121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #8787

A Creative Experience for Chemical, Food, and Environmental Engineering Students in a Material Balances Course

Mrs. Silvia Husted, Universidad de las Americas Puebla

Silvia Husted is Science, Engineering, and Technology Education Ph.D. Student at Universidad de las Americas Puebla in Mexico. She teaches design related courses. Her research interests include creative thinking, cognitive processes, and creating effective learning environments.

Dr. Nelly Ramirez-Corona, Universidad de las Americas Puebla
Prof. Aurelio Lopez-Malo, Universidad de las Americas Puebla
Dr. Enrique Palou, Universidad de las Americas Puebla

Professor Palou is Director, Center for Science, Engineering, and Technology Education as well as Distinguished Professor and Past Chair, Department of Chemical, Food, and Environmental Engineering at Universidad de las Americas Puebla in Mexico. He teaches engineering, food science, and education related courses. His research interests include emerging technologies for food processing, creating effective learning environments, using tablet PCs and associated technologies to enhance the development of 21st century expertise in engineering students, and building rigorous research capacity in science, engineering and technology education.

A Creative Experience for Chemical, Food, and Environmental Engineering Students in a Material Balances Course

Abstract

Creative thinking includes the capacity to combine or synthesize existing ideas, images, or expertise in original ways and the experience of thinking, reacting, and working in an imaginative way characterized by a high degree of innovation, divergent thinking, and risk taking[1]. Despite all that has been demonstrated regarding problem solving and creative thinking, many engineering schools are still relying on the traditional lecture-homework-quiz format of well-defined problems and single correct answers. Unfortunately, while efficient, this format has not shown to be effective at producing the critical, innovative thinking skills needed to solve difficult technological problems[2, 3].

This paper describes a module for promoting students' creativity in a Material Balances second semester required course for Chemical, Food, and Environmental Engineering at *Universidad de las Américas Puebla* (Mexico). Major goals include stimulating and strengthening student cognitive flexibility that could allow them to be creative thinkers. The proposed four class-sessions module is an active and cooperative experience that was implemented as course final project. Students explored creativity through multiple representations of a problem that should be presented in written, graphic, and audio-visual manner to an expert audience for its evaluation. According to the *Cognitive Flexibility Theory*[4, 5], multiple representations of knowledge promote the transfer of abstract knowledge to different contexts while cognitive flexibility is one of the four base elements of creativity[6]. For the design of the learning environments of the module, we followed Jonassen[7]. Final projects were presented to experts in the field that assessed student creative thinking by means of a rubric adapted from the *Investment Theory of Creativity* developed by Sternberg and Lubart[6, 8, 9], which provided a multidimensional assessment of creativity. Additionally a *Fluency Rubric* was developed, which was divided into four modules that correspond to each project deliverable (dossier, poster, video, and oral presentation).

Students were able to build concrete examples of a material balance in an everyday situation and represent them in many ways (physically, verbally, symbolically, and by means of a multimedia presentation). Mean values from rubric assessment of final projects were 3.13 for *creative performance*, 3.80 for *knowledge of domain* (application of formal and informal knowledge), 3.31 for *intellectual style* (includes indicators such as autonomy and rules), 3.28 for *motivation* (level of commitment, project pride, and interest in task), 3.02 for *intellectual processes* (which includes indicators such as sensitivity, problem identification, ideation, ability to recognize ideas that have potential to be valued, as well as ability to sell your ideas effectively and persuade of its value), and 2.90 for *creative personality* (with indicators such as tolerance for ambiguity, risk taking, will, and perseverance). The vast majority of students attained final project expected outcomes at an acceptable level.

Introduction

Creativity is an intellectual skill that every engineer should possess and practice in order to be adequately prepared to face modern world requirements[10]. The challenging problems facing our society are not likely to be solved by conventional means. To the extent that these problems are technological, creative engineers are needed to solve them[2]. However, in engineering schools students are primarily taught analytical sciences, based on theories and concepts, where creativity has no place[11, 12]. Therefore it is very likely that most students will become purely analytical thinkers that never reach a creative and innovative solution in solving problems[13]. Besides, even when teachers can engage engineering students to interpret the physical world in mathematical terms, they find a great difficulty to relate mathematics to objects around them or in real life problems[14]. This is because most engineering courses related with mathematical skills are still presented in a traditional teaching format, "lecture-homework-exam", that even if it is an efficient way to present a lot of information in a reduced time, it definitely does not prepare students to solve real problems[2]. Some colleges have developed a number of programs to increase student exposure to these crucial skills, for instance the *Professional Practice Skills Program* at Rose-Hulman Institute of Technology, the McMaster *Problem Solving Program*, and the Dartmouth *Project for Teaching Engineering Problem Solving*, as well as specific courses such as *Problem Solving, Troubleshooting and Making the Transition to the Work Place* at the University of Michigan[15].

According to Guilford [16, 17], every individual has two ways of thinking, convergent and divergently. Divergent thinkers have the ability to look a situation from different perspectives, while convergent thinking is referred to people's skill to solve well-defined problems with a unique solution. In some cases people can use and switch both kinds of thinking, this ability determines the level of creativity that an individual might possess because this flexibility is the most important process of creativity.

A creative person develops the following processes: cognitive fluency, cognitive flexibility, originality, cognitive elaboration, and redefinition[18]. Therefore, it is essential to have an open mind, without prejudices that limit the cognitive processes, and consequently allows achieving original responses[19]. Spiro *et al*.[5] suggest that in order to assimilate a complex knowledge, this complexity must be broken down in small units, analyzing them through multiple perspectives (flexible representations), which facilitate a better understanding of the topic under discussion. This flexibility will be reflected in the students' ability to demonstrate the relationships between same elements in different ways along different conceptual contexts or in the ability to form different representations of a same situation depending on the task[20]. Flexible representations have three levels of learning: *image level*, which refers to the initial holistic image of a concept or a phenomenon; *schema level*, where people outline images as a result of the search for regularities in their experiences; and a *theoretical level* where theory is constructed in relation to the scheme, including a logical explanation of features[21].

The aim of this work was to design a creative experience for a Material Balances course. A material balance is the mathematical representation of the law of conservation of mass, and constitutes the basis of process engineering. In this area, achieving the proficiency at expert level involves going through various courses and learning experiences, thus the general objective of this first course is to create a flexible conceptual base that enables students to move onto the next stages of subject knowledge. Therefore, the purpose of this study was to design an active learning environment as a constructivist approach based on problem solving experiences[7, 22] that allow students to achieve a level of cognitive flexibility in order to establish relationships between what they learn in class and what they can experience in life itself, giving meaning to the course contents and contextualizing them from a holistic and creative approach.

Methodology

Material Balances is an introductory course that was taught in a traditional format, "lecture-homework-exam", which constitutes a pillar course in Chemical, Food, and Environmental Engineering curricula at *Universidad de las Américas Puebla*, and corresponds to the second semester of these three undergraduate programs. As many courses in engineering science, the subject content is usually presented as abstract knowledge, where the attained knowledge is conditioned to the styles of learning and intelligence possessed by each student, factors that make it impossible to maintain a consistent teaching pace. In the proposed new learning environment, a change on the traditional format of teaching is introduced through an active-creative experience, where the main goal is that students reach the level of knowledge required to solve material balances, strengthen their cognitive flexibility while achieving a level of fluency that allow them to perform and explain various representations of a material balance to an expert audience.

The final grade for this course was determined according with the following criteria: 45% corresponded to mid-term exams, 15% for quizzes, 20% for homework, and 20% for the final team project. Mid-terms were used to evaluate knowledge of material balance principles, quizzes were used to assess key concepts by means of short online questions, homework were divided into traditional exercises and project oriented assignments. The final project grade was obtained through the *Fluency Rubric* average score, taking into account self-, peer-, expert-, and instructor assessments (See Appendix A). The *Investment Theory of Creativity Rubric* score was used as extra credit to enhance students' motivation.

The assigned final project was carried out in two stages (Figure 1). Thirty-eight students (from the three undergraduate programs) were grouped in teams of three to four members. Learning objectives for the proposed learning environment include: 1) Identify material balances in everyday situations, 2) use appropriate terminology to describe a material balance, 3) draw and completely annotate a flow chart, 4) choose a calculation basis to solve a material balance problem, 5) identify the overall system and subsystems in a material balance process, 6) identify the appropriate equations to calculate the missing process variables, 7) prepare a professional report of a material balance process, 8) demonstrate ability in oral communication to describe a material balance process, and 9) think creatively.

