Problem-Solving Learning Environments for an Introduction to Food Engineering Course

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Abstract

The main task of a food engineer is to design and operate processes to transform raw materials into final products, particularly with the aim to control, prevent, or delay spoilage caused by chemical reactions, physical effects, and/or biological activity. At Universidad de las Américas Puebla (UDLAP) food engineering (FE) students recognize the knowledge and skills required to function in the different fields of FE, distinguish the main factors responsible for food spoilage and deterioration and combine theory and practice for the preservation of representative food products in the first-semester course entitled Introduction to Food Engineering.

Problem solving is an essential 21st century skill, specifically the ability to solve different kinds of problems and to identify and ask significant questions. Research has shown that knowledge constructed in the context of solving problems is better comprehended, retained, and therefore more transferable. Therefore, we designed and implemented some problem-solving learning environments (PSLEs) for the studied course. In this first semester introductory course is intended that students have a vision of what will be their undergraduate studies and future professional life. Through the incorporation of PSLEs the course pretends to recognize the importance of problem solving and evaluate course learning outcomes through the progress of solutions (and corresponding argumentations) posed by the students.

Problems vary in different ways, so different kinds of problems call on different conceptions and skills. Based on those differences among problems, different kinds of food engineering problems were developed, such as story problems (utilized as worked examples by the teacher), decision-making problems, troubleshooting/diagnosis problems, and design problems. Initial implementation of three PSLEs in the studied course during two different semesters was exploratory, intended to provide formative evaluation. Primary data sources were student assessments through an argumentation rubric and an in-depth interview with the students at the end of the semester. Furthermore, in order to evaluate student transfer of learning, a final project involving a decision-making/strategic performance problem (students had to identify dietary deficiencies of different people and generate proposals for improving their health) was applied.

Introduction

Practicing engineers are hired, retained, and rewarded for solving problems. Thus, engineering students should learn how to solve workplace problems. In general, workplace engineering problems are substantively different from the kinds of problems that engineering students most
often solve in the classroom; therefore, learning to solve classroom problems does not necessarily prepare engineering students to solve workplace problems\textsuperscript{2,3,5}. Therefore, the primary purpose of engineering education should be to engage and support learning to solve problems\textsuperscript{2,3}. Hence, we designed and implemented several problem-solving learning environments (PSLEs), a term that represents problem-solving instruction in a more open-ended way than problem-based learning\textsuperscript{3}.

The main task of a food engineer is to design and operate processes to transform raw materials into final products, particularly with the aim to control, prevent, or delay spoilage caused by chemical reactions, physical effects, and/or biological activity. At \textit{Universidad de las Américas Puebla} (UDLAP), food engineering (FE) students develop the knowledge and skills required to function in the different fields of FE, distinguish the main factors responsible for food spoilage and deterioration and combine theory and practice for the preservation of representative food products in the first-semester course entitled Introduction to Food Engineering, which learning outcomes include that students will be able to: a) identify the major components of food and the factors responsible for deterioration during storage, b) identify the main technologies available for food processing, c) identify the nutritional needs of humans, d) explain how processing operations affect the stability of foods, e) distinguish the role of microorganisms in the stability and safety of food, and f) explain how to maintain or to assess food quality.

Problem solving is a schema-based activity\textsuperscript{3-5}. That is, in order to solve problems, learners must construct schemas for problems. Constructing models of problems greatly facilitates schema development. Having constructed a robust schema for different kinds of problems, learners are better able to transfer their problem-solving skills. Learning to solve problems requires practice in solving problems, not learning about problem solving\textsuperscript{3}. PSLEs assume that learners must engage with problems and attempt to construct schemas of problems, learn about their complexity, and mentally wrestle with alternative solutions\textsuperscript{3,4}. Hence, we built PSLEs to engage and support students in learning how to solve problems by practicing solving problems\textsuperscript{5}.

