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Toyota Kata patterns to help teach Process Design: Applying a Project-based learning model

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Abstract.

Introducing the concept of Process Design in the higher education system is essential to help shape future professionals face real problems through a holistic view. For this, project-based learning (PBL) can be used since it provides the active participation of students to achieve specific results. Therefore, this study aims to apply a PBL theoretical model to teach Process Design through Toyota Kata patterns. The model presents four Target Conditions and their deliverables. To achieve them, students use a systematized routine with small experiments and reflections on the actions performed. To show the applicability of the proposed model, Mechanical Engineering undergraduate students were considered. The model was performed in a Computer Numerical Control (CNC) Laboratory of a Brazilian Federal University over seven days. The students registered the results in a storyboard, describing the seven PDCA (Plan, Do, Check, Action) cycles, the lessons learned, and the main obstacles faced. The contribution of this paper is the application of a PBL model of designing the teaching process, promoting active participation of the students when performing this activity, focus value, and knowledge sharing.

Keywords: Project-based learning, Mechanical Process Design, Process Planning, Toyota Kata.

1 Introduction

Because of the global competition, manufacturing companies are developing and deploying advanced technologies to reduce product development costs and lead time while ensuring product quality. Process Design plays an essential role in this area. Machining features sequencing, vital in achieving efficient and high-quality manufacturing, has received much attention in the last years [18].

Therefore, introducing the concept of Process Design in the education of undergraduate engineering students is essential to help these future professionals to face these

problems with a holistic view. In an active-learning approach in higher education, activities should focus on learning outcomes, promote student reflection, and get students to think about their learning [4]. For this purpose, researchers recommend using PBL and new assessment methods for core courses in engineering [4,12]. This methodology is beneficial for the Sustainable Development Goals (SDGs) – in particular, Goal 4¹ – and because there is a guideline in Brazil entitled "National curriculum guidelines for the undergraduate engineering programs" that recommends the use of active approaches [8,12].

In this context, the Toyota Kata (TK) acts as a framework for conducting and managing PBL [11]. TK patterns seek to develop the engagement of participants by advocating a systematic routine that uses experimentation in short cycles. It focuses on learning by doing, i.e., the teacher (coach) corrects students' actions according to their needs [13].

In traditional teaching practices, students are merely the passive receptors of information based on lectures and practical exercises. They have no predictions of how they would act on a problem [4]. Therefore, this study aims to apply a theoretical PBL model to teach process planning using the TK approach. In this way, each step presents a set of requirements (deliveries) by the students. The contribution of this paper is the application of a PBL model teaching process design by promoting active participation, i.e., engagement of students when doing this activity, focus value, and knowledge sharing.

The rest of the paper is organized as follows. Section 2 summarizes the relevant literature available on PBL with Process Design. Section 3 shows the theoretical background on the main topics covered in this research. In Sect. 4, we describe the proposed model. The results that were attained so far are stated and discussed in Sect. 5. Finally, Section 6 concludes this research, indicating the implications, limitations, and future work.

2 Related Works

In recent years, several research papers have been published that have addressed structuring and formalizing PBL, mainly related to Process Design. This section presents related work (specifically journal articles) that have applied this methodology. [12] and [4] developed a PBL methodology as a training strategy for engineering students, and it allows interaction between students from different semesters on the same project. For its applicability, [12] considered a project for the industrial production of ethanol from sugarcane, and [4] considered a preliminary design of a second-generation bioethanol plant in the Process Design course.

[10] presented student, faculty, and industry perceptions of integrating employability skills of creativity and teamwork through a non-work-integrated learning experience into a chemical engineering course placement work. [9] presented a learning transformation framework to analyze how learning evolves during the PBL process. [2] analyze whether monitoring quizzes allow them to assess individual teammate responsibility in

¹ SDG 4: Ensure inclusive and equitable and quality education and to promote lifelong learning opportunities for all [17].

a chemical process design project. [7] present a PBL to teach sustainable engineering-including product, process, and infrastructure design and industrial ecology. [6] evaluated whether using PBLs improves students' understanding of sustainability and their use of sophisticated analysis tools. [3] present a PBL to train manufacturing engineering students to focus on product life cycle management, problem-solving, and teamwork.

