Thinking. All engineering students answered the SEHS-HE Socio-Emotional Skills questionnaire translated by the project team.

4 Results and Discussions

Some results of the pilot project to implement active teaching and learning methodologies in the curriculum components of the Civil Engineering and Production Engineering courses will be presented below.

In the case of the Curriculum Component of General Physics, one of the questions on the FCI questionnaire that none of the students got right, either from the control class or the test class, before the content study (pre-test situation), was question 5, showing that Students are still unclear about the types of forces that are present in interactions between bodies, as no student has indicated the correct alternative (5B), or present alternative conceptions related to common sense that are not scientifically correct (Figures 03 and 04). In this issue, the most frequent distractor was the belief that obstacles do not exert force (alternative 5A). After the study of the content (post-test situation), question 5 had a 24% yield, as can be seen in figure 05.



Question 5 - What above force(s) act(s) on the sphere when it is inside the frictionless tube in the "q" position?
Consider the following distinct forces: 1. A downward force due to gravity. 2. A force exerted by the pipe pointing from "q" to "O". 3. A force in the direction of movement. 4. A force that points from "O" to "q".

- A) 1 only.
- B) 1 and 2.
- C) 2 and 3.
- D) 1, 2 and 3.
- E) 1, 3 and 4.

Fig. 3. Questions 5 of FCI Questionnaire

From the application of the FCI questionnaire it was noticed that the students' performance was in the low normalized percentage gain range (G <0.3) for both the control class and the test class, with some specific cases in the normalized average percentage gain range. (0.7> G> 0.3) (Table 01). In the control class, there were cases of negative normalized percentage gain, which may evidence the lack of interest in the content taught, using the traditional methodologies of lectures.

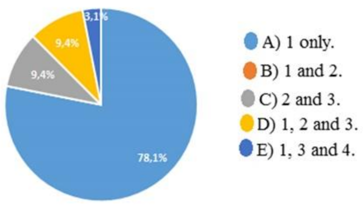


Fig. 4. FCI Question 5 Answers in Pre-test Situation (Correct: B)

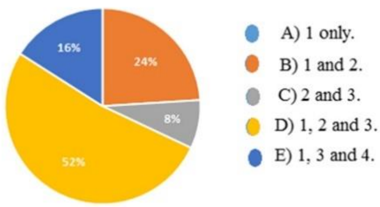


Fig. 5. FCI Question 5 Answers in Pos test Situation (Correct: B)

Making a general statistical consideration between the two control (Civil Engineering) and test (Production Engineering) classes, in both Pre-Test and Post-Test groups we had an increase of the averages for both Control and Test classes. However, in the case of the test class, the actual values of the Pre-Test (30.00%) and Post-Test (46.67%) medians are higher than those of the control class, as well as the difference between the Pre-Test medians. Test and Post-Test is higher for the test class (16.67%), and may show a learning gain in the Production Engineering test class using the active teaching-learning methodology (Table 02).

In the case of the Technical Drawing and CAD curriculum component, the results refer to the evaluation in 27 students of the Civil Engineering course before (N1) and after (N2) the application of teamwork (Table 03).

Table 1. Percentage gain normalized for both classes

Normalized Percent Gain (G)	
Control Class	Test Class
0.06	0.26
0.09	0.30
0.27	0.25
0.00	0.33
0.09	0.21
0.19	0.44
0.52	0.16
0.06	0.08
- 0.08	0.11
0.09	0.25

Table 2. Statistical analysis of General Physics FCI results

	Construction Engineering (Control Class)		Production Engineering (Test Class)	
	Pretest	Post test	Pretest	Post test
Average	25.64%	33.59%	25.57%	43.03%
Median	26.67%	30.00%	30.00%	46.67%
Standard Deviation	11.42	15.48	8.95	13.03
Minimum	3.33%	6.67%	13.33%	20.00%
Maximum	46.67%	66.67%	40.00%	66.66%
Number of Notes (n)	13	13	11	11

Table 3. Statistical analysis of Technical Drawing and CAD notes

	Group	
	N1	N2
Average	7.54	7.78
Median	7.90	9.30
Standard Deviation	2.00	1.98
Minimum	2.60	1.90
Maximum	10.00	10.00
Number of Notes	27	27

The application of the socio-emotional skills questionnaire already translated into Portuguese was made during the implementation of the pilot project of active teaching and learning methodologies. Some results showing the profile of students of Civil Engineering and Production Engineering courses can be seen in figure 06. It can be noted that the answer profile of question 7 shows that students of Civil Engineering and Production Engineering courses demonstrate some difficulty concentrating as 31% admitted that they identify only a little with a profile that keeps themselves focused while studying while ignoring distractions. Another trait related to resilience could be studied by analyzing the profile results obtained from question 27, which shows 13.8% of students have great difficulty in emotional control in stressful situations (Figure 07).

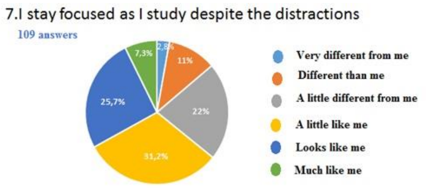


Fig. 6. SEHS-HE Question 7 Answers

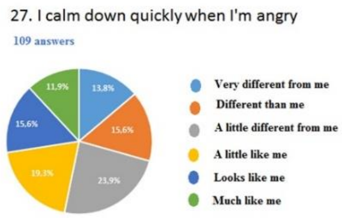


Fig. 7. SEHS-HE Question 27 Answers

5 Conclusions

From the application of the FCI questionnaire in the General Physics curriculum component it was noticed that students' performance was in the low normalized percentage gain range (G <0.3) for both control and test class, with some specific cases in the range with average normalized percentage gain (0.7> G> 0.3). For general statistical analysis between the two control (Civil Engineering) and test (Production Engineering) classes, in both Pre-Test and Post-Test groups we had an increase of the averages for both control and test groups. However, in the case of the test class, the actual values of the Pre-Test (30.00%) and Post-Test (46.67%) medians are higher than those of the control class, as well as the difference between the Pre-Test medians. Test and Post-Test were higher for the test class (16.67%), which can show a learning gain in the Production Engineering test class using the active teaching-learning methodology. In the Curricular Component of Differential and Integral Calculus, it was noted from the analyzes performed that although the test class had greater interest in classes conducted with active methodology, control class had a better performance in the general test, being the topic of improper integrals only a part of the questions. The results obtained in the implementation of the pilot project of the active methodologies PBL and Design Thinking in the curriculum component of Innovation and Product Development showed that there was an optimization of the learning process of the students, as they were motivated and engaged in facing the proposed challenges, obtaining solutions with creativity, self-management, responsibility and innovation. In the case of the curriculum components of Urbanism and Architectural Design and Technical Design and CAD all students were committed during its development, going beyond the expected competences and presenting good project results. The data obtained in the present work suggest that active methodologies have proved to be alternatives for the optimization of the teaching-learning process in technology-based courses.

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