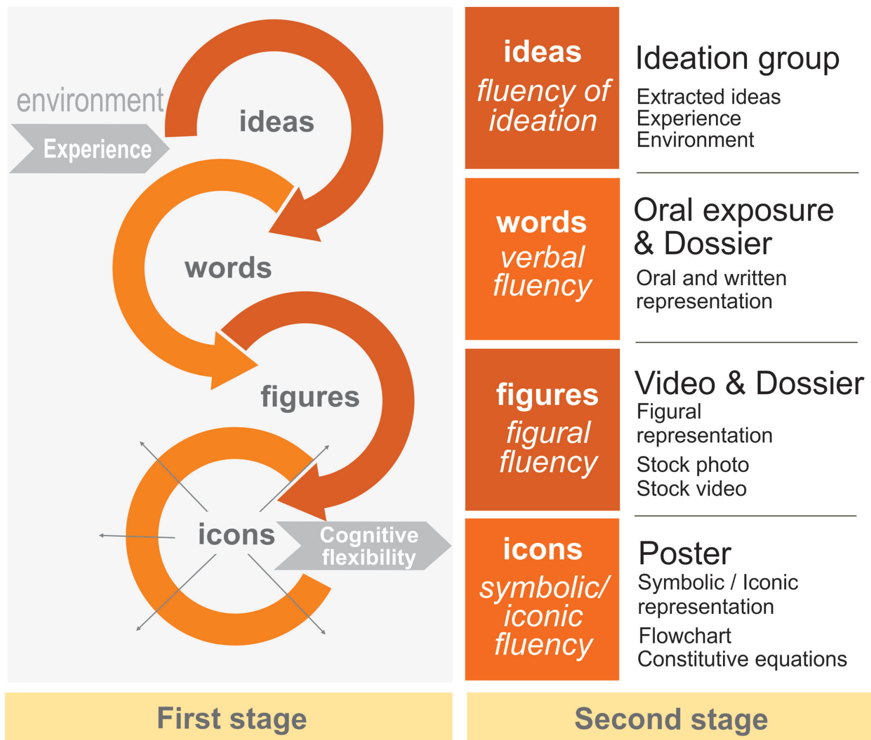


Figure 1. Outline of the proposed learning environment

In the first stage, in order to activate the process of flexible representations at three levels as previously described[20], we asked students to individually initiate a process of generating ideas and identify two material balances problems in their everyday (*image level*), that were of interest for them and from which they could demonstrate the mass conservation (that is accessible for representation and with enough information available). Subsequently, these problems had to be schematized in flowcharts (*schema level*), and solved (*theoretical level*) as a team; then by means of a multi-voting process, they chose the most feasible to be carried out experimentally. During four class sessions teams worked with total autonomy. In a second stage, we focused on re-activating the processes of flexible representations at three levels, analyzing the same item several times, in different contexts and for different purposes[5, 21]. At this second stage students went through every step of problem solving; based on their ideas, made decisions as a group, performed a logical planning process, evaluated materials to represent the material balance in oral, written, graphical, and symbolic ways (*ideas representation*)[16]. During this process students developed a video of their chosen process and conducted a photographic sequence of the mass balance to document the process in a dossier *(graphical representation)*. The students prepared a poster that included a flowchart of the material balance processes, as well as their systems, subsystems, and constitutive equations (*symbolic representation*). Finally, they documented the material balance process in a written report form (part of the dossier) and the entire team presented their material balance to an expert audience, explaining the material balance aided by their posters, videos, and dossiers (*oral and written representation*).

Final projects were presented to experts in the field (chemical, food, and environmental engineering teachers and senior undergraduate students) that assessed student creative thinking by means of a rubric adapted from the *Investment Theory of Creativity* (ITC) developed by Sternberg and Lubart[6, 8, 9], which provided a multidimensional assessment of creativity. The *ITC Rubric* assessed six areas: *Knowledge domain* (formal and informal), *Intellectuals styles* (autonomy and tolerance for ambiguity), *Motivation* (level of commitment, pride, and interest in the task), *Intellectual processes* (sensitivity to problems, ideation, ability to identify potential ideas, and ability to sell their ideas and persuade about its value), *Creative personality* (tolerance of ambiguity, risk taking, and perseverance), and *Product* (originality, quality, relevance, and feasibility). Possible performance levels were from *exemplar* (value of 4) to *benchmark* (value of 1). Additionally a *Fluency Rubric* was developed, which was divided into four modules that correspond to each project deliverable (dossier, poster, video, and oral presentation), and assessed fluency of ideas, verbal fluency, as well as graphical and symbolic fluency. Fluency Rubric performance level ranged from 4 (*excellent*) to 1 (*insufficient*), where 3 represents *sufficient* and 2 *deficient* performances.

Each project was evaluated in the following way: 1) Self-assessment, the *Fluency Rubric* should be self-assessed by the team; then 2) Peer-assessment, every team assessed another team deliverables (to compare theirs to other projects, recognize the contributions of other team, and learn to evaluate a material balance) by means of the *Fluency Rubric*; 3) Expert-assessment with both tested rubrics, a group of ten experts were visiting the exposition stands of projects (two projects for each expert); 4) Instructor assessment, every project was assessed by the course instructor by means of the *ITC* and *Fluency Rubrics*.

Results and discussion

Students were able to construct concrete examples of a material balance from an everyday situation (preparing pancakes; home-produced recycled paper; fruit juice extraction; cocktail making; sweet potato candy –*camote*– production; homemade cheese, pineapple marmalade, and gummy bears; lemonade making; preparing *dulce de leche*, and so on) and represent it in many ways (ideas, figures, iconic/symbolic, oral, and written). See Appendix B for specific examples.

Fluency Rubric

1) Ideas: Students achieved an average score of 3.6/4.0 in the generating ideas aspect; 90% of students were able to undertake an ideation process, participating with several proposals for the team project. This assessment includes sensitivity to problems in context and decision-making; every team reached a consensual agreement on the mass balance process for their final project. Interestingly, most teams chose some type of food processing for their project.

2) Figures: the average score obtained in this process representation was 3.5/4.0. Regarding flowchart development students obtained a mean grade of 3.3/4.0, although in some cases students did not identify in which process step the mass was lost; therefore, they were not able to represent it on the diagram.

3) Symbols: Most teams (70%) were able to perform a proper symbolic representation of their selected process. However, 13% of the class population failed to explain the reasons why in some cases there exists a "loss of mass", so they needed to made inferences and adjust numerical fractions in order to make the required calculations. 90% of the class population was able to define the constitutive equations for their mass balance process; even so their numerical solutions were scored with a mean of 2.8/4.0.

4) Oral: According to the experts' assessments, students successfully described the problem definition and solution and the group average score was 3.8/4.0. Only 30% of the teams were ranked as *sufficient* while 70% were scored as *excellent.*

Investment Theory of Creativity Rubric

Table 1 summarizes the obtained results regarding the *ITC Rubric*. It is important to remember that *knowledge of domain* includes application of formal and informal knowledge, which considers the ability to use factual, conceptual and procedural knowledge (formal) as well as the knowledge based on their experiences (informal). *Intellectual styles* includes indicators such as autonomy and rules, where they create their own rules and follow them, considering that their decisions must be constrained by the problem context and that their performance will be subjected to others' judgment. *Motivation* assesses the level of commitment, project pride, and interest in the task, which must be reflected on the presentation and defense of each deliverable. *Intellectual processes* include indicators such as sensitivity, problem identification, ideation, ability to recognize ideas that have potential to be valued, as well as ability to sell their ideas effectively and persuade of its value. *Creative personality* involves indicators such as tolerance for ambiguity, risk taking, will, and perseverance, demonstrating that they are able to overcome obstacles and persevere to achieve their main goal, as well as their willingness to continue growing and creating.

Table 1. Summary of *Investment Theory of Creativity Rubric* results

	Mean values	Standard deviation	Team #									
			1	2	3	4	5	6	7	8	9	10
Intellectual processes	2.94	0.44	3.00	3.43	3.29	3.29	2.00	2.71	2.71	3.14	3.29	2.57
Knowledge of domain	3.10	0.77	3.50	2.50	4.00	4.00	3.00	3.00	2.50	3.50	3.50	1.50
Intellectual styles	3.23	0.47	3.67	3.00	3.67	3.67	2.67	3.00	2.33	3.33	3.67	3.33
Motivation	3.38	0.52	3.75	3.00	3.75	3.75	2.75	3.00	2.50	3.75	4.00	3.50
Creative personality	3.28	0.51	3.25	3.75	3.50	3.75	2.50	2.75	2.75	3.50	4.00	3.00
Product	2.95	0.67	3.75	3.50	3.25	3.75	2.00	2.25	2.00	3.00	3.25	2.75

As can be noticed from the obtained results, most teams achieved a high score (>3.0/4.0) in every assessed criterion. *Motivation* was the best-judged criterion (3.38/4.0), therefore the video and project presentation allowed evaluators to identify a high level of project pride and interest in task. Students' motivation was much higher than in previous semesters' final projects. Another criterion with a high score was *creative personality*; although most teams chose some type of food processing for their every day situation, most of them were able to analyze their processes from different perspectives, including creative ideas in order to develop a professional material balance project, for instance naming their cookware as processing equipment (stove as a heater, blender as a mixer, spoon as an agitator, etc.). *Intellectual processes* and the *product* itself were the lowest scored features; in the case of the former, these lower grades are related to the lack of variety in their initial ideas; although formal knowledge was properly utilized, they were not able to use more widely their informal knowledge in order to look for more diverse examples. The obtained *product* was evaluated in terms of originality, technical quality, importance, and viability.

As can be observed in Table 1, seven of the studied teams (1, 2, 3, 4, 8, 9, and 10) achieved a similar score (> 3.0/4.0) for every assessed criterion, while the other three teams (5, 6, and 7) obtained lower scores. An interesting observation regarding these last result was detected through students' comments during the self-assessment stage: in these teams with lower performances, the commitment level of some team member(s) was not the adequate throughout project development, which was reflected on the quality of requested deliverables, including the final presentation.

The *Consensual Assessment Technique* (CAT) is a powerful tool used by creativity researchers in which panels of expert judges are asked to rate the creativity of creative products such as stories, collages, poems, and other artifacts[18, 23]. In our case, experts in the domain (chemical, food, and environmental engineering teachers and senior undergraduate students) in question (material balances) served as judges. The CAT is based on the idea that the best measure of the creativity of a work of art, a theory, a research proposal, or any other artifact is the combined assessment of experts in that field. The CAT is a powerful tool for assessing creativity. It has been well validated and is used widely in creativity research[23]. In our case, inter-rater reliabilities using *ITC* and *Fluency Rubrics* and the CAT, for the different assessed criteria ranged from 0.72 to 0.89.

It is worth mentioning that the proposed learning environment did had an effect on the learning objectives since students' performance was close to *exemplar* or *excellent* with regards to objectives: 2) use appropriate terminology to describe a material balance, 3) draw and completely annotate a flow chart, 4) choose a calculation basis to solve a material balance problem, 5) identify the overall system and subsystems in a material balance process, 7) prepare a professional report of a material balance process, and 8) demonstrate ability in oral communication to describe a material balance process; while for objectives 1) Identify material balances in everyday situations and 6) identify the appropriate equations to calculate the missing process variables, student performance was assessed as *sufficient*. As can be inferred from the *ITC* and *Fluency Rubrics*' results, the proposed learning environment enhanced creative thinking while material balances' problem solving.

Furthermore, reflections integrated in the final project dossiers, suggest that this project allowed students to strengthen their learning and understanding of key concepts regarding course learning objectives, expand their notion of a material balance and link this knowledge to real life. Some relevant thoughts that teams included in their dossiers are as follows:

- "It helped us to understand in a practical way a material balance ... and completely finish learning the concepts of mass, mass fractions, equations and subsystems"
- "We realized many things ... in real life a material balance doesn't always fit perfectly, in some cases equipment retain material and inlets are not equal to outlets"
- "It was really helpful to see how to put into practice the material balances course"
- "Making this project gave me the experience that I could not get in class, see how you can use this stuff in real situations"
- "It helped me to see the entire scenery of the wider material balances"
- "It helped us to understand more deeply"
- "I learned that everything around us is related to material balances"
- "It is not the same when you do not get all the data"

Final remarks

It is not new that there is a wide difference between active and traditional learning environments; even so it is gratifying to confirm this on a course that is traditionally based on the mathematical representation of different processes. In every case, students were able to build concrete examples of a material balance for an everyday situation and represent them in many ways (physically, verbally, symbolically, and by means of a multimedia presentation). The vast majority of students attained final project expected outcomes at an acceptable level. Regarding to transfer of learning, students clearly were able to create a link between abstract knowledge and a real context, demonstrating an appropriate understanding.

Acknowledgments

We acknowledge financial support from HEWLETT-PACKARD (HP) through the HP Catalyst Grant Initiative for the project "Critical Support Systems to Enhance the Development of 21st Century Expertise in Engineering Students: Using Tablet PCs and Associated Technologies, the *Framework for 21st Century Learning*, and Guidelines from Research on *How People Learn*". Author Husted gratefully acknowledges financial support for her PhD studies from *Programa de Mejoramiento del Profesorado* (PROMEP) of the Mexican Ministry of Public Education (SEP) and *Universidad Autónoma de Ciudad Juárez*.

References

1. AACU. 2013. *Association of American Colleges and Universities (AACU) Value Rubrics*. Available at: http://www.aacu.org/value/rubrics/index_p.cfm?CFID=27703138&CFTOKEN=51989935; accessed 8/30/2013.
2. Felder, R. M. 1987. On Creating Creative Engineers. *Engineering Education*, 77(4): 222-227.
3. Jonassen, D. H., Strobel, J., and Lee, C. B. 2006. Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education*, 95(2): 1–14.
4. Spiro, R., Coulson, R., Feltovich, P., and Anderson, D. 1988. Cognitive Flexibility Theory: Advanced knowledge acquisition in ill-structured domains. In *Proceedings of the 10th Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum.
5. Spiro, R., Vispoel, W., and Schmitz, J. 1997. Knowledge Acquisition for Application: Cognitive Flexibility and Transfer in Complex Content Domains. In *Readings in Executive Control Processes*. Hillsdale, NJ: Lawrence Erlbaum.
6. Sternberg, R. J. and Lubart, T. I. 1993. Creative Giftedness: A Multivariate Approach Investment. *Gifted Child Quarterly*, 37(1): 7-15.
7. Jonassen, D. H. 2011. *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments*. New York: Routledge.
8. Sternberg, R. J., Lubart, T. I., Kaufman, J. C. and Prelz, J. E. 2005. Creativity. In K. J. Holyoak and R. G. Morrison (Eds.) *The Cambridge Handbook of Thinking and Reasoning* (pp. 351-369). New York: Cambridge University Press.
9. Sternberg, R. J. and O' Hara L. 2005. Creatividad e Inteligencia. *Cuadernos de Información y Comunicación*, 10: 113-149
10. Richards, L. G. 1998. Stimulating creativity: Teaching engineers to be innovators. *Proceedings of the Frontiers in Education Conference*. 3: 1034-1039.
11. Donald, J. 2002. *Learning to Think: Disciplinary Perspectives*. San Francisco: Jossey-Bass.
12. Törnkvist, S. 1998. Creativity. Can it be taught? The Case of Engineering Education. *European Journal of Engineering Education*, 23(1): 5-12.

13. Felder, R. M. and Brent, R. 2004. The intellectual development of science and engineering students: Teaching to promote growth. *Journal of Engineering Education*, 93(4): 279–291.
14. Sheppard, S., Macatangay, K., Colby, A. and William, W. 2009. *Educating Engineers: Designing for the Future of the Field*. The Carnegie Foundation for the Advancement of Teaching. San Francisco: Jossey-Bass.
15. Senra, M. and Fogler, H. S. 2014. Teaching Creative Thinking and Transitioning Students to the Workplace in an Academic Setting. *Chemical Engineering Education*, 48(1): 9-16
16. Guilford, J. 1950. Creativity. *American Psychologist*, 5: 444-454.
17. Guilford, J. 1967. *The Nature of Human Intelligence*. New York: McGraw-Hill.
18. Baer, J. 1993. *Creativity and Divergent Thinking: A Task-Specific Approach*. Hillsdale, NY: LEA Ed.
19. Carevic, M. 2009. *Creatividad (I)*. Available in: http://www.psicologia-online.com/articulos/2006/creatividad.shtml; accessed 12/10/2013.
20. Naveh-Benjamin, M., McKeachie, W. J. and Lin, Y. G. 1998. Assessment and modification of flexibility of cognitive structures created in university courses. *Contemporary Educational Psychology*, 23: 209-232.
21. Korthagen, F. and Lagerwerf, B. 1995. Levels in learning. *Journal of Research in Science Teaching*, 32: 1011-1038.
22. Jonassen, D. H. 2000. El diseño de entornos constructivistas de aprendizaje. In C. Reigeluth (Ed.) *Diseño de la Instrucción: Teoría y Modelos.* Madrid, Spain: Santillana.
23. Baer, J. and McKool, S. S. 2009. Assessing Creativity Using the Consensual Assessment Technique. In C. S. Schreiner (Ed.). *Handbook of Research on Assessment Technologies, Methods, and Applications in Higher Education*. Hershey, PA: Information Science Reference