3 Theoretical Background

3.1 Process Design

Process Design is a knowledge-intensive activity that transforms the product design model into manufacturing processes and determines the optimal operating sequences for production [20]. It is the systematic determination of the techniques that enable economic and competitive manufacturing [1]. It is a connection between product design and manufacturing systems [16]. It also plays a crucial role in maintaining high levels of responsiveness and adaptability while propagating various pipelines into the process.

According to [5], Process Design is the ordered sequence of machining operations to be applied to achieve the geometric shape according to specifications. The development of a process planning consists of:

- defining all machining operations for each machined feature;
- for each operation, determining the tool and optimizing the cutting conditions and machining strategy;
- sequencing all operations;
- Selecting clamping systems, support faces;
- Selecting control instruments and processes;
- Determining production tolerances;
- Calculating machining and non-machining times, calculating associated costs;
- Generating technical documentation.

3.2 Project-based learning

All stages of education can use PBL – from higher education in different fields of knowledge ranging from health science-related areas to engineering [6, 7, 12]. It provides a concrete and active learning environment for students [21], enhances their critical thinking and idea synthesis skills [2]. Also, it promotes problem-solving, strategic planning, and idea development in the educational environment [12].

For PBL to be successful, [15] presents five fundamental criteria corresponding to PBL-centered teaching, the existence of a guiding question, the need for a constructivist inquiry, developing students' knowledge or skills, encouragement of autonomy, and focus on real problems.

3.3 Toyota Kata

According to [13], TK refers to the form or pattern that helps develop particular skills. Moreover, it is a new mentality by applying the scientific method following the PDCA's cycles. Like agile methods, there is a small change in processes, then it evaluates the results and finalizes plans in response to learning. The goal is to develop well-trained mental circuits, not for solutions but for systematic and scientific ways of developing solutions in dynamic and uncertain situations. Figure 1 shows the two complementary TK routines: Improvement Kata and Coaching Kata.

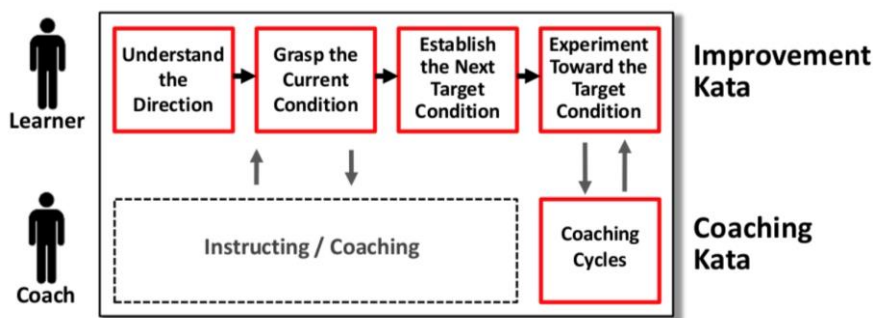


Fig. 1. Improvement Kata and Coaching Kata [13].

Improvement Kata aims to make continuous improvement a systematic capability, with the purpose of training and teaching. It begins by establishing the Challenge, a future condition that a process should achieve long-term. Then, the Current Condition of the process is analyzed. By comparing the Current Condition with the Challenge, a Target Condition that points towards the Challenge is set. The Target condition is an intermediary condition that the process should achieve in a not so long-term as the Challenge. The Target Condition is pursued by overcoming Obstacles that prevent the process from achieving the Target Condition. By achieving successive Target Conditions, the process will achieve the Challenge [13].

Coaching Kata presents itself as a training standard to teach and help the learner to internalize the Kata Improvement approach cyclically. Figure 2 illustrates the learner's storyboard template in widespread use for practicing scientific thinking. The coach's presence favors the practice of the path efficiently and effectively for changing the mentality and mastery of the new standard [13,14].