PSLEs were developed by following the design activities proposed by Jonassen\textsuperscript{3}: 1) First we interacted with the professor of the studied course to identify and articulate problems relevant to the discipline; 2) We analyzed problems, first by creating a causal model of the problem space; 3) Then we conducted an activity theory analysis to identify the historical, cultural, experiential factors that affect problem solving on the context chosen\textsuperscript{6}; 4) Determined what kind of problems were each one of them; 5) Constructed case supports and cognitive scaffolds for each problem type; 6) To then construct each PSLE that included some combination of case components and cognitive strategies; 7) Finally implemented and assessed the effects of the developed PSLEs.

Problems vary in different ways, so different kinds of problems call on different conceptions and skills; consequently learning methods should also vary\textsuperscript{2-4}. Based on those differences among
problems, different kinds of introductory food engineering problems were developed, including story problems (utilized as worked examples by the teacher), decision-making problems, troubleshooting/diagnosis problems, and design problems. Through the incorporation of PSLEs the course pretends to recognize the importance of problem solving and evaluate course learning outcomes through the progress of solutions (and corresponding argumentations) posed by the students.

Argumentation is one of the most important cognitive processes engaged in solving most kinds of problems\(^4\). In most PSLEs, problem solving may be engaged by including some form of argumentation in the environment\(^3\). Purposes of those argumentation activities are to support better problem solving or to assess students’ understanding of both, domain content and problem-solving skills. Argumentation may be used to justify problem interpretations\(^3\). During the course, following the presentation of a case as problem to solve by the teacher, students utilized cases as analogues, cases as prior experiences, or cases as alternative perspectives\(^3,4\) to characterize what kind of problem was being solved and what important questions or issues need to be addressed. All of these are open to interpretation and therefore subject to argumentation. So, students were required to construct arguments in support of their problem interpretations.

Arguments should also be used to help students to justify alternative solutions to the problem\(^3\). Clearly, dialectic forms of argumentation are appropriate. During the course, individual students or groups of students had to make claims about the “best” solution and justify it in terms of warrants or case evidence which they garnered from the case as presented by the teacher or from their research outside classroom. The teacher provided several prompts as argument scaffolds, helping students to construct a coherent argument. Some prompts and directions were specific to the problem case they were discussing.

Argumentation is the means by which we rationally resolve questions, issues, and disputes and solve problems\(^3\). An argument consists of a claim (solution or conclusion) that is supported by principles (warrants), evidence (premises), and rebuttals against potential counterarguments. Fostering argumentation in PSLEs promotes problem solving. Arguing for alternative interpretations or solutions to problems is especially important when addressing ill-structured problems\(^3,5\).

One of the most comprehensive conceptions of the skills of argument is provided by Kuhn\(^8,10\), who proposes thinking as a form of formulating and weighting the arguments for and against a course of action, a point of view, or a solution to a problem\(^8\). She identifies five essential skills of argumentation:

- Generate causal theories to support claims (*supportive theory*)
- Offer evidence to support theories (*evidence*)
- Generate alternative theories (*alternative theory*)
- Envision conditions that would undermine the theories they hold (*counterarguments*)
- Rebut alternative theories (*rebuttal*)

According to Kuhn, an argument can be considered strong if it contains these components; while for Blair and Johnson⁷, a good argument must meet the following three criteria:

- there is an adequate relationship between the contents of the premises and the conclusion
  - *relevance*
- the premises provide enough evidence for the conclusion
  - *sufficiency*
- the premises are true, probable, or reliable
  - *acceptability*

These criteria are sufficient for judging the effectiveness of most arguments and useful to know how students developed their ability to argue throughout PSLEs. Initial implementation of three PSLEs in the studied course during two different semesters was exploratory, intended to provide formative evaluation. Primary data sources were student assessments through an argumentation rubric and an in-depth interview with the students at the end of the semester. Furthermore, in order to evaluate student transfer of learning, a final project involving a decision-making/strategic performance problem (students had to identify dietary deficiencies of different people and generate proposals for improving their health) was implemented.

**Methodology**

The course *Introduction to Food Engineering* is offered to students in their first semester of the *Food Engineering Licenciatura* (BS) at UDLAP. The studied course was conducted in two weekly sessions of 75 minutes each during fall 2011 and 2012 semester in which eight (6 women) and five students (4 women) were enrolled, respectively. One weekly session was dedicated to reviewing theoretical basics of the discipline at introductory level, such as the concepts of food quality, food safety, food spoilage and stability, food preservation, food sensory evaluation, and human needs in terms of nutrition, among others. The other weekly session was conducted in a laboratory where they perform practically some of the concepts that were covered in the theory portion. Further, students participated in the elaboration/preservation of a wide variety of processed foods such as cheese, tofu, confectionery products, baked goods (bread), canned food, dehydrated food, and frozen foods, among many others.

Learning outcomes of the course include that students will be able to:

1. identify the major components of food and the factors responsible for deterioration during storage
2. identify the main technologies available for food processing
3. identify the nutritional needs of humans
4. explain how processing operations affect the stability of foods
5. distinguish the role of microorganisms in the stability and safety of food
6. explain how to maintain or to assess food quality.

A survey that assessed students’ perception regarding the importance of these outcomes as well as their progress in achieving them was applied at the end of the course.

Initial implementation of three PSLEs in the studied course during two different semesters was exploratory, intended to provide formative evaluation. Primary data sources were student assessments through an argumentation rubric and an in-depth interview with the students at the end of the semester. The three problem-solving learning environments (PSLEs) for the introductory course in Food Engineering that will be presented were categorized (following Jonassen\(^3\)) as a troubleshooting/diagnosis problem, a design problem, and a decision-making=strategic performance problem.

We followed Kahn\(^{11}\) to develop PSLEs scenarios that were:
- Hypothetical: representing a possible future
- Selective: representing one possible state of complex, interdependent, dynamic and affairs
- Bounded: consisting of a number of states, events, actions, and consequences that may occur in the future
- Connected: by causally related elements and events
- Assessable: providing a judgment based on probability

The following paragraphs describe each of the assessed PSLEs:

**Problem 1. Troubleshooting/Diagnosis Problem**

You attended to a big party where they served a wide variety of dishes (appetizers, entrees, salads, soups, main courses (made from meat, fish, seafood and chicken), desserts, and pastries. During the days after the party, they heard that several of the guests became ill. Some of your friends mentioned that the disease was related to food consumption and in particular with the organism mentioned below (a different microorganism was assigned to each student, microorganisms include: Staphylococcus aureus, Listeria monocytogenes, Salmonella, Clostridium perfringens, Escherichia coli O157: H7, among others)

As a specialist in Food Engineering, you need has to prepare a document (3 pages maximum) explaining what could have happened? Must contain some details (see below) to help your friends understand what happened:
- How common is this disease?
- Name at least two premises about what happened to get sick the guests
- Characteristics of the organism
What are the characteristics of the disease, what are the symptoms?

Related foods and conditions that promote the presence of the organism, as well as conditions under which the food was contaminated

Groups of people who are most affected

Infectious dose to cause disease

What is your conclusion about what happened to the food served that day?

What is your recommendation to avoid this problem?

You can consult as a starting point the information contained in the class website. However, your final document should include additional references.

Troubleshooting is one of the most common forms of everyday problem solving. Although troubleshooting is most commonly taught as a procedure, it requires a combination of domain and system knowledge (conceptual models of the system including system components and interactions), flow control, fault states (fault characteristics, symptoms, contextual information, and probabilities of occurrence); troubleshooting strategies such as search and replace, serial elimination, and space splitting; and fault testing procedures.

The first part of diagnosis-solution problems, diagnosis, is quite similar to troubleshooting. Most diagnosis-solution problems require identifying a fault state, just like troubleshooting. However, in troubleshooting, the goal is to repair the fault and to get the system back online as soon as possible, so the solution strategies are more restrictive. Diagnosis-solution problems usually begin with a fault state similar to troubleshooting. In a spiral of data collection, hypothesis generation and testing, the problem-solver focuses in a differential diagnosis to suggest a solution. Frequently, there are multiple solutions and solution options that are imposed by the problem. It is this ambiguity in solution options that distinguishes diagnosis-solution problems from troubleshooting. Note that as problem-solvers gain experience, the diagnostic process becomes more of a process of pattern recognition.

Some of the most important characteristics of troubleshooting/diagnosis problems that were used for design this PSLE are:

- appear ill-defined because the troubleshooter must determine what information is needed for problem diagnosis
- require deep-level understanding of the system being troubleshooting
- usually possess a single fault state, although multiple faults may occur simultaneously
- rely most efficiently on experience-based rules for diagnosing most of the cases, making it more difficult for novices to learn
- require learners to make judgments about the nature of the problem
- vary significantly in terms of system complexity
Problem 2. Design Problem
You are requested to make a video explaining a process of food preservation (food processing). Some of your friends/colleagues did not know the important steps to transform and preserve food using this technology (a different technology was assigned to each student, food processes include: freeze-drying, drying, cheese-making, canning, gum technology, among others).

As a specialist in Food Engineering you need to prepare a document (3 pages maximum) and a video (3-5 min) that explain and help to understand the process.

- What process is based?
- What equipment can be used?
- Description of equipment
- How does it work?
- What foods can be processed / transformed with this technology?
- Examples

You can consult as a starting point the information contained in the class website. However, your final document should include additional references.

Perhaps the most ill-structured kind of problem is design\textsuperscript{3,12}. Design problems require applying a great deal of domain knowledge with a lot of strategic knowledge. They possess multiple solutions, with multiple solution paths. Perhaps the most vexing part of design problems is that they possess multiple criteria for evaluating solutions, and these criteria are often unknown. Ultimately, the designer must please the client; however, the criteria for an acceptable design are usually unstated. Design problems often require the designer to make judgments about the problem and to defend them or to express personal opinions or beliefs about the problem; so ill-structured problems are uniquely human interpersonal activities\textsuperscript{3,12}.

Problem 3 (Final Project). Decision-Making/Strategic Performance Problem
For this assignment you are required to prepare a written report (3 pages) and a 5-7 minute presentation about nutrition requirements and diet among your friends/colleagues:

- Apply the questionnaire (gender, height, weight, daily physical activity, foods consumed in one day) to at least 10 people
- Analyze the results obtained regarding caloric needs
- Analyze information about diet
- Analyze and discuss the data obtained
  - Identify deficiencies and/or abuses in at least three nutrients and propose solutions (food to eat or reducing their consumption) according to your findings

You can consult as a starting point the information contained in the class website. However, your final document should include additional references.
Decision-making problems usually require that problem solvers select a solution from a set of alternative solutions. Traditional conceptions of decision making posit a set of alternative criteria that decision makers work through in order to identify the optimal solution. Those criteria may be provided to the problem solver(s), or the solver(s) may have to identify the most relevant criteria. Everyday life is replete with decision-making problems. Businesses also daily solve many decision-making problems. Though these problems typically require selecting one solution, the number of decision factors to be considered in deciding among those solutions as well as the weights assigned to them can be very complex.

According to Yates and Tschirhart, there are many different kinds of decisions, including:

- **Choices**: where you select a subset from a larger set of alternatives
- **Acceptances/rejections**: a binary choice in which only one specific option is acknowledged and must be accepted or not
- **Evaluations**: statements of worth that are backed up with commitments to act
- **Constructions**: attempts to create ideal solutions given available resources

Decisions, regardless of kind, include the following features:

- **Action**: Action is taken by the decision maker, typically involving a selection
- **Commitment**: Decisions are made as soon as there is a commitment to act
- **Intention**: Decisions are driven by a purpose or intention (usually thought to be optimization of value, benefit, or utility)
- **Satisfying results**: Decisions that provide the greatest utility are the most satisfying
- **Specified individuals**: Decisions are made for someone by someone

Strategic performance entails real-time, complex activity structures where the performers apply a number of tactical activities to meet a more complex and ill-structured strategy, usually under significant time pressure. In order to achieve the strategic objective, the performer applies a set of complex tactical activities designed to meet strategic objectives. Typically there are a finite number of tactical activities that have been designed to accomplish the strategy; however, the mark of an expert tactical performer is his or her ability to improvise or construct new tactics on the spot to meet the strategy. Strategic performances can be quite complex yet performed in real time. The options can be quite numerous and their implementation quite complex.

For the three PSLE assignments a specific rubric (Table 1) was utilized to assess students’ argumentation skills. Students’ papers and videos were evaluated by four reviewers (the course instructor, a professor from UDLAP Food Engineering faculty, and two students from UDLAP’s PhD program in Science, Engineering, and Technology Education).
Table 1. Argumentation Rubric (adapted from Jonassen^3)

<table>
<thead>
<tr>
<th></th>
<th>Needs improvement 1</th>
<th>Fair 2</th>
<th>Good 3</th>
<th>Excellent 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequacy of Premises</td>
<td>No premises stated; only unsupported conclusions.</td>
<td>Few premises stated; most unclear.</td>
<td>Most premises stated explicitly; most clear.</td>
<td>All premises stated explicitly.</td>
</tr>
<tr>
<td>Credibility of Premises</td>
<td>Sources of evidence are weak, filled with unsupported evidence and propaganda.</td>
<td>Sources of evidence are questionable or origin is unknown.</td>
<td>Sources of evidence mostly valid with limited amounts of unknown data.</td>
<td>Sources of evidence (personal, written, etc.) are unimpeachable; accepted as fact.</td>
</tr>
<tr>
<td>Organization of Arguments</td>
<td>Arguments are indistinguishable; unorganized; do not support each other.</td>
<td>Arguments identified; relationships to each other not obvious.</td>
<td>Arguments articulated but partially integrated; relationships to each other usually positive.</td>
<td>Each argument separated; sequenced logically to support solution to problem.</td>
</tr>
<tr>
<td>Quality of Conclusions (claims)</td>
<td>Conclusions unrelated to problem needs or solution.</td>
<td>Few conclusions relate to problem needs or solutions; inconsistent relationships.</td>
<td>Conclusions relate to problem generally, but some unclear; usually support stated solution.</td>
<td>All conclusions relevant to problem; support solutions; related to needs.</td>
</tr>
<tr>
<td>Writing (content/ideas)</td>
<td>Writing is extremely limited in communicating knowledge, with no central theme.</td>
<td>Writing does not clearly communicate knowledge. The reader is left with questions.</td>
<td>Writing is purposeful and focused. Piece contains some details.</td>
<td>Writing is confident and clearly focused. It holds the reader’s attention. Relevant details enrich writing.</td>
</tr>
</tbody>
</table>

**Results and discussion**

Figure 1 displays the students’ perception about Introduction to Food Engineering course learning outcomes; for course outcomes 1, 2, 4, 5, and 6 the importance of the outcome was greater and significantly different (p<0.05) from the progress students perceived they achieved regarding the corresponding outcome. For outcome 3 (identify the nutritional needs of humans) the difference was significant at p<0.10. It is not surprising that for Food Engineering first-semester students the evaluated outcomes were all important since they represent valuable topics of the discipline; about their progress they felt that because of taking the course they moderately achieved the learning outcomes, which is expected for an introductory course and first-semester students.
Figure 1. Introduction to Food Engineering students’ perception regarding importance of (and progress in achieving them) course learning outcomes: 1) identify the major components of food and the factors responsible for deterioration during storage, 2) identify the main technologies available for food processing, 3) identify the nutritional needs of humans, 4) explain how processing operations affect the stability of foods, 5) distinguish the role of microorganisms in the stability and safety of food, and 6) explain how to maintain or to assess food quality.

Figure 2 presents the mean of the student scores obtained through the argumentation rubric (Table 1) for each tested problem and Figure 3 the global average scores. No significant difference (p>0.05) was found among the scores obtained for the three assessed problems regarding each one of the assessed criteria by means of the rubric. In relation to credibility of premises, organization of arguments, and writing (content/ideas), students obtained scores close to 3.0 points (out of 4.0), which represent that they accomplished the criteria being assessed but can further improve their performance. Regarding adequacy of premises, students need additional improvement; while for the quality of conclusions (or claims) they obtained their highest scores. Depending on the nature of the problem (troubleshooting/diagnosis, design, or decision-making/strategic performance), the mean scores varied, being more difficult for first-semester students, in general, problem 1 (troubleshooting/diagnosis), followed by the final project (decision-making/strategic performance). It can be observed in Figure 3 that the criterion adequacy of premises was scored the lowest while quality of conclusions was the one with the highest scores, this can be attributed to the following: students at the beginning of the problem stated, in general, their premises without having enough information to support to them as well as their hypotheses. However, for their final solution (or conclusion) of the problem, they investigated and analyzed bibliographic material, problem context, processes involved, etc. This allowed them to have more information to assert their conclusions.
Figure 2. Mean scores (and standard deviations) of the student scores obtained through the argumentation rubric (Table 1) for each tested problem (1: troubleshooting/diagnosis, 2: design, or 3: decision-making/strategic performance) in the course Introduction to Food Engineering.

Figure 3. Mean scores (and standard deviations) of the student scores obtained through the argumentation rubric (Table 1) in the course Introduction to Food Engineering.
During the in-depth interviews with the students at the end of the semester, the vast majority reported to be very or highly committed with the final PSLE that as stated before was utilized to evaluate student transfer of learning; 57% of students constructed coherent explanations about the outcomes of each option they pursued, precisely explained their thought process, as well as the project purpose and steps followed to solve the project; while 29% of students recognized only part of these, and 14% of students did not clearly recognized their decision-making processes to support their choices.

Science (and engineering) educators have become especially supportive of argumentation when learning and problem solving. They argue that argumentation is central to scientific (and engineering) thinking\textsuperscript{3,5,10,14,15}. Practicing scientists engage in argumentation in order to articulate and refine their own scientific knowledge\textsuperscript{16}. Argumentation is also associated with a social-constructivist conception of meaning making, where students learn through reflective interactions (arguments) that engage the social co-construction of knowledge\textsuperscript{3,14,15}. Although science educators widely endorse inquiry learning, Duschl and Osborne\textsuperscript{17} argued that teaching science (engineering) as a process of inquiry without the opportunity to engage in argumentation, the construction of explanations and the evaluation of evidence is to fail to represent a core component of the nature of science (engineering) or to establish a site for developing student understanding. Science (engineering) as argument is to link the primary thinking activity of scientists (engineers) to our students\textsuperscript{10}.

Another reason for fostering argumentation is that it engages deeper and more mature epistemological levels of learning\textsuperscript{3}. By arguing the basis on which claims are made, students investigate the epistemological foundations of knowledge domains\textsuperscript{15}. At the very least, argumentation engages student thinking at the multiplicity level (some knowledge is right or wrong, but most is not yet known) on Perry’s scale\textsuperscript{18}, and it is likely that argumentation may result in contextual relativism (students learn methods of their discipline) and possibly even commitment with relativism (choices made in the face of legitimate alternatives)\textsuperscript{3}. Another motive to foster argumentation is its effects on conceptual change. Conceptual change occurs when learners change their understanding of concepts they use and the conceptual frameworks that encompass them, reorganizing their frameworks to accommodate new perspectives. Argumentation leads to conceptual change\textsuperscript{3}.

Embedding argumentation in science (engineering) learning environments enhances conceptual and epistemic understanding and helps to make scientific (engineering) reasoning visible\textsuperscript{17}. Constructing arguments engages conceptual change because of the high conceptual engagement in students\textsuperscript{19}.
Final remarks

Problem-solving learning environments applied in this first implementation, favored the development of students’ ability to argue. In general, their quality of conclusions (or claims) were good, while their credibility of premises, organization of arguments, and writing (content/ideas) were adequate for first-semester students but can further improve their performance. In subsequent semesters more work is needed regarding adequacy of premises in order to further promote them and help students detect by means of specific argumentation scaffolds during problem solving\textsuperscript{20} these inconsistencies in their argumentations.

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