APPENDIX A: FLUENCY RUBRIC

Team		Project name			Date
Items		Excellent	Sufficient	Deficient	Insufficient
DOSSIER	Characteristics of Technical work	The work is presented stapled, it has a cover page with the names of all team members and project name. There is a context that guides the reader. The work is professional, legible, correct and clean. Content refers to what is proposed in the context, it has a photographic sequence describing the process accompanied by their respective discussion. There is a conclusion and final thoughts. It integrates the assessment rubric	The work is presented stapled, it has a cover page with the names of all team members and project name. There is a context that guides the reader. The work is professional, legible, correct and clean. Content refers to what is proposed in the context, it has a photographic sequence describing the process accompanied by their respective discussion. There is a conclusion.	The work is presented in a folder, it has a leaf at the beginning with the names of all team members and project name. There is a context that guides the reader. Work has misspellings. Content refers to what is proposed in the context, a photographic sequence has no description. There is a conclusion.	The work is presented in a folder, it has a leaf at the beginning with the names of all team members and project name. There is not a context that guides the reader. Work has misspellings. Content refers to what is proposed in the context, a photographic sequence has no description
		Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts
	Presentation of the problem	Integrate the two proposals made each of the team members, the problems are properly resolved. There is a written statement that mentions how they agreed on the problem to represents. The chosen problem is in writing and integrates the flowchart.	Integrate the two proposals made each of the team members, only some problems are resolved. There is a written statement that mentions how they agreed on the problem to represents. The chosen problem is in writing and integrates the flowchart	Present some problems of the team members unresolved. Present the problem in writing and integrates the flowchart.	Only present the problem represented in the flowchart
		Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts
POSTER	Flowchart	A poster flowchart where all elements of the process is properly presented, indicate the overall system and its subsystems if any properly identified. The basis of calculation clearly at all stages is identified. Realize an analysis of degrees of freedom of the overall system and the possible subsystems.	A poster flowchart where the elements of the process is presented, indicate the overall system and its subsystems if any properly identified. The basis of calculation clearly at all stages is not identified. Realize an analysis of degrees of freedom of the overall system.	A poster flowchart where the elements of the process are identified and their subsystems are presented. The basis of calculation is not identified nor did the analysis of degrees of freedom.	The poster is not presented in the exhibition, only can be checked in the dossier.
		Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts
	Constitutive equations	The equations used to calculate the variables determined by the process are clearly identified. (matter, mols) and the important terms. The equations are presented in the order they were used and in each of its stages.	Expose and identify equations that are the problem, but does not identify what stage were used.	Only use rule three in all stages of the process.	Cannot be identified the type of equation are used.
		Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts
	Analytical numerical solution	The methodology used is clearly identified, the way it operates and clearly exposes the simplifications, justifying the "order" of the method.	The name of the numerical or analytical method is identified, and its justification is indicated.	The information about the algorithm used can be extracted of the syntax or memories.	The methodology or algorithm used are not clearly.
		Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts
VIDEO	The process	The video shows the names of all members in the end. All members participate in both: the video and presentation. All elements and fails of the process are clearly presented, and currents can be identified, sinks or sources at all stages.	The video does not cover or show team members. All members participate in both: the video and presentation. Show all elements of the process and fails clearly, and currents can be identified, sinks or sources at all stages.	The video shows the names of all members in the end. Not all members participate in either video or presentation. The video shows the process but currents, sinks and sources are not identified.	The video does not show the names of members in the end. It is difficult identify the process.
		Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts
EXPOSITION	Physical representation of the project	All students are presented punctually for preparing their display tables. The display table exposes the project dossier for evaluations. Students realize the representation of their projects orderly facing the experts. All students are capable of describing the process facing the experts and respond their questions.	Missing a team member. The display table exposes the project dossier for evaluations. Students realize the representation of their projects orderly facing the experts. Students can describe the process facing experts and respond their questions.	All members are presented. The display table exposes the Project dossier for evaluations. Only some team members can explain the problem facing the experts, and only one of them respond their questions.	Missing team members. The display table exposes the Project dossier for evaluations. Only one of the team members responds the questions.
		Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts	Selfassessment / Pairs / Teacher / Experts

Scores

		Excellent	Sufficient	Deficient	Insufficient
EXCELLENT	Teams must have gotten excellent at least six sections and one sufficient (there are seven sections)				
SUFFICIENT	Teams must have gotten excellent at least five sections and any insufficient.				
DEFICIENT	Teams are deficient in three sections				
INSUFFICIENT	Teams are insufficient in two sections				
Team	Self Assessment Names of members				
Team	Pairs Assessment Names of members				
Teacher Assessment	Sign				
Expert Assessment	Sign				

Evaluation Material created by: Silvia Husted and Nelly Rámirez (2013) UDLAP,
Universidad de las Américas Puebla.
Engineering and Environmental Chemistry Department.
San Andrés, Cholula, Puebla México.

Figure A1. Fluency Rubric

APPENDIX B: EXAMPLES OF STUDENT WORK PRODUCTS

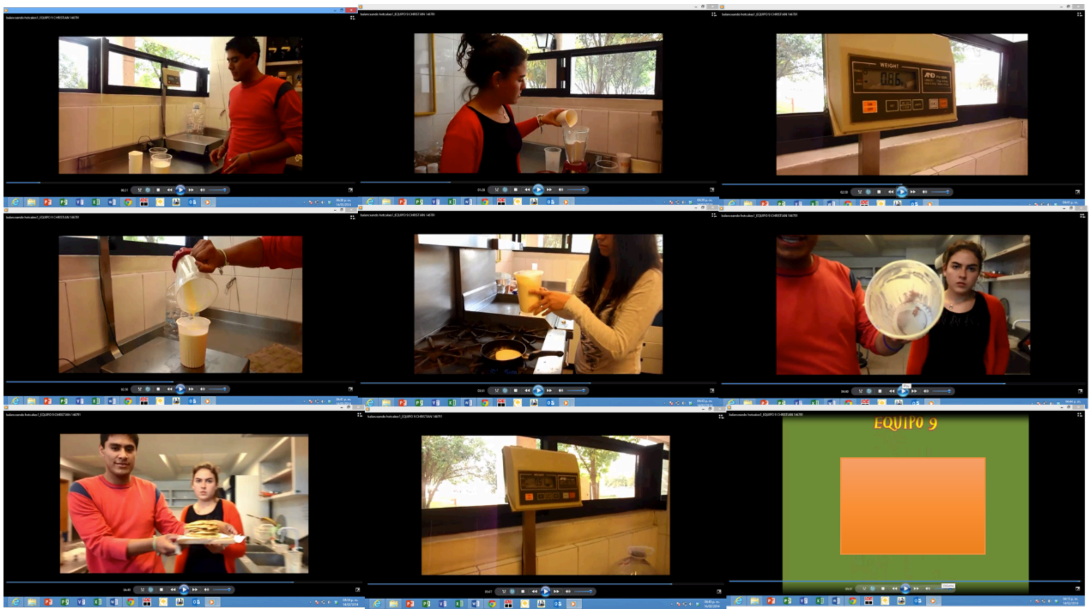
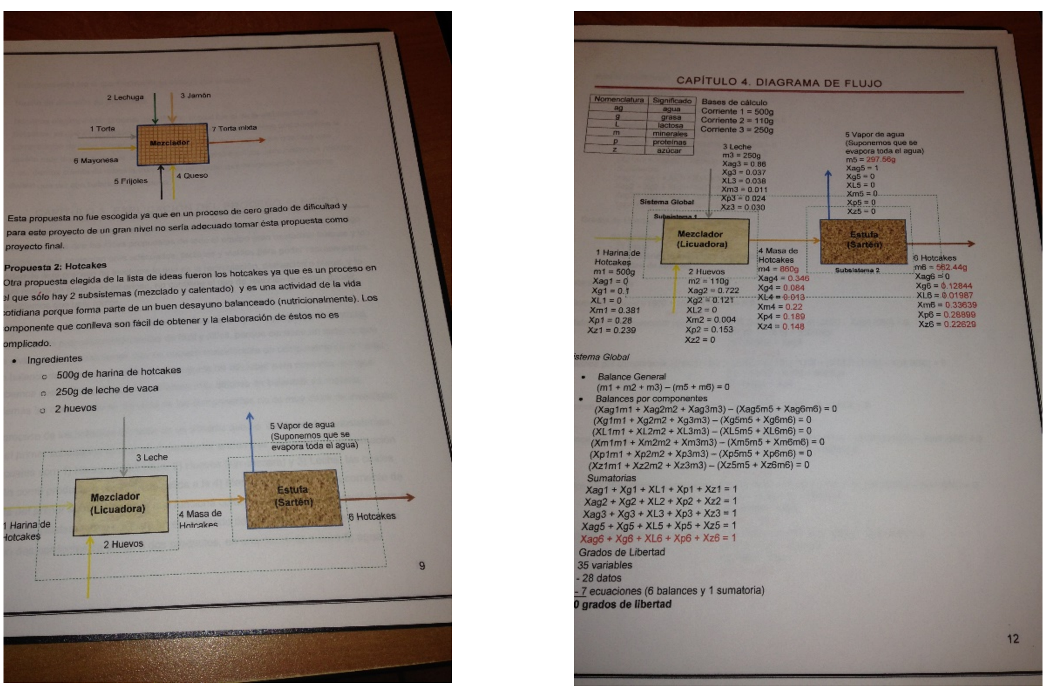


Figure B1. Video for pancake processing



2 Lechuga
3 Jamón
1 Torta
Mezclador
7 Torta mixta
6 Mayonesa
5 Frijoles
4 Queso

Esta propuesta no fue escogida ya que en un proceso de cero grado de dificultad y para este proyecto de un gran nivel no sería adecuado tomar ésta propuesta como proyecto final.

Propuesta 2: Hotcakes
Otra propuesta elegida de la lista de ideas fueron los hotcakes ya que es un proceso en el que sólo hay 2 subsistemas (mezclado y calentado) y es una actividad de la vida cotidiana porque forma parte de un buen desayuno balanceado (nutricionalmente). Los componente que conlleva son fácil de obtener y la elaboración de éstos no es complicado.

- Ingredientes
  - 500g de harina de hotcakes
  - 250g de leche de vaca
  - 2 huevos

3 Leche
5 Vapor de agua (Suponemos que se evapora toda el agua)
Mezclador (Licuadora)
Estufa (Sartén)
1 Harina de Hotcakes
4 Masa de Hotcakes
6 Hotcakes
2 Huevos

9

CAPÍTULO 4. DIAGRAMA DE FLUJO

Nomenclatura	Significado
ag	agua
g	grasa
L	lactosa
m	minerales
p	proteínas
z	azúcar

Bases de cálculo
Corriente 1 = 500g
Corriente 2 = 110g
Corriente 3 = 250g

3 Leche
m3 = 250g
Xag3 = 0.86
Xg3 = 0.037
XL3 = 0.038
Xm3 = 0.011
Xp3 = 0.024
Xz3 = 0.030

5 Vapor de agua (Suponemos que se evapora toda el agua)
m5 = 297.56g
Xag5 = 1
Xg5 = 0
XL5 = 0
Xm5 = 0
Xp5 = 0
Xz5 = 0

Sistema Global
Subsistema 1
Mezclador (Licuadora)
Estufa (Sartén)
Subsistema 2

1 Harina de Hotcakes
m1 = 500g
Xag1 = 0
Xg1 = 0.1
XL1 = 0
Xm1 = 0.381
Xp1 = 0.28
Xz1 = 0.239

2 Huevos
m2 = 110g
Xag2 = 0.722
Xg2 = 0.121
XL2 = 0
Xm2 = 0.004
Xp2 = 0.153
Xz2 = 0

4 Masa de Hotcakes
m4 = 860g
Xag4 = 0.346
Xg4 = 0.084
XL4 = ~~0.013~~
Xm4 = 0.22
Xp4 = 0.189
Xz4 = 0.148

6 Hotcakes
m6 = 562.44g
Xag6 = 0
Xg6 = 0.12844
XL6 = 0.01987
Xm6 = 0.33639
Xp6 = 0.28899
Xz6 = 0.22629

istema Global

- Balance General
  (m1 + m2 + m3) – (m5 + m6) = 0
- Balances por componentes
  (Xag1m1 + Xag2m2 + Xag3m3) – (Xag5m5 + Xag6m6) = 0
  (Xg1m1 + Xg2m2 + Xg3m3) – (Xg5m5 + Xg6m6) = 0
  (XL1m1 + XL2m2 + XL3m3) – (XL5m5 + XL6m6) = 0
  (Xm1m1 + Xm2m2 + Xm3m3) – (Xm5m5 + Xm6m6) = 0
  (Xp1m1 + Xp2m2 + Xp3m3) – (Xp5m5 + Xp6m6) = 0
  (Xz1m1 + Xz2m2 + Xz3m3) – (Xz5m5 + Xz6m6) = 0

Sumatorias
Xag1 + Xg1 + XL1 + Xp1 + Xz1 = 1
Xag2 + Xg2 + XL2 + Xp2 + Xz2 = 1
Xag3 + Xg3 + XL3 + Xp3 + Xz3 = 1
Xag5 + Xg5 + XL5 + Xp5 + Xz5 = 1
Xag6 + Xg6 + XL6 + Xp6 + Xz6 = 1

Grados de Libertad
35 variables
- 28 datos
- 7 ecuaciones (6 balances y 1 sumatoria)
0 grados de libertad

12

Figure B2. Dossier (in Spanish) for pancake processing material balances

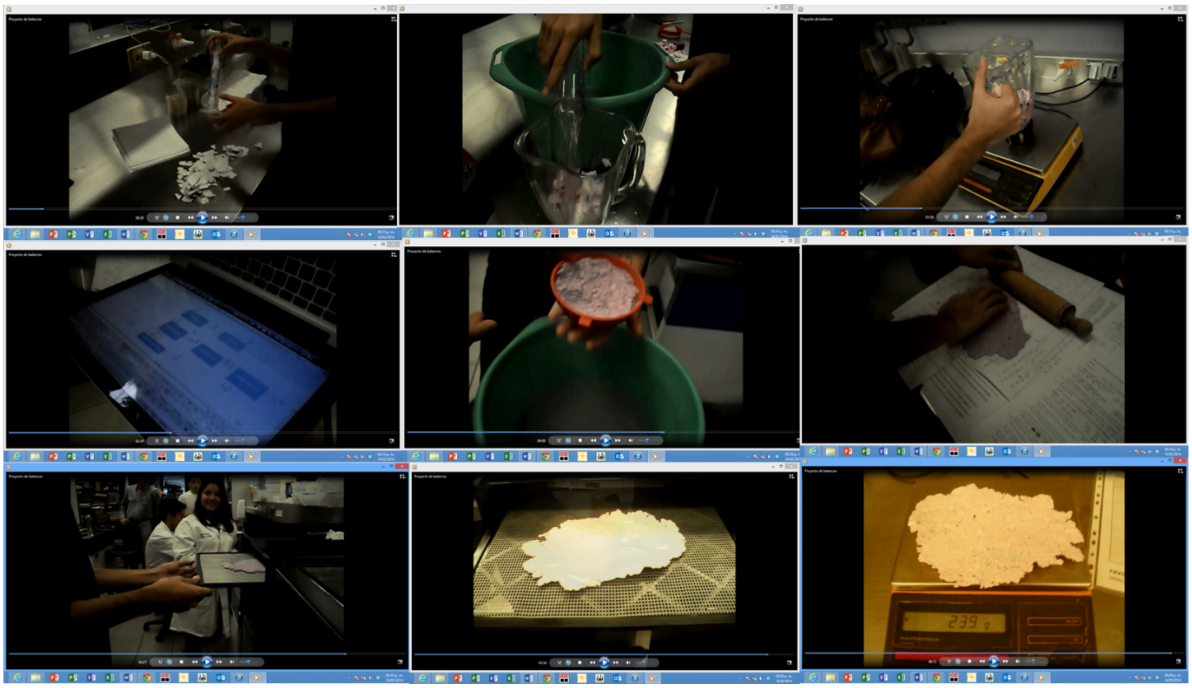


Figure B3. Video for a recycled paper process

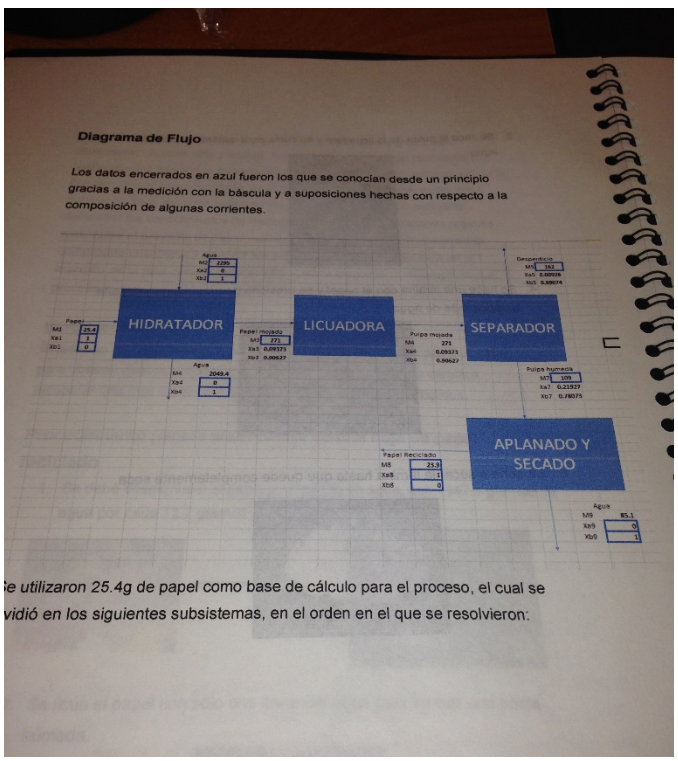


Figure B4. Dossier (in Spanish) for material balances of a recycled paper process