One coaching cycle essentially entails the mentor going through the following five questions: 1) What is the target condition? 2) What is the actual condition now? – turn the card over; 3) What problems or obstacles are now preventing you from reaching the target condition? Which one are you addressing now? 4) What is your next step? (Start of next PDCA cycle) 5) When can we go and see what we have learned from taking that step? [13].

The back of the card has four questions to reflect on the last step taken: 1) What did you plan as your last step? 2) What did you expect? 3) What actually happened? 4) What did you learn? – return to question 3 (on the front of the card) [13].

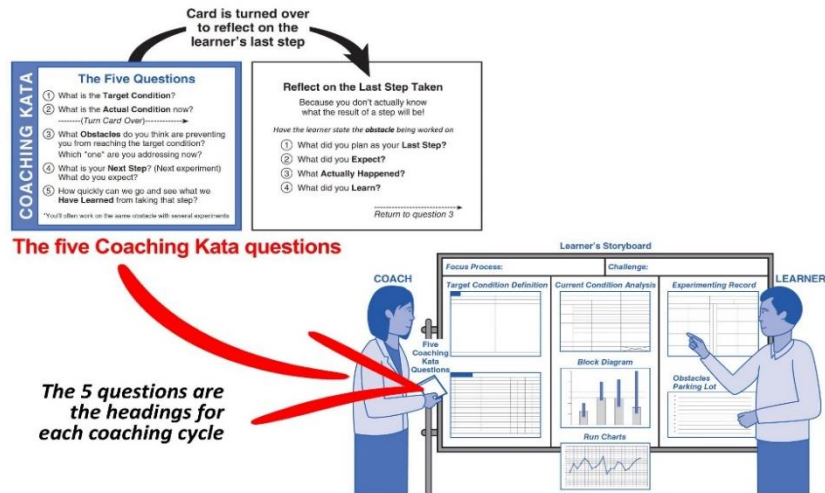


Fig. 2. Coaching cycles and the five questions [13].

4 Theoretical Model

We associate the necessary information for elaborating the Process Design with the PBL methodology to formulate this theoretical model. Students should be able to develop solutions through each step based on TK patterns. Thus, we propose an adaptation of the Improvement Kata approach. It aims to solve problems in a systemic perspective to reach each step of Process Design. The system's transformation actions and outputs are oriented to achieve the desired Target Condition while developing the students' knowledge (Direction), as seen in Fig. 3.

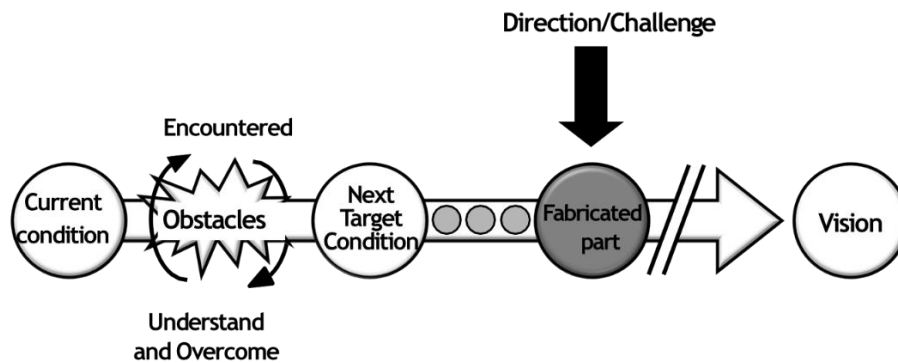


Fig. 3. Overview of the adaptation of the Improvement Kata for Process Design (Adapted from [13]).

This model aims to show how it is possible to organize and sequence the Process Design in small experiments, promoting the students' active learning and achieving a good situation while ensuring benefits of cost, quality, and adaptability of the production process.

Figure 4 presents the four Target Conditions corresponding to the Process Design's activities that need to be overcome. The target condition is not the list of activities to be performed. It is a combination of desired requirements at a specific date.

The planned experiments are conducted to overcome these identified obstacles. However, before these actions occur, the coach evaluates the planned and the expected description (Kata Coach). After the scheduled execution, the students should describe what happened, highlight the main items, and describe what they learned about what they performed. This routine encourages reflection on what happened with the planned action. We recommend a storyboard to document the cycles and support the interaction between the students and the teacher (coach).

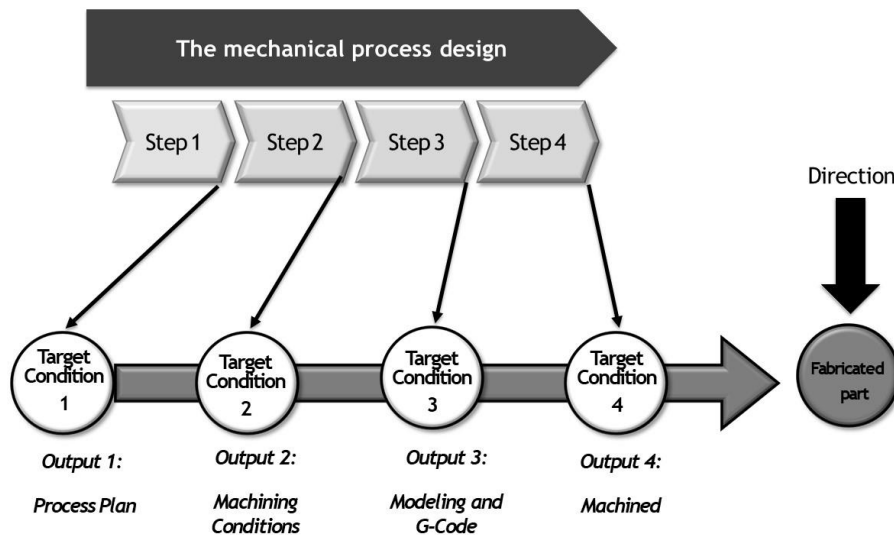


Fig. 4. Model for the elaboration of the Process Design through the TK pattern (Adapted from [11, 13]).

In this case, the Challenge is to produce a mechanical part that matches the project specifications. The following are the details of the target conditions of the proposed model:

- The first step can be taken by analyzing the 2D drawing of the part provided by the teacher (coach). It contains all the designer's specifications, such as the structure of the part, tolerances, observation of critical and less critical surfaces, and the material to be used.
- For Target Condition 1, the deliveries required for the Process Plan are machine tools used; tools used; a fixing device used; machining routing (sequencing of the tool path by the part); and measuring devices used.

- In Target Condition 2, students define the possible machining parameters, i.e., detailing the machining specifications from the previous step. They should use the technical information (machine tools, tools, and the defined sequence of operations). In this step, the necessary deliverables are the cutting speed, feed rate, depth of cut of the operation, the need or not of the cutting fluid. In addition, the used measurement procedures should be defined, such as the place and time for the measurements.
- In Target Condition 3, students can perform the part modeling using CAD software (Computer-Aided Design) with CAM integration (Computer-Aided Manufacturing) to get the G-Code. The purpose of this step is to include drawings representing the tool trajectories. However, they can elaborate manually, transcribing the routes of machining for G-Code. This choice depends on the resources available and the objective of the course. The students or teacher can also make it. This step can be implemented when the course or the teacher intends to teach and use CNC (Computer Numeric Control) equipment. If the teacher or course does not intend to carry out this activity, this step may not be necessary.
- Target condition 4 consists of manufacturing the part, practicing the plan of the previous steps. For this, cycles can be performed according to each process or step. Reflection and learning come from each activity performed on the part. If the students identify problems, the process plan should be changed to deliver the part according to the initial specifications. At each stage of machining, measurements are taