**Using the book for teaching Lean Product Development (LPD)**

**Abstract**

The approach suggested here is based on how we used the book’s content to structure a Lean Product Development (LPD) course at the *Instituto Tecnológico de Aeronáutica* – ITA ([www.ita.br](http://www.ita.br)). The course was offered in the Mechatronic Engineering graduate program, in the period from 2011 to 2016, and the attendees were Master candidates, Doctorate candidates, and product development practitioners from the industry.

## 1. Introduction

The lean thinking (or philosophy) is a way to specify value, align the value-added actions, when requested execute these actions without interruption, and improve continuously (Womack and Jones, 2003). In product development, adding customer value can be less a function of doing the right activities (or of not doing the wrong ones) than of getting the right information in the right place at the right time (Kennedy, 2003). Hence, the focus of lean must not be restricted to activity “liposuction” (waste reduction), but must address the PDP as a system (value creation) (Browning et al. 2002).

One of the first challenges we faced was embedding the lean philosophy into the course. The resulting “Lean Journey”, which is proposed by the course, has a value-centric approach, and advocates that learning LPD is not about learning tools, but understanding how to apply the lean philosophy.

In order to deliver the proposed value, the course was structured using the book’s metaphor of a “Lean Wheel System” (Figure 1). The Lean Wheel System shows pictorially that the tools, techniques, and processes are means and not the end: the lean philosophy itself comprising the concepts of delivering value and yet reducing waste, added to the continuous improvement approach are the core of the LPD System.

The Lean Wheel System is composed by the following elements:

* **The Track**: Each wheel has to be designed considering the terrain where it is used; in this case, the environment is composed by the Product Development characteristics, particularly its relation to the market the company is in. Therefore, the concepts, tools, and techniques presented in this book might not fit other “tracks” properly.
* **The Car**: Any wheel has to fit the car it is attached to. Failing to mount on the car reduces its capacity to provide high performance and a safe drive. In this metaphor, the car represents the whole company for which a successful stream of new products moves it forward.
* **The Wheel Hub**: The hub guarantees that the Lean Product Development initiatives are not alone, but connect to the whole lean enterprise (the car). Included in this part is the “Core Lean,” composed of Continuous Improvement and the concepts of Value and Waste which are applied to the Product Development.
* **The Wheel**: The wheel itself includes all supporting organizational aspects encompassing the Lean Product Development Organization (LPDO) culture: Organizational Structure, Knowledge Management, and Continuous Improvement aspects.
* **The Tire**: This is the part that actually interfaces with the track, and includes: Lean PDP, Lean PD Tools, and Lean PD Techniques.

The remaining of this material is organized as follows. Section 2 presents the course’s proposed “lean journey”; Section 3 describes the homework and classroom exercises; and Section 4 includes some practical remarks from the previous experience while offering the course.

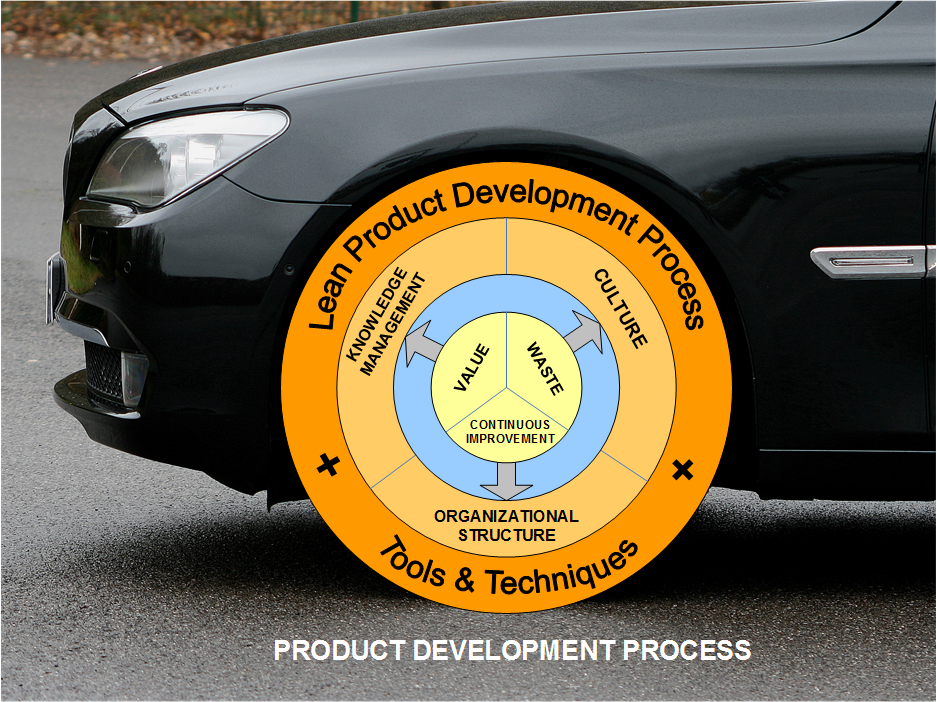


Fig.1: The “Lean Wheel System”

## 2. The Lean Journey Path

The course schedule set the lean journey path, where the Lean Wheel System’s elements are presented in an interlaced way. The schedule, which is composed by sixteen three-hour meetings, is divided into two blocks. At the end of each block, the students are evaluated according to their theoretical and practical knowledge.

In sequence each of the week’s meetings is described and related to the book’s chapters. Note that each book chapter references supporting bibliography, which are optional reading to the course. We although require some additional reading to better illustrate the classes’ topics. The homework and exercises are described in Section 3.

## Week 1

|  |  |
| --- | --- |
| **Objective** | Presenting the course, getting acquainted with the attendees, describing the context in which the course is set (the product design and development process + the lean philosophy), and discussing the course-long practical exercise. |
| **Topics** | - Course presentation and expectation’s setting.  - Product Development Overview.  - Lean Principles Overview.  - Course-long practical exercise description. |
| **Book chapter and additional reading** | Book Chapters 1, 2 and 3.  Radeka and Sutton (2007). |
| **Pedagogic resource** | Lecture, Homework 1. |

## Week 2

|  |  |
| --- | --- |
| **Objective** | Presenting the concept of value across several disciplines, and showing how it plays a central role in the lean philosophy, particularly in the case of LPD. |
| **Topics** | - Homework 1 groups’ presentation.  - The concept of “Value”.  - LPD value creation obstacles. |
| **Book chapter and additional reading** | Book Chapter 4 and Appendix A. |
| **Pedagogic resource** | Presentation, Lecture, Exercise 1. |

## Week 3

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| --- | --- |
| **Objective** | Experiencing in a game environment the consequences of some common practices in the traditional (non-lean) PDP. |
| **Topics** | - Game presentation and rules description.  - Game playing. |
| **Book chapter and additional reading** | Game material. |
| **Pedagogic resource** | Exercise 2 |

## Week 4

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| --- | --- |
| **Objective** | Presenting the concept of waste, by discussing the negative aspects perceived during the previous week’s game (Exercise 2), and by determining how these aspects could be avoided. |
| **Topics** | - The concept of “Waste” in the product development context.  - How to identify the wastes in the PDP.  - Waste reduction/elimination prioritization in the PDP.  **-** Continuous improvement. |
| **Book chapter and additional reading** | Book Chapters 5 and 6.  Pessôa et al. (2009); Pessôa and Seering (2014). |
| **Pedagogic resource** | Lecture, Exercise 3. |

## Week 5

|  |  |
| --- | --- |
| **Objective** | Presenting the Lean Product Development Process, introducing the Value Function Deployment, and describing the study phase’s value identification activities. |
| **Topics** | - How to define and keep track of the value proposition.  - Modified Data Flow Diagram (DFD) and objective tree.  - From Value to Requirements.  - Prioritizing the value. |
| **Book chapter and additional reading** | Book Chapters 9 and 10. |
| **Pedagogic resource** | Lecture, Exercise 4. |

## Week 6

|  |  |
| --- | --- |
| **Objective** | Presenting the Lean Product Development Organizational Culture and advising the groups about the development of the course-long practical exercise. |
| **Topics** | - Aspects from the lean enabling organizational culture.  - Advising the groups as part of the course-long practical exercise. |
| **Book chapter and additional reading** | Book Chapter 7. |
| **Pedagogic resource** | Lecture, students advising (while advising a group, the other groups keep working in their project as part of the course-long practical exercise). |

## Week 7

|  |  |
| --- | --- |
| **Objective** | Evaluating the theoretical knowledge. |
| **Topics** | - Individual Test  - Sole and group reflection of the progress so far. |
| **Book chapter and additional reading** | Book Chapters 1, 2, 3, 4, 5 and 6. |
| **Pedagogic resource** | Classroom Test |

## Week 8

|  |  |
| --- | --- |
| **Objective** | Evaluating the practical knowledge. Each of the groups of students presents their VFD’s value identification matrix as part of their course-long exercise. |
| **Topics** | - Course-long practical exercise – Intermediate Presentation. |
| **Book chapter and additional reading** | Book Chapters 9 and 10. |
| **Pedagogic resource** | Group presentation. |

## Week 9

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| **Objective** | Let the students have a week break. This week is also a buffer and can exceptionally be used to replace a missing class. |
| **Topics** | - Course Break. |
| **Book chapter and additional reading** | -- |
| **Pedagogic resource** | -- |

## Week 10

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| --- | --- |
| **Objective** | Describing the study phase’s value proposition activities. |
| **Topics** | - Updating your obeya.  - Filling the VFD’s rework avoidance sub-matrix.  - Exploring the solution space using morphological chats and 7 ways.  - Risk management and set-based concurrent engineering (SBCE). |
| **Book chapter and additional reading** | Book Chapter 11.  Ward et al. (1995); Sobek, Ward, and Liker (1999). |
| **Pedagogic resource** | Lecture, Exercise 5. |

## Week 11

|  |  |
| --- | --- |
| **Objective** | Presenting the Lean Product Development Organization Knowledge Management and advising the groups about the development of the course-long practical exercise. |
| **Topics** | - The Lean Organization is a knowledge management organization.  - The A3 report planning method.  - Advising the groups as part of the course-long practical exercise. |
| **Book chapter and additional reading** | Book Chapter 8. |
| **Pedagogic resource** | Lecture, students advising (while advising a group, the other groups keep working in their project as part of the course-long practical exercise). |

## Week 12

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| --- | --- |
| **Objective** | Describing the study phase’s planning activities and advising the groups about the development of the course-long practical exercise. |
| **Topics** | - Study Phase - Planning Activities.  - Pulled development execution => Pull events. |
| **Book chapter and additional reading** | Book Chapter 12. |
| **Pedagogic resource** | Lecture, students advising (while advising a group, the other groups keep working in their project as part of the course-long practical exercise). |

## Week 13

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| --- | --- |
| **Objective** | Presenting development project cases. |
| **Topics** | - Thermo Baby Development Project.  - Robot Based Flight Simulator Development Project. |
| **Book chapter and additional reading** | Book Chapters 15 and 16. |
| **Pedagogic resource** | Lecture. |

## Week 14

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| **Objective** | Describing the execution phase’s activities and advising the groups about the development of the course-long practical exercise. |
| **Topics** | - The project execution obeya.  - Breaking down the VFD as the design detailing progresses.  - The VFD and changing management. |
| **Book chapter and additional reading** | Book Chapter 13. |
| **Pedagogic resource** | Lecture, students advising (while advising a group, the other groups keep working in their project as part of the course-long practical exercise). |

## Week 15

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| --- | --- |
| **Objective** | Discussing strategies for changing a traditional development process into a lean product design and development process. |
| **Topics** | - Setting your attitude.  - Before you begin the journey.  - Setting a travel plan.  - On the “bumpy” road |
| **Book chapter and additional reading** | Book Chapter 14. |
| **Pedagogic resource** | Lecture, students advising (while advising a group, the other groups keep working in their project as part of the course-long practical exercise). |

## Week 16

|  |  |
| --- | --- |
| **Objective** | Evaluating the theoretical knowledge. |
| **Topics** | - Individual Test  - Sole and group reflection about the course. |
| **Book chapter and additional reading** | Book chapters 7, 8, and 9. |
| **Pedagogic resource** | Classroom Test |

## Week 17

|  |  |
| --- | --- |
| **Objective** | Evaluating the practical knowledge. Each of the groups of students presents their course-long exercise’s results. |
| **Topics** | - Course-long practical exercise – Final Presentation. |
| **Book chapter and additional reading** | Book Chapters 9 to 13. |
| **Pedagogic resource** | Group presentation. |

## 3. Practical driving lessons

In order to “roll” the Lean Wheel System through the path, a course-long practical exercise, homework, and a series of 5 short classroom exercises where included into the course. The exercises aim to practice the theory and foster discussion (Figure 2), when they can “go and see/perceive” how the theory is applied to practice. In sequence we present a short description of the homework and the exercises.

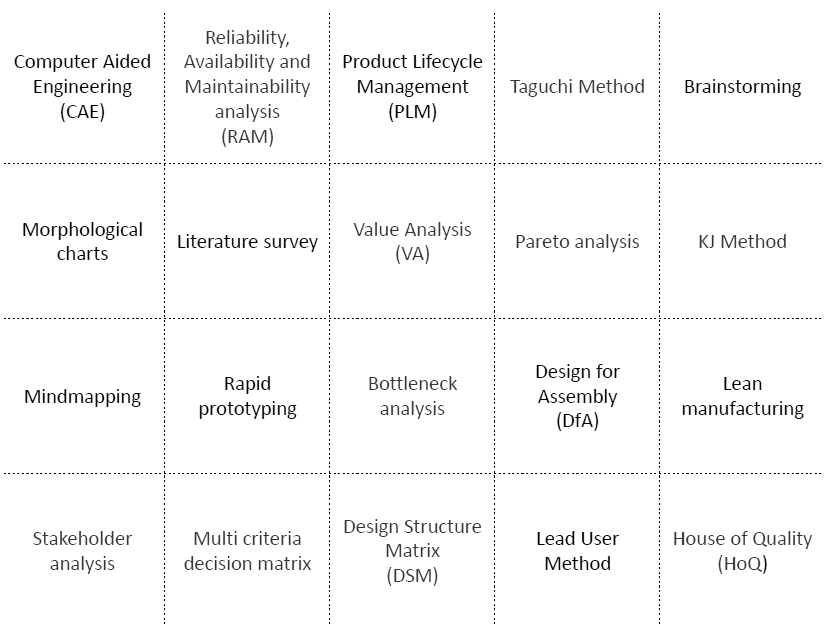
**Fig.2**: Theory into practice

## Homework 1: Design Tools

The objective of this homework is to review a set of design tools. The class is divided in groups of two students, and each group is assigned the task of preparing a small presentation of a determined design tool (from Figure 3). Each presentation must contain the following topics: short description; input requirements, deliverables; and product design process phase(s) in which it can be applied. In the case there are less than 40 students, each group gets more than one tool.

## Exercise 1: PDP value creation obstacles

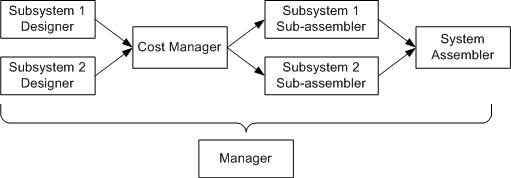
The objective of this practice is to support making a relation between value and waste. The idea is to look at possible obstacles (waste causes) to a high performance (high value delivery) product design and development process. In the first moment, the class is divided in groups of four students, and each group has to identify 20 possible issues that negatively impact the PDP performance. In sequence, the results from each group is discusses with the whole class, while the lecturer summarizes the findings into a list. Finally the list is compared to the product development performance drivers presented in the book’s Appendix A.



**Fig.3**: Design tools in the scope of homework 1.

## Exercise 2: Waste Concept Practice 1

This exercise stresses the waste concept in the product development context. During the practice the class is divided into groups of 9 people: 1 manager, 2 subsystem designers, 1 cost manager, 2 subsystem assemblers, 1 final system assembler, and 2 observers. The groups compete to develop, build (using Knex™ blocks) and sell the same predefined product, and have to follow strict development roles (Figure 4): (1) Each designer draws the subsystem under his/her responsibility; (2) the cost manager checks the acceptability of the design; (3) each sub-assembler assembles the subsystem under his/her responsibility according to the approved design; (4) the system assembler assembles the whole system; (5) the manager makes the link among the team members and with the client. No team members talk to anybody but the manager. The observers take note of perceived issues and improvement possibilities.



**Fig.4**: Function structure of the waste/Knex™ exercise

## Exercise 3: Waste Concept Practice 2

In the same groups as in the previous exercise, the students discuss the wastes they faced during the Exercise 2. While the observers take a central role in the discussion, the other team elements give also example of wasteful experiences they faces. They are required to drawing the PDP process they executed (based on Figure 4), mapping the wastes (check Figure 5.1 from the book), including examples from the exercise, relating these examples to the performance drivers from appendix A, and proposing counter measures.

## Exercise 4: Value Concept Practice

The objective of this practice is to stress the value concept and the process of creating a value proposition. In the first moment, the students are divided into 4 groups, with the task of eliciting the value to be delivered from a “Lean Product Development Course” according to different points of view: the students themselves, the lecturers, the organization offering the course, and the companies that might send some of its employees to attend the course. In a second moment, the whole group discusses their different perspectives, while the lecturer guides them to define a final value set.

## Exercise 5: SBCE Practice

This exercise was first seen in the Lean Product Development Certification training, from the University of Michigan. We highly recommend this training for practitioners, once it is a short and hands-on course. The objective of this exercise is to understand the implication of deciding to search the solution space through a point or set based approach. The class in then divided into groups of 5 students (remaining students might become observers). Through a card game, each team of 5 students competes against each other to have an “optimal hand” of 5 cards. They play 2 rounds with different rules (Table 1): the former following a point-based search of the solution space, and the latter applying the set-based approach.

By this simple game, they can understand the pros and cons of each approach. On the one hand, the point based approach has lower initial cost; this cost, though, quickly escalates in the case of needed changes (rework). On the other hand, the set based approach has higher initial cost (once it explores more widely the solution space), but has no (in the game, but expected fewer in reality) need of changing.

**Table 1**: SBCE card game rules.

|  |  |  |
| --- | --- | --- |
| **General rules** | **Round 1 specific rules** | **Round 2 specific rules** |
| **Scoring**:  - Face cards = 10 points.  - Other cards = face value (ace =1, 2, 3, … 10)  **Bonus**:  - All the same color (black or red) = +10 points.  - All the same suit (spade, heart, etc.) = +25 points.  - 4 of same type (i.e. 2s, kings, etc.) = +50 points.  - 5 in sequence and same suit (2, 3, 4…) = + 50 points. | **Game play**: 5 total plays.  Each player initially draws 1 card from the deck.  Up to 4 additional plays where, team accesses score and may:  - stop and keep the existing hand as-is.  - Keep some cards, reject others and re-draw from the deck.  Drawing and redrawing costs:  - (-1) for each initial draw (play 1).  - (-3) for each additional draw (plays 2 and 3).  - (-5) for each additional draw (plays 4 and 5). | **Game play**: 1 play.  Each player initially draws 5 cards from the deck.  Team members compare “sets” of cards to create the highest possible scoring hand.  Drawing costs:  - (-3) for each player for the initial 5 draws  - total team cost = (-15).  - There are no additional draws. |

## Course-long practical exercise

The class is divided into groups of 5 or 6 students. Each group has to execute a product development project according to a predefined theme (see Table 2 for the past project themes). During the project, the students are required to apply the method presented in Chapters 9 to 13.

**Table 2**: Past project themes.

|  |  |
| --- | --- |
| **Year** | **Theme** |
| 2012 | Twin stroller |
| 2013 | Coffee and tea machine |
| 2014 | Cleaning robot |
| 2015 | A product for the assistive/ rehabilitation industry |
| 2016 | A product-service system |

The exercise’s backbone is the filling of the Value Function Deployment Technique. During the exercise, the groups are also requested to create an Obeya to control their progress (Figure 5). While they fill the VFD’s matrices, they also apply several LPD, IPD, SE and PM tools, techniques and concepts. Figure 6 shows how the exercise evolves through the classes, where the VFD matrices’ elements are printed in italic bold, and some of the used tools and techniques are underlined.



Fig. 5: Students’ Obeya sample.

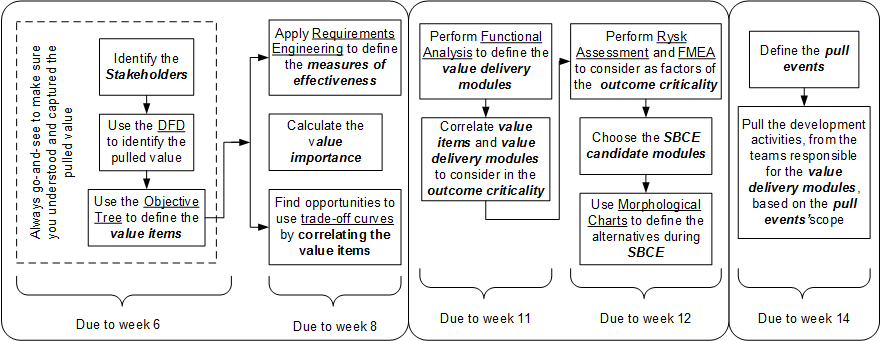


Fig. 6: The Value Function Deployment through the LPD Course.

## 4. Lessons from the past Mileage

After years offering the course, the main lessons learned were keeping the focus on the core lean (value, waste, and continuous improvement), and foster discussions comparing each student’s particular professional scenario and culture with the Toyota scenario and culture. While the former guarantees stressing what concepts are important to be kept no matter where the LPD is going to be applied, the latter molds a critical mindset needed for adapting the LPD to one’s reality. A challenge for the next years is to explore alternatives to introduce more reality into the course-long practical exercise.

The practical exercises were concluded paramount by the students. Investing at least 1/3 of the class time to exercises has been proved positive. The course-long exercise has been proved an important factor to consolidating the concepts. By using the Value Function Deployment technique as the exercise’s backbone, useful insight is gained about the implications of interlacing LPD concepts, tools and techniques together with the concepts from Integrated Product Development, Systems Engineering, and Project Management.

The challenges faced so far were: (1) prioritize the theory to be presented in a 50 hour course; (2) define the pedagogic resources to fit different mixes of attendees, considering their previous experience with lean; (3) to not deviate from the philosophy, and give more importance to the tools (maintain the sensei attitude).

**References**

Browning, T.; Deyst, J.; Eppinger, S.; Whitney D. (2002) Adding value in product development by creating information and reducing risk. IEEE Transactions Engineering Management, 49(4):443–458.

Kennedy, M. N., 2003, “Product development for the lean enterprise”. Richmond: Oaklea Press.

Pessôa, M.V.P; Seering, W.; Rebentisch, E.; Bauch, C. (2009) Understanding the waste net: a method for waste elimination prioritization in product development. In: Chou, S., et al. (Org.). Global Perspective for Competitive Enterprise, Economy and Ecology. London: Springer-Verlag, p. 233-242.

Pessôa, M.V.P.; Seering, W. (2014) Trapped on the waste net: a method for identifying and prioritizing the causes of a corporation’s low product development performance. In: Marjanovic, D. et al (Ed.) Proceedings of the Design 2014 Conference. Glasgow: The Design Society, Vol 3, p. 1641-1650.

Radeka, K; Sutton, T. (2007) What is *lean* about product development? PDMA Visions, June 2007, Vol. XXXI, No. 2, Pages 11-15.

Sobek, D. K.; Ward, A. C.; Liker, J. K. (1999) Toyota’s principles of set-based engineering. Boston: Sloan Management Review, p. 67-83, winter 1999.

Ward, A. C.; Liker, J. K.; Cristiano, J. J.; Sobek, D. K. (1995) The second Toyota paradox: how delaying decisions can make better cars faster. Boston: Sloan Management Review, p. 43-61, spring 1995.

Womack, J. P., and Jones, D. T., 2003, “Lean Thinking,” New York: Free Press.

**Integrated Product Design Exercise – Word Factory**

**Abstract**

The presented exercise works the differences between serial and integrated design approaches. The students are divided in to groups that populate different Word Factories. During two rounds the groups compete to produce more words. In the first round the game rules force a serial development approach, while in the second round an integrated approach is allowed. At the end of the exercise, the lecturer fosters a discussion to compare both approaches.

**1. Introduction**

New product design and development is the interface between the enterprise and the market, being responsible for the identification, and even the anticipation, of the market’s needs in order to propose solutions to fulfill those needs according to the company’s business model.

Although the marketing, design and development, and production activities were completely integrated during the artisan’s pre-industrial work, this changed due to the industrial revolutions, which were driven by mechanization, specialization, automation, and communication, respectively.

With the 1st and 2nd Industrial Revolutions also came the division of work into specific technical areas. The product development process mirrored the serial production line, thus adopting the serial approach as well. The mass production era split the technical areas of the product development process into separate departments (i.e., silos), based upon highly skilled people within them, but with almost no interaction among them. Within the PDP, a typical Serial Product Development through multiple departments is to finish their jobs as quickly as possible and throw them over the “wall” to the next department.

Integrated Product Development (IPD) embraces the challenge of bringing back the, where Product Development Process (PDP) should be capable of integrating the work and information produced by the several different actors, from the diverse knowledge areas required to design the product.

The game was developed with the objective of giving the students a hands-on experience showing the differences between the serial (sequential) and integrated approaches to product design. This game is also an alternative to be used as the “Waste Concept Practice 1” during the Lean Product Design and Development Master Course we offer (see the file “Using the book for teaching Lean Product Development (LPD)” also in the book’s online material).

**2. General Game Rules**

A “raw material phrase” is given by the lecturer at the begging of each round.

The groups, following the specific dynamics from each round, can create words and phrases by using the letters that appear in the given phrase, constrained also by the number of times the letters appear.

The quality criterion for the developed phrases is:

* Each phrase must have a verb;
* Each phrase must have – at least – three words;
* Each word used in one phrase cannot be used in another phrase;
* No word from the raw material phrase can be used in any phrase.

**3. Round 1 Dynamics**

The class is divided into factories. Each factory is constituted by 3 departments with – at least – 3 students in each department. These are: department of “words”, department of “phrases”, and department of “quality”. A manager completes the factory´s personnel. The lecturer orientates the students to place their chairs in a serial layout of as shown in Figure 1.



Fig.1: The serial layout of the factory of words

The lecturer handles the exercise’s rules description. These are the following:

1. A “raw material phrase” will be given by the lecturer at the begging of the exercise. Example: “That straight track is made of concrete”;
2. The employees of the department of “words” – only them – can make words out of the raw phrase such as “star”, “train”, “main”, “costumer”, “late”, “has”, “missed”, “the”. As long as a letter appears in the raw material phrase, it can be used as a seed for a word. The employees write the words into slips of paper and deliver them to the employees of the department of “phrases”. No communication is allowed among the departments. It´s only allowed among the employees of the same department.
3. The employees of the department of “phrases” – only them – can make phrases with the words delivered by the department of words. Example: “A late costumer missed the train”. They write the phrases into slips of paper and deliver them to the employees of the department of “quality”.
4. The employees of the department of “quality” evaluate the phrases according to the quality criterion
5. No elaborate feedback information is allowed to the previous department. This department can – solely – accept or reject the written phrases. Then, they write the accept phrases in a clean sheet of paper and give them to the manager. S/he, by her/his turn, handles the “package” of selected phrases to the lecturer.
6. The 1st round’s duration is 20 min.

**4. Round 2 Dynamics**

A coffee break is welcome before starting the second phase of the practice.

After the break, the lecturer presents the students the rules for the second part of the practice:

1. A different “raw material phrase” will be given;
2. The quality criterion remains the same;
3. It´s up to the students to define:
   1. The layout of the factory;
   2. The way to improve communication;
4. The roles of the employees (ex. at the beginning of the exercise, everyone is temporarily employed at the department of words);
5. The manager (could be a different person from the 1st. round) draws in a sheet of paper, the strategy decided for the 2nd round of the exercise. The students are given 10 minutes to decide upon it.
6. The 2nd round’s duration is 20 min.

**5. Counting the Score**

At the end of each round, the lecturer collects all the “packages of phrases”, count them and draws in a white board – or similar – a table as exemplified in Figure 2. S/he asks everyone to embrace the role of a quality department employee, and start to read the produced phrases. All the students are allowed and incentivized to evaluate the phrases of the competitor´s factory.

In the first round, it few phrases (around 7 or 8) are expected in total, and usually fewer valid phrases (around 4). It is expected that the results from the 2nd round outnumber the first part in both total number of phrases and of valid phrases. By asking the managers to explain the strategy practiced, the lecturer has the opportunity to draw the student’s attention to some key IPD features, such as:

* Team work;
* Complementary competences and skills;
* Co-localization and communication.



**Fig.2**: A way to register the outcome of the practice

**6. Final Remarks**

In the case of using this exercise for teaching Lean Product Design and Development, the role of observer must be added to the game. The observer will analyze the dynamics during the 1st round and identify the wastes in the process. Before the start of the 2nd round, while the groups are deciding their strategy, the identified wastes can be considered to support their decision. During the final discussion, the lecturer should also highlight some key LPD features.