A CONTENT ASSESSMENT AND PEDAGOGY ALIGNED CURRICULUM TO AN INTRODUCTORY COURSE IN SYSTEMS THINKING.

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1. COURSE INTRODUCTION

1.1 Course overview

The course "Systems Thinking" is a course that is a three credit course that meets regularly twice a week for 16 weeks. The course is intended for first and second year engineering students of the faculty of engineering at Pontificia Universidad Javeriana. The course objective is to go further the technical content and provide a better understanding of the complexity of real problems and the need of the use of the systems thinking paradigm to contribute to their solution.

The course content has four components: an introduction to systems thinking, the principles of systems thinking theory, approaches based in systems to solve problems and lab sessions.

This is an active, social, project learning course. The projects will be related to one of the seven problems that the University intends to solve in its mission (the mission of Universidad Javeriana is cited in the section 0). These problems are open-ended and are not specifically related to any discipline which is an opportunity for helping students to broaden their vision (To see "the big picture" is one of the enduring understandings of this course).

During the course, students will be required to work by themselves for self-reflection, and in groups not only to strengthen their workgroup skills, but also to develop communication skills.

1.2 Setting for the Curriculum Project

1.2.1 Salient characteristics of the institution or sponsoring organization

The main characteristic of the institution is that their curriculums should intend to address the problems that are expressed in the mission of Pontificia Universidad Javeriana

The Pontificia Universidad Javeriana is a catholic denominational University that is regimented by the Society of Jesus. According to the mission of the University, curricula offered should address these problems in order to contribute to their solution. The Mission statement is: (The original version is in Spanish (Pontificia Universidad Javeriana, 1992) and the translated version that is cited here is found at the webpage of the faculty of engineering (Facultad de Ingeniería, 2011):

> "In the immediate future, the Javeriana University will drive research and integrated education based on curricula offered by its faculties; it will strengthen its role as an interdisciplinary university; and it will invigorate its presence in the country, making key contributions to find solutions for the following problems:

- The ethical crisis and the treatment of humans as mere instruments.
- The low appreciation of national values and the lack of appropriation of cultural identities.
- Intolerance and ignorance of plurality and diversity.
- Social discrimination and the concentration of economic and political power.
- The inefficiency and poor infrastructure of the state's principal institutions.

- Deficiencies and slowness in scientific and technological development.
- Irrational practices and illogical thinking in the management of environmental and natural resources.

Additionally, the University follows the Ignatian pedagogy that asks that their students , "must include a world view" (The International Commission on the Apostolate on Jesuit Education, n.d., p. 5), which reinforces the idea of developing a broad vision through the use of the seven problems in the curriculum.

1.2.2 Salient characteristics of the intended learners

The author has taught this course since 2004. One year he taught it at Catholic University and since 2006, he has taught at Pontificia Universidad Javeriana Bogotá. According to that experience, the author describes in the following paragraphs his interpretation of the characteristics of the intended learners.

One of the characteristics of engineering students at Javeriana (although at Catholic University the situation was similar) is that typically they come to this course with the pre-conception that the content of the course is technical and that they will deal with close-ended problems. It happens because some of the courses that they take in high school are related to science, physics and math. The problems in those disciplines have one solution and explain short-term causal relationships. On the other hand, in their first semester (the course in systems thinking is usually taken by students in their second semester) some of the courses they see are from the departments of basic sciences and math. Besides, in their first semester most of the students take the engineering basic course "algorithmic thinking" in which although its problem can be solved in different ways, those are close-ended. Therefore students don't have to think about long-term implications of the solution, emergence and adaptation, key concepts in systems thinking and typical characteristics of open-ended problems.

The other characteristic we will consider is that the age of students ranged typically between 16 to 19 years old, so their experiences are smaller in quantity and different in quality than the experience of adults (Jarvis, 2006, p. 187).

1.1.1 1.2.3. Other important contextual issues

This three credit course meets twice a week over the span of 16 weeks. Since this course meets three hours a week, it is expected that students do extra-class work of at least 6 hours a week because the concept of a one credit hour implies one hour in a classroom and two hours of independent work. So that, the extra-class activities must be design having this consideration.

1.3. Motivation for designing a curriculum in Systems Thinking

This course plays a key role in engaging engineering students with the profession since they perceive a bigger contribution in the application of what they know. The course also shows students the relevance of developing transversal engineering skills like critical thinking, communication, team work, etc., skills that are immersed in the identity and requirements of the engineer of the future (ABET, 2006; National Academy of Engineering, 2004). Besides, the course can play a role in developing student identity as Javeriano (a person who have a degree from this University – Pontificia Universidad Javeriana, is called Javeriano), which one of their characteristics is social awareness.

Additionally, the course was first designed focus on teaching content to students, but, in the time that the author has been involved in the teaching and the design of the course (about six or seven years), considerations like alignment between that content, the assessment and the pedagogy has never been taken in consideration.

Besides that, in his personal experience as student (while studying his bachelor's degree) and as teacher of the course for several years, he has found that this course is perceived as a "very boring course" by students. A reason that can explain this perception is that the content is taught most of the times following a pedagogy focus on transmission, and students don't get engaged easily in abstract content taught with this pedagogy.

2. CURRICULUM BODY

2.1. Content

2.1.1 Curricular Priorities

A. The process of defining the Curricular Priorities

The curricular priorities for the course in systems thinking are defined after considering three different sources that have proposed skills and knowledge that must be learned in order to develop the systems thinking ability or "capacity" (M. Frank, 2002):

1. The current course syllabus of systems thinking in the department of systems engineering at Pontificia Universidad Javeriana.
2. Characteristics of engineering systems thinking-a 3D approach for curriculum content (M. Frank, 2002).
3. The characteristics that Sweeny and Meadows define for a systems thinker (2010).

1. The current course syllabus of systems thinking in the department of systems engineering at Pontificia Universidad Javeriana

The course proposes as enduring understanding a better perception of the real problems and the creative solution of problems. It also says that the course intends to develop a holistic vision for problems solution and the design of systems (Departamento de Ingeniería de Sistemas, 2011). Javeriana also defines in their syllabus content related with the history of systems thinking, the general principles of general systems theory and solving problems approaches based on systems. There are lab sessions as well in a computer room with a software simulation tool. Those are provided to reinforce concepts related with one of the solving problems approaches based on systems: systems dynamics.

2. Characteristics of engineering systems thinking defined by Frank (2002) and by Frank and Elata (2002; 2005)

Frank (2002) and Frank and Elata (2005) proposed a curriculum approach that includes four areas: The principles of systems thinking, requisite engineering knowledge, requisite skills and behavioral competences. The first area (principles of systems thinking) is composed of the following sections:

- Principles of general systems theory
- The principles of systems thinking
- The principles of engineering systems thinking

Besides that, the following set of thirty engineering skills and fourteen behavioral competences were proposed by Frank (2002, pp. 208–209):

Skills in which the course has a unique opportunity to contribute in their development	**Skills that can be taught in other courses or in professional practice**	
Describe the goal, objectives, and uses of the required system	Use systems design considerations	Use standard protocols or algorithms
Carry out preliminary design of the system	Anticipate future changes in the system and their implications	Prepare RFI and RFP
Define the system's boundaries	Conduct an applicability or feasibility study	Learn or analyze the customer's or market's needs
Characterize, define, examine, test, or design the system inputs and outputs	Carry out interface design	Prepare or examine wiring and installations drawings
Take into account non-engineering considerations (Those could be societal, environmental or both)	Prepare final requirements specifications	Design, execute or supervise qualification tests
Use simulations	Carry out a design, compatible with different systems	Perform economic optimization
	Design by standards	Examine and suggest

		considerations for integrating partners or subcontractors
	Characterize, design, or perform inspections, tests and integration	Make use of economic and business considerations
	Characterize or prepare the initial requirements specifications	Examine or write hardware, software, and system development documents
	Coordinate between industries	Define, examine, or design man-machine-interface (MMI)
	Use tools designated for systems design	Perform engineering optimization
	Forecast or anticipate the long-term future	Define or design architecture
	Characterize and structure simulations	

Table 1 - Engineering skills categorized for contribution opportunity

Behavioral competences found by Frank (2002, pp. 209–211):, the behavioral competences were classified according to the opportunity of being developed in the course of systems thinking as well:

Competences in which this course has a unique opportunity to contribute in their development	**Skills that will be develop in other courses as well**	
Perceive what's what (Critical thinking)	Innovate	Compare different discipline systems
Relate to other people and communicate with them	Raise good questions	Organize and manage capability
Learn by himself/herself	Work with a team	Delve into systems topics

Be imaginative	Be inquisitive and curious	
Think creatively		

Table 2 - Behavioral competences categorized by contribution opportunity

3. The characteristics that Sweeny and Meadows defined for a systems thinker (2010).

Sweeney and Meadows (2010) stated that a systems thinker is a person who:

Sees the whole picture.	Changes perspectives to see new leverage points in complex systems	Looks for interdependencies
Considers how mental models create our futures	Pays attention to and gives voices to the long-term	"Goes wide" (Uses peripheral vision) to see complex cause and effect relationships
Finds where unanticipated consequences emerge	Focuses in structure not in blame.	Holds the tension of paradox and controversy without trying to resolve it quickly.
Sees oneself as part of, not outside, of the system.	Seeks out of stocks or accumulations and the time delays and inertia they can create	Watches for "win/lose" mindsets, knowing they usually makes worse in situations of high interdependence
Makes systems visible through causal maps and computer models.		

The next step in the definition of the curricular priorities was to look for coincidences in the three different approaches and in that way define the content, the skills and the behavioral competences that this curriculum in systems thinking will intend to develop. On one hand, Frank's skills categorized as "opportunity" can be developed when applying the general concepts to a real problem. It implies than in the content, we must include sections to explain the general concepts, and sections to help students to visualize the application of those concepts. However, since the goal of the course, more than learn concepts is related to develop in students characteristics of systems thinkers,

B. Curricular priorities for the course in Systems Thinking

The curricular priorities for the course systems thinking will be divided in three categories (Wiggins & McTighe, 2001, pp. 10 – 11):

- "Enduring understanding … what we want students to "get inside of" and retain after they forgotten many of the details"
- "Important to know and do … student learning is incomplete without mastery of these essentials".
- "Worth being familiar with: "What do we want students to hear, read, view, research or otherwise, encounter?"

B.1. Enduring Understanding

B.1.1. The black box representation is useful to characterize open-ended problems as systems and the interrelated sub-systems.
B.1.2 Open-ended problems have high levels of complexity, emergent properties and long-term effects. To understand them, is necessary to see the big picture.
B.1.3. It is necessary to consider the big picture before making any decision.
B.1.4. Systems adapt to the environment that surround them.

B.2. Important to know and do

B.2.1. The control subsystems and the concepts of Homeostasis and equilibrium.
B.2.2. The flow of information in a system: The concepts of Entropy and negentropy.
B.2.3. Relevance of taking into account non-engineering considerations (Those could be societal, environmental or both).

B.2.4. Learn by himself/herself.
B.2.5 Critical thinking.
B.2.6. How to carry out a preliminary design of the system by defining: The goal of the system, the system's boundaries, the system inputs and outputs, recipient, outputs, the transformation process, Input's sources and feedback loops.
B.2.8. A system can be composed of more systems.
B.2.9. Understand himself/herself as part of a system.
B.2.10. Student and student's team are one system that shares the responsibility.
B.2.11. The system is visualized by the systems thinker and he can see those systems everywhere.

B.3. Worth being familiar with

B.3.1. The Pontificia Universidad Javeriana's mission problems
B.3.2. Differences between open-ended and close-ended problems
B.3.3. There are hard and soft systems
B.3.4. Approaches based in systems to understand and approach problems: Hard and soft systems methods.
B.3.5. Use computer simulations
B.3.6. Tips to successfully help your audience to see your system
B.3.7. How the systems paradigm emerged
B.3.8. Students will develop social awareness
B.3.9. The concept of system or its definition
B.3.10. The elements of a System

2.1.2 Content Structure:

The content structure can be found in the Figure . This mind map was built based on the curricular priorities that were defined in the previous section.

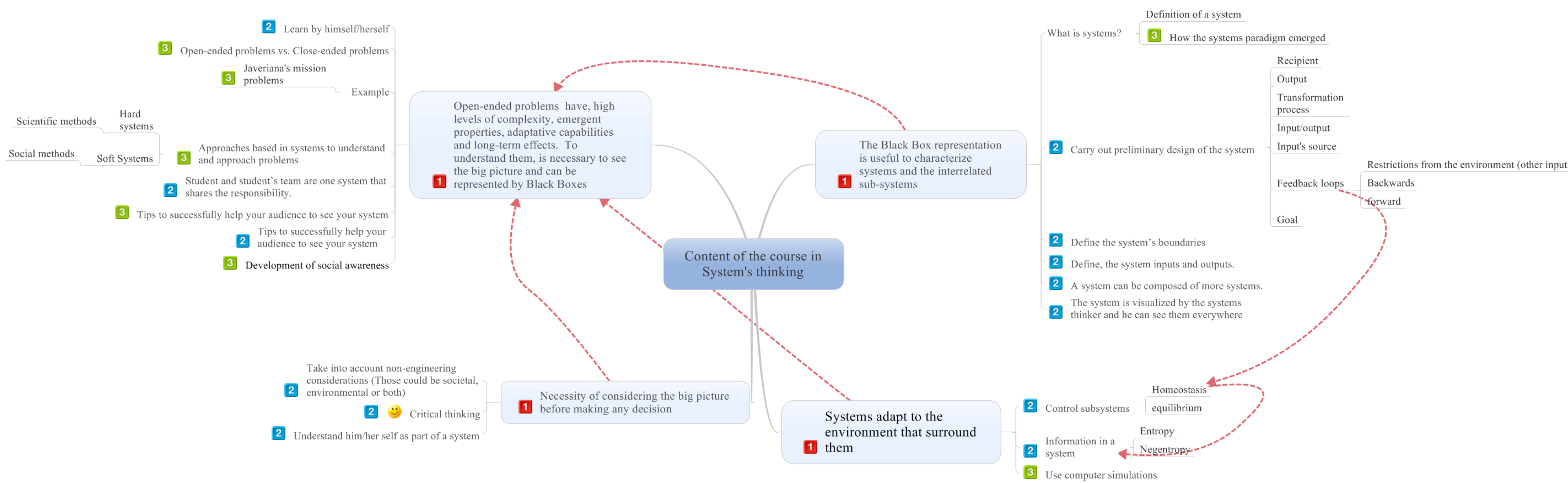

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Figure 1 - Mindmap with the content of the course in systems thinking

2.1.3 How do people learn systems thinking?

Systems thinking is an abstract way of thinking. Abstract thinking is not acquired without training or without being taught about it (Piaget mentioned that many people don't reach the final stage of his cognitive developmental theory (Crain, 2011)). On the other hand, students' thinking is mostly related with the mechanical thinking paradigm as it was explained in the section 1.2.2 Salient characteristics of the intended learners. Since mechanical thinking is as useful to engineer as it is systems thinking, students should understand their difference and be able to recognize in which situations they are useful.

<u>a. Misconceptions, Preconceptions, and Difficult concepts</u>

It is not easy to differentiate the misconceptions from the pre-conceptions because they are related to each other. The author of this course, from his experience, has identified that one salient misconception that students bring from previous courses in engineering and high school is that the elements of the world are linearly connected, most of the times in short-term cause-effect relationships. As it was explained in section 1.2.2 Salient characteristics of the intended learners, First year students have learned that the world works following the laws of the mechanical physics. Some of the characteristics of this world are that for every cause, there is an effect, these two are linearly connected, and there is always a solution in the short-term. The courses in math and reinforces these ideas. Students, maybe because of that, tend to think about the solution of problems without taking into account non-engineering considerations like social or psychological social issues related with the problems.

Related to their perception of the world as a machine, is their pre-conception about emergence, "students misrepresent an emergent kind of processes as a direct kind ... and it is challenging to move from one perspective to the other" (Chi, 2005, p. 189) .

b. Difficult concepts:

Emergence of new properties or emergent processes: This is a key concept in systems thinking, and it is difficult because requires a conceptual change. This change is difficult to achieve because it requires students to “re-categorize” their conceptions from entities to processes, because entities and processes can be considered to be distinct ontological categories (Chi, Slotta, & De Leeuw, 1994; Chi, 2005).

Other difficult concepts are related with the understanding of the following conditions (L.B. Sweeney & Meadows, 2010, p. 81):

- Significant delays between actions and the consequence of those actions
- Multiple "feedback" loops
- Significant non-linearity between actions and consequences.

Finally, Frank and Elata (2005) mentioned the following difficulties for learners:

- Inability to see “the general picture and not get stuck in details” (2005, p. 191).
- Realizing how important it is to understand the exact requirements that the system must accomplish (2005, p. 192).

- To consider alternative solutions in a parallel way, instead of considering them by following a sequential strategy (2005, p. 192).

The inability to perceive the emergence or emergence processes proposed by Chi (2005), is related to the ability to see the big picture proposed by Frank and Elata (2005) , which is also connected with the inability to perceive the delays that are mentioned by Sweeny and Meadows. Since this difficult concept is common in the three authors finding, we will consider the big picture as the difficult concept that will be addressed by the curriculum.

2.2. Assessment

2.2.1 Learning objectives.

<u>a. Learning goals associated to the category "enduring understanding”:</u>

a.1 Students will be able to use black box modeling to construct a representation of the big picture of an open-ended problem as a system, which is also composed of interrelated sub-systems.

a.2 Students will select situations in which the complexity, the emergent properties or the long-term effects were not considered and will state what the non-considered big picture was.

a.3 Students will identify that is crucial to get the big picture before attempting to solve an open-ended problem (This learning goal is related to the enduring understanding B.1.3).

b. Learning goals related to the category "important to know and do"

b.1 Students will translate into examples the concepts of homeostasis, emergence, recursion, systems, and subsystems.

b.2 Students will interpret what possible information a system is getting from the environment to adapt itself to the changes of the environment.

b.3 Students will identify the relevance of including non-engineering considerations when proposing a technical system.

b.4 Students will show that they learned about one of the Javeriana's mission problems in their independent study hours.

b.5 Students will create and use criteria to define boundaries, inputs and outputs of systems.

b.6. Students will describe different systems within a system.

b.7. Students will understand himself/herself as part of a system

b.8. Students will be aware of their team and will understand themselves as a team.

c. Learning goals associated with the category "Good to be familiar with"

c.1 Students will review the evolution of mechanical thinking and the evolution of systems thinking.

c.2. Students will describe the main characteristics of two approaches that solve problems using systems: Soft systems methodology and systems dynamics.

c.3. Students will identify the interaction within systems components through the use of computer simulations.

c.4. Students will be able to communicate effectively the system that they interpreted or visualized.

c.5 Students will recall that the mission of Pontificia Universidad Javeriana is attached with the solution of seven social issues.

2.2.2 Fink's taxonomy and Learning Objectives

In order to frame the learning objectives in a framework, the Taxonomy proposed by Fink (2003) was used. This decision relies on the idea of seeking to nurture other dimensions beyond the cognitive one. We will now show how the learning goals are matched the taxonomy:

Foundational knowledge	b5, c2, c3
Application	a2, b1, b2, b6,
Integration	a1, a3, b3,
Human dimensions	a3, b3, b7, c5
Caring	b8.

Learning how to learn	b.4, c4

2.2.3 Assessment triangle (Cognition, Interpretation and observation) of the three most relevant learning outcomes

Once we have stated the learning outcomes, we can now define the way in which we are going to measure the accomplishment of the learning goals using the assessment triangle (Pellegrino, Chudowski, & Glasser, 2001)

a. Assessment triangle for the learning goal a.1: Students will be able to use black box modeling to construct a representation of the big picture of an open-ended problem as a system, which is also composed of interrelated sub-systems.

Observation (Task)	Students will be asked to show one of the seven problems that are stated in the mission of Pontificia Universidad Javeriana as a system.
Interpretation	Students who pass will present in their models the following sections: • Students will show the criteria they use to choose the different answers. • Elements: goal of the system, recipients of the outputs of the system, outputs, transformation process, Inputs, sources of the inputs. • They will show how the environment creates restrictions or reinforces the system. • Students will show their interpretation of homeostasis, feedback and feedforward loops, emergence, and adaptability. • Students will present different subsystems within that big problem that interact between each other.
Cognition	Since case studies and analyzing real systems is proposed as a way of learning systems thinking (M. Frank, 2002), and in the same way PBL is also proposed as a way of building skills over the fundamentals (M. Frank, 2002; L.B. Sweeney & Meadows, 2010), this task is coherent with those principles.

b. Assessment triangle for the learning goal a.3: Students will identify that is crucial to get the big picture before attempting to solve an open-ended problem.

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Observation	Role play: A student will be asked to solve a problem in which they should play the role of the new administrator of a neighborhood called the Oaks. He is replacing someone who has been there for many years and who had to leave abruptly. The first activity that the student is required to do as the new administrator is to answer the mails that have been in the inbox of the Oaks administration mail several days. This is an open-ending problem. One of the key ideas to succeed in doing this task is that students will realize that there are many mails that are interrelated and that it is necessary to understand the big picture before making any decision, which is aligned with the learning goal. This activity also demands from students, critical thinking because it is necessary to categorized the different mails. This task will be performed individually in class for 45 minutes. After that, students will be asked to write down their feelings and thoughts while performing the task. After that they will be asked to share with their peers and they will be required to build a schema of the big picture and a matrix categorizing the different kind of e-mails. In order to assess if they understood the key role of the big picture, an individual homework will be required. They have to write a reflection with well supported arguments answering what the importance is of getting the big picture, especially when facing an open-ended problem.
Interpretation	In order to pass, students must accomplish two requirements: a. In class, he/she try to solve the problem on their own, and also they might be engaged in the discussion with peers. With their team, they present their perception of the big picture that explains the situation of the neighborhood and the critical analysis of the mails. b. The reflection in which he will use his/her personal experience in this activity and in other experiences in his life to support the statement that explains the crucial role of the big picture before attempting to solve open-ended problems.
Cognition	PBL and role plays are proposed as a way of building skills related to see the big picture (M. Frank, 2002; Linda Booth Sweeney & Meadows, 2010). On the other hand, a complementary learning approach will be used in order to

	take advantage of the learning environment that PBL brings students can get reinforced in the perception of the big picture (difficult concept) through scaffolding (Crain, 2011). individual reflection after the action is proposed by the Ignatian Pedagogy (The International Commission on the Apostolate on Jesuit Education, n.d.) in order to understand what happened and perceive improvements for the future. Vigotsky's theory also proposed that a student, after experience, students should reflect upon what they learned.

<u>c. Assessment triangle for learning goal a.2: Students will select situations in which the complexity, the emergent properties or the long-term effects were not considered and will state what the big picture that must be considered was.</u>

Observation	Students will be asked to work in teams and watch two of the following movies: "Bruce almighty", "The butterfly effect", "The wave" and "Back to the Future II". They are also required to watch two of the following documentaries: "Bowling from columbine", "An inconvenient truth", "Supersize me". After watching the movies and documentaries, they will be required to look for situations in those movies in which the complexity, the emergent properties and the long-term effects were not considered and/or they will be asked to explain the big picture that should be considered. They will be asked also to explain how, in the documentaries, systems thinking contributes to understand the problem They will be required also to watch for other situations in real life in which decisions are made without considering the big picture.
Interpretation	Students who pass will: • Show criteria in order to select their cases. • Explain why this situation is complex and what the outcomes were after considering the problems related to the situation as close-ended. • Offer a possible big picture that was not considered, including emergence properties and long-term effects.
Cognition	Since Frank proposes that the learning environment in which students start developing systems thinking is simulation, the movies will serve as a simulation environment in which the concepts of interactions, long term cause effect, etc. are perceived as close-ended problems instead of open-

	ended. Pre-conceptions: The relationships between cause and effect are direct and short-term. Difficult concepts: emergence

2.2.4. Assessment matrix (This matrix links learning objectives to assessment tasks and scoring criteria).

a. Assessment matrix for learning goal a.1: Students will be able to use black box modeling to construct a representation of the big picture of an open-ended problem as a system, which is also composed of interrelated sub-systems.

Assessment	General	**Peer assessment, oral assessment**
	Claim	Students will present an open-ended problem as a system that frames smaller systems (open-ended problems) using visual (black boxes) and verbal models (Gilbert & Boulter, 2000).
	Task	Students will be divided into groups of three and will be asked to do a presentation of an open-ended problem. Students will be required to do a research about one of the problems that Universidad Javeriana stated in its mission. In order to gather information, they will be required to look at the news, look for YouTube videos, institutional webpages, academic papers, real life experiences, etc. Once they gather the information, they will be asked to define criteria to define the information that will be useful for them in order to do the task. They will be required to interpret how the concepts of recipients, outputs, transformation process, inputs, suppliers, environment, etc., can be instantiated in the real

	world that they found through their documentation. Students will identify sub open-ended problems and will see how do they interact and produce emergence properties. Students will also narrate how the properties of systems can be interpreted from the problems. Rubrics: A: High Performance: The group of students remains together until the end of the project. Any of the students can present the project alone. The presentation is done in non-technical language. Students do not read the slides during the presentation. Each slide of the presentation has a proportion of 70% visual and 30% text. Students show familiarity with the problem and are able to explain the big picture. They present evidences that support their definition of each element and each sub-system using academic and non-academic sources. They considered at least 16 different sources. Their inferences of how the properties, emergence and long-term effects can be instated are supported as well by evidences found in the research process. In this case, they can propose at least two examples per each property. B: Good Performance: The group of students remains together until the end of the project. Students require not to be selected randomly to present. The presentation is done in non-technical language. Students do not read the slides during the presentation. Each slide of the presentation has a proportion of 70% visual and 30% text. Student show familiarity with the problem and are able to explain the big picture. Their evidences that support their definition of each element and each sub-system are based only in non-academic sources; however the number of references is ten or more. Their inferences of how properties like homeostasis, emergence and long-term effects can be instated are supported as well by evidences found in only in non-

	academic sources. They proposed at least two examples of each property. C: Acceptable performance The group of students doesn't remain until the end, but they have evidences that show that the group tried to find ways to be together. Students choose who present the project. The presentation is done in a technical language. Students read the slides during the presentation. Each slide of the presentation has a proportion of 70% text and 30% images. Student show some familiarity with the problem and partially explain the big picture. The evidences that support their definition of each element and each sub-system are based in a small number of non-academic sources. Their inferences of how properties like homeostasis, emergence and long-term effects can be instated are supported as well by evidences found in only in non-academic sources. They proposed at least two examples of each property. D: Low performance: The group of students doesn't remain until the end, and have no evidences that show that the group tried to find ways to be together. Students choose who present the project. The presentation is done in a very informal way. Students read the slides during the presentation. Each slide of the presentation has a proportion of only text or only images. Student show not too much familiarity with the problem and is not able to explain the big picture. The evidences that support their definition of each element and each sub-system are based in ill-perceptions of their personal experiences. They show a shallow understanding and incomplete evidence in their explanation of the properties of emergence, homeostasis and long-term effects.

	Evidence	They have to present a bibliography with the different sources they used to understand the problem. A proposal of how the problem can be perceived as a system of at least four problems, describing those systems as interrelated through their inputs and outputs. They have to propose possible inputs that are creating those outcomes. A power point or a poster presentation with the system that contributes to the solution of the problem is required. It must count with the four general proposals, the criteria to choose one of them and a detailed description of the alternative chosen including the properties of the proposed system.

b. Assessment matrix for learning goal a.3 Students will identify that is crucial to get the big picture before attempting to solve an open ended problem.

Assessment	General	Self-assessment, peer-assessment, Verbal assessment, written assessment
	Claim	Students will realized of how important is to understand the big picture before attempting to solve an open-ended problem.
	Task	Role play: A student will be asked to solve a problem in which they should play the role of the new administrator of a neighborhood called the Oaks. He is replacing someone who has been there for many years and who had to leave abruptly. The first activity that the student is required to do as the new administrator is to answer the mails that have been in the inbox of the Oaks administration mail several days. This new administrator will deal with typical issues that arise in Colombian apartments buildings and some organized neighborhoods: Choosing a security company, renew maintenance contracts or look for new service providers, decision for possible investments and expenses that may benefit most of the people or just some of them,

	issues between neighbors, recovery of debt portfolio, neighbors who break the cohabitation rules, etc. This is an open-ending problem. One of the key ideas to succeed in doing this task is that students will realize that there are many mails that are interrelated and that it is necessary to understand the big picture before making any decision, which is aligned with the learning goal. This activity also demands from students critical thinking, because it is necessary to categorize the different mails. This task will be performed individually in class for 45 minutes. After that, students will be asked to write down their feelings and thoughts while performing the task. After that they will be asked to share with their peers and they will be required to build a schema of the big picture and a matrix categorizing the different kind of e-mails. In order to assess if they understood the key role of the big picture, an individual homework will be required. They have to write reflection answering what the importance is of getting the big picture, especially when facing an open-ended problem. Rubrics: A: High Performance: Student gets involved in the exercise and share with others. He work individually in the first part of the task and after the time finishes, he write down his feelings and thoughts. The students share with their peers respecting other people perspectives. At the same time, student look for scaffolding his/her peers. The reflection will present three sections: How did I feel, what did I learned, other examples from my experience. The previous experiences must be explained coherently with the situation related with considering the big picture. They also will state an answer to the question (based on evidence) what the crucial role is of considering the big picture before making decisions. The reflections will be well written following the APA format. No grammar errors or major mistakes will be perceived.

		B: Good performance Student gets involved in the exercise and share with others. He work individually in the first part of the task and after the time finishes, he write down his feelings and thoughts. The students share with their peers respecting other people perspectives. The reflection will present one of the following sections: How did I feel, what did I learned, and also other examples from his/her experience. The previous experiences must be explained coherently with the situation related with considering the big picture. The reflections will be well written following the APA format. No grammar errors or major mistakes will be perceived C: Acceptable performance Student gets superficially involved in the exercise and eventually participates sharing with others. The reflection will present one of the following sections: How did I feel, what did I learned and offers examples of previous experience. However, these examples are not understandable and the connection between the exercise and the examples is not easily logic. There is an explanation of the role of the big picture. The reflections are without format but are well written. Some minor grammar errors or minor mistakes are perceived D: Low performance Student doesn’t work individually or fail when sharing with peers. The reflection is shallow and no personal experiences are presented. There is no mention of the big picture or the analysis is poor. No explanation of the role of the big picture is provided or is scarce. The reflections are without format but are poorly written. Grammar mistakes and grammar errors are present.
	Evidence	Individual exercise: Individual worksheet with problem solution.

		Group exercise: Worksheet with the letter of every student of the team. Reflection: The reflection presents a set of personal experiences

c. Assessment matrix for learning goal a.2: Students will be able to identify situations in which decisions are made, or problems are understood by following the thinking principles of the mechanical paradigm, or of the systems thinking paradigm. Similarly, they will also be able to provide arguments in order to defend their interpretation.

Assessment	General	Oral assessment – Peer assessment
	Claim	Students will be able to recognize possible outcomes when problems wrongly understood as close-ended and the complexity, the possible emergent outcomes and the long-term effect is not considered.
	Task	Students will be required to work in teams that are going to be selected by a software based in a survey about skills and interest and schedule and watch two of the following movies: • The butterfly effect • Bruce almighty • Sherlock Holmes • The Wave Students will be required to watch the following documentaries • Bowling for Columbine • An inconvenient truth • Supersize me After watching the movies and documentaries, they will be required to look for situations in those movies in which the complexity, the emergent properties and the long-term effects

	were not considered and/or they will be asked to explain the big picture that should be considered. They will be asked also to explain how, in the documentaries, systems thinking contributes to understand the problem They will be required also to watch for other situations in real life in which decisions are made without considering the big picture. A: High Performance: Students will be considered in this category if the group of students remains together until the end of the project. The presentation is prepared as a team since there is only one file with the slides and the slides share the same voice and template. Students also use other different media to show their evaluation. They all interact all the time in the presentation (instead of monologues, they present together, maybe using a possible script was prepared), and in the scenario, they look like a team (Also they wear in a similar way). Students do not read the slides during the presentation. Each slide of the presentation has a proportion of 70% visual and 30% text. Student's present the criteria they use in order to choose the situations they identify. These criteria show considerations of term, complexity and emergence. For every claim presented, argument and evidences are supporting it. B: Good Performance: Students will be considered in this category if the group of students remains together until the end of the project. The presentation is prepared as a team since there is only one file with the slides sharing the voice and the template. There is some interaction during the presentation, but most of the time students are found alone during the presentation, however, in the scenario, somehow they look like a team. Students do not read the slides during the presentation. Each slide of the presentation has a proportion of 70% visual and 30% text. Student's present the criteria they use in order to choose the situations they identify. These criteria show considerations of term, complexity and emergence.

		The claims that are presented by the students are shows arguments and evidences. C: Acceptable performance: Students will be considered in this category if the group of students doesn't remain together. Also if they are together but their presentation looks like if it was prepared separately and was joined some minutes before class. There is no interaction during the presentation, and students present their analysis through monologues. Students read the slides during the presentation. Each slide of the presentation has a proportion of 70% text and 30% visual. The criteria they use in order to choose are not presented. The claims that are presented by the students show arguments and evidences. D: Poor performance: Students will be considered in this category if the group of students doesn't remain together. Also if they are together but their presentation looks like if it was prepared separately and was joined some minutes before class. There is no interaction during the presentation, and students present their analysis through monologues. Students read the slides during the presentation. Each slide of the presentation has a proportion of mostly text or mostly graphics. The criteria they use in order to choose are not presented. The claims that are presented by the students are poorly defended and the evidences are mainly based in opinions.
	Evidence	Team work: the team remains together until the end of the project. There are different moments in which the team meets the teacher and the perception of the professor is that they are working together.

		Interaction and communication in the scenario in order to present their ideas to the public (classmates). Uniformity in the wearing, and in the products, show that students are working as a team and that all of them share the responsibility of the team. Coherence between claim, argument and evidences. Evidences presented by students relate the situation, the minute in the movie, or the sources of the real life examples.

2.2.5 Alignment between Content and assessment

The curricular priorities were the basis to define the content of the course and the learning goals. The assessment of the learning goals is based in asking students to perform simulations, evaluate case studies and get involve in role plays, which are coherent with the cognition section that explains how people learn systems thinking and with the cognition corner of the assessment triangle.

4. PEDAGOGY

4.1. Incorporation of the seven (7) principles of "Making learning whole" (Perkins, 2010).

4.1.1. Play the whole game

In this course, students are challenged to learn and think about one social open-ended problematic from the mission statement of Pontificia Universidad Javeriana as a system composed of subsystems. Since those problems are related to the Colombia that they may perceive in the news, they may understand the general situation and will get engaged in trying to explain, based on arguments and evidences, and using the tools they are learning in the course, the problem. In fact, they must define what the big problem and the subproblems are for them while trying to define the transformation process. This implies that the course is not only about problem solving, but also about problem finding. The final product might be a model based on systems.

4.1.2 Make the game worth playing

Leaders, entrepreneurs and managers among others are recognized for being able to perceive the big picture and its complexity. Additionally, they are known for being able to perceive interrelations and interdependences, for being able to work effectively with others and for communicate effectively. Even though the course is non-technical, it contributes to develop those transversal skills that are crucial for engineers in the career and in their professional life. Students will hear about that in different classes, especially at the beginning. The professor will bring quotes from possible role models in which they talk about the relevance of these skills. Also, the professor will find connections between this course and previous or future courses that the student took and will take. Especially with the courses student will take, the professor will show them slides or general content of those courses, and will try to convince them that the topics are not difficult if students accomplish the enduring understanding of this introductory course in systems thinking.

4.1.3 Work on the hard parts

This course will have a big concerned related to facilitating students awareness of the big picture, the long term effects and the emergence. In order to do that, three different tasks that assess the enduring understanding are defined and in all of them students are required to apply the difficult concepts. In these tasks, possibilities for self-assessment and scaffolding are provided. The former with personal reflections and individual work, and the latter with team work and group discussions.

Since some of the concepts that are difficult for students are abstract, students will have to do several presentations and graphics of systems in order to organized their knowledge and learn it. The professor will be asking regularly to meet him to talk about their advances and difficulties.

4.1.4 Play out of town

The transference from the classroom to different kinds of scenarios where the same concepts can be perceived and apply is a premise of the course. The concepts of the course will be observed and applied in the three different activities that were created to assess the enduring understanding. These activities require from student to understand, to abstract and to put in a different context the concepts in order to understand other different situations.

4.1.5 Uncover the hidden game

This course is about uncovering the hidden game of understanding the big picture and finding the circular long-term causal relations among the elements. As it is explained, students have the misconception that the world works following the principles of mechanics. So they might be focusing their attention in what is observable, visible and reachable by them. However, through the course, they will have the opportunity to face open-ended problems and understand that there are situations in which the mechanistic approach is not enough to deal with a problem, especially if this problem is open-ended and non-engineering concerns must be taken into account when solving the problem. Also, the exercise of role playing as administrator is intended to help them to uncover the hidden game.

4.1.6 Learn from the team

Students will be asked to interact and to depend on each other's in different activities and tasks. In this way, they will be scaffold if necessary or they will scaffold their peers. They will be receiving oral and written (through discussion boards in blackboard) feedback from their peers in order to improve some of their deliverables. Besides that, many in-class activities will require the presence and participation of all students in order to set a learning environment with role-plays or simulations.

4.1.7 Learn the game of learning

Students will have to learn on their own about one of the seven problems stated in the mission of Universidad Javeriana. In this project, because there are no correct answers, students will be the ones who make decisions about. They will decide what problem to study, what the sources are, what the relevant content is and what are the useful topics are in order to show to the rest of the class and the professor and possible guests their problem definition as a system of systems. This activity requires development of critical thinking since there is too much information and it is necessary to classify it and define what is what, and besides that, critical thinking helps the learner to realize of their learning process. Finally, the activity of writing a reflection, as it is required in the second task, helps them to understand their own learning process.

4.2 Syllabus of the course

4.2.1. Course goals, objectives and expectations

Purpose: the purpose of this course is to help students to become systems thinkers (Capra, 1997; Checkland, 1986; Gonzalez Couture, 2003; Herrscher & Gharajedaghi, 2003; Senge & Senge, 1991; L.B. Sweeney & Meadows, 2010) or, in other words, to develop capacity for engineering systems thinking (M. Frank, 2002). A systems thinker is a person who, in order to understand his/her reality use systems. Sweeney and Meadows (2010) defines a systems thinker as a person who sees the whole picture (the system that contains the others), looks for interdependencies (between the identified elements of the system), considers how mental models creates his/her future (not every person oversees the same system), pays attention to the long term (there might be unexpected outcomes in the future), sees him/her as part of, not outside of the system (2010, p. 1). We can complement this definition by including the scope of their vision. They go beyond seeing events to seeing patterns of interaction and underlying structures which are responsible for the patterns (M. Frank, 2002).

4.2.2. General ideas about the grades.

Students will be graded under the basis of fair and equivalence. Since open-ended problems have no unique answer, in order to succeed, students must support their claims with arguments and evidence. Also, it is relevant for the class that students get involved in the in-class activities lead by the professor or lead by the students. That is why grading related to active participation of students exist in this course.

4.2.3. Grading system

1. First exam: students will show that they are able to reach the first two levels in the cognitive process dimension: Remember and Understand (Anderson et al., 2000). 20%
2. Reflections. Students will be required to write reflections about their learning and they will be graded based in student's contribution to the previous activity and the cohesiveness and deepness of his/her reflection. 15%
3. Movies project: Students will be graded taking into account two considerations. On one hand, their effectiveness in doing team work, and on the other hand, in their ability to build arguments supported by evidence. 15%
4. Explanation of computer simulation: A simulation of a dynamic system will be studied by the students. They have to identify the different elements of the system and the relations between the variables. They will have to interpret the outcomes and how they get affected after the interaction between the components that are simulated.
5. Final project: the criteria to grade the final project are the same that was used for the movies project: Students will be graded taking into account two considerations. On one hand,

their effectiveness in doing team work, and on the other hand, in their ability to build arguments supported by evidence. 25%

6. Attendance, active participation in the in-class activities, scaffolding and peer-assessment: The success of the course relies also in understanding the class as a system. Contributing to the class at least in this forms will create a learning environment plenty of opportunities to develop knowledge. 10%.

7. Self-assessment: Students will have to opportunity to give a value in his own grade. This grade must be supported by evidences in order to be accepted. 5%.

4.2.4 You can expect from the classes.

We will have different kind of classes. Most of the classes will mix professor's presentations with students' activities facilitated by the professor. There is no pre-supposed order for what kind of activity is performed first because sometimes the theory can be first, but other times, an exercise that propose reflection can go first and the content of the class could be base in the situation that just happened, so the experiences and thoughts and difficulties can be understood better and have a theoretical context.

4.2.5. What should students do to be prepared for class and what do I expect from students during a class session

Students are expected to read before class and prepare a mind map of the readings following the template that is published in the virtual platform. In those maps, students are required to set the big picture of the reading and the general components that the author is making interact in order to transmit the message.

In class is expected that they participate and contribute to their peers in the different activities, role games, discussion and through scaffolding students who need support to get the concepts.

4.2.6 What to expect from me as your instructor

I, as instructor, will be open to dialogue and communication in order to help you to reach the knowledge and the level of application and integration that the course requires. I will be able to meet you and talk to you anytime we agreed. Since I like active meetings, I will ask you to prepare the meeting in advance. Bring clear questions and goals for the meeting. I will not give you exact answers, but I will give you ideas of where to go or what to do if you feel lost or overwhelmed. Students can also expect from me a fair treatment and equal opportunities for all. Before approving exceptions like extensions or others, I will ask the whole course if they agreed on making that exception and if they want it too. Finally, you can expect from me that, because I feel passion for teaching this course and because I know how important it is for your future as professional of engineering, that I will do my best to help you learn and enjoy the content. So please, ask for help, I will be always happy to help you.

4.2.7 Advice on how to read/approach the materials for this class

I will provide some of the materials for the class like readings, presentations of some basic concepts, videos and in-class and outclass activities. However, students will have to face other materials they can find in the web or in libraries. The best advice is to try not to get overwhelmed and develop criteria to decide which one is relevant and which one is not because is not contributing to achieving your goal.

4.2.8 Advice on how to study for exams

We will have only one exam which is related mainly to your ability to recall the definition of concepts and their understanding. Also you may think about the relationship between those elements since some of the questions in the test might require that you know the definition of a concept, but also its relation to other concepts.

4.2.9 Schedule.

Week. Session (week 01 session 01: w01S01)	**Class focus**	**Assigned readings**	**Deliverables**
W01S01	Course overview, what is a systems thinker? students and teacher presentations		
	Module 1 what is a system?		
W01S02	The concept of systems, parts of a system	(Herrscher & Gharajedaghi, 2003, p. chapter 1 and 2), (Johansen, 1982, p. chapter 1)	
W02S01	The concept of systems, parts of a system – in class activity	No readings to prepare	
	System's adaptation to the changes in the environment		
W02S02	Concepts: feedback, feedforward, entropy and negentropy	(Capra, 1997, p. chapter 4)	
W03S01	Concepts:		

	homeostasis		
W03S02	Concepts: emergence	(Herrscher & Gharajedaghi, 2003, p. chapters 4 and 5)	
W04S01	Lab 01 – feedback and feedforward.	Students must do the first two tutorials in order to learn how to use the tool.	
W04S02	Lab 01 – feedback and feedforward presentation.		
W05S01	Exercises with black box modeling applying the concepts of systems		
W05S02	First exam		
	Open-ended problems		
W06S01	Open-ended problems vs. close-ended problems: mechanical thinking vs. systems thinking	(Capra, 1997, p. chapter 2), (Herrscher & Gharajedaghi, 2003, p. chapter 1), (Rosnay, 1979, p. chapter 1)	
W06S02	Javeriana's mission problems as open-ended problems	(Pontificia Universidad Javeriana, 1992)	
W07S01	Why should we take into account non engineering considerations when defining a problem? How to do it?	(Cabrera & Lleras, 2002; Herrscher & Gharajedaghi, 2003; Mendoza-Garcia & Lleras, 2004; Senge & Senge, 1991)	
W07S02			
W08S01			
W08S02			
W09S01	Hard systems vs. soft systems	(Checkland, 1986)	
W09S02	The need to see the big picture.	(M. Frank, 2002; M. Frank, Zwikael, & Boasson, 2007)	Reflection
W10S01	Student's presentation of movie cases		Presentation
W10S02	Student's presentation of movie cases		Presentation

W11S01			
W11S02	Students’ draft of their analysis of an open-ended problem as a system.		Materials that will be used to present.
W12S01	Students’ draft of their analysis of an open-ended problem as a system.		Materials that will be used to present.
W12S02	Lab 02 – higher complexity models		
W13S01	Lab 02 – higher complexity models – student’s oral presentation.		Students will prepare an oral presentation of the model defining the elements and properties of systems that can be perceived while the model runs.
W13S02	Tools for managing information and criteria definition	(Linda Booth Sweeney & Meadows, 2010)	
W14S01	Tips for defining the boundaries of a system	(Checkland, 1986; Jackson, 2000)	
W14S02	Tips to perform presentations and help the audience to visualize what is in your head.		
W15S01	Session of peer assessment of final projects		
W15S02	Emergent properties and complexity and other simulation tools	(Cabrera & Lleras, 2002; Rosnay, 1979)	
W16S01	Students’ presentation of their analysis of an open-ended problem as a system.		Student’s presentation
W16S02	Students’ presentation of their analysis of an open-ended problem as a system.		Student’s presentation

4.3 Alignment between content, assessment and pedagogy

The design of this course followed the backwards design. Now the instruction that is delivered is aligned with the curricular priorities and with the content. For example, one curricular priority is that students understand that it is necessary to consider the big picture before making any decision. To assess if students getting that understanding, an assessment triangle (a task and an interpretation based on the way the content is learned) was proposed. The task is an exercise in which students must face a non-typical situation. It is non-typical because they have to think about making decisions in open-ended problems, where the big picture is require to succeed. The three corners of the assessment triangle are also aligned with the pedagogy because it is helping the student to discover the hidden game of circular long-term causal relationships and it is also enable students to transfer the knowledge to new situations or to learn the game of learning because they have to write about their learning experience.

Another example we can present here is that we are proposing a task in which the students must learn about one of the societal problems that are explained in the mission statement from Pontificia Universidad Javeriana. This is aligned with the assessment triangle. The cognition corner that says that systems thinking is learned better through PBL and the study of cases and a rubric related is also offered among with a rubric based on the effectiveness in doing the task. Finally, this is aligned with the pedagogy. The pedagogy is also aligned because through this project we are helping them to play the whole game (they need the knowledge from the course in order to succeed with the project), hopefully to make the game worth playing (they will understand that this skills are crucial for his future as professionals), to work on the hard parts and uncovering the hidden game (through their understanding of the big picture that leads to the understanding of complexity and long-term causal relationships), to learn from their team (they will work with their peers to improve their deliverables), and finally, the project will help them to learn the game of learning since they will be in “the driver’s seat” defining the model that explains the problematic as a system while the teacher will be playing a role of passenger who reinforces or help them to reflect about their processes.

In general, in this document, for the three enduring understandings, an assessment triangle and an aligned pedagogy are offered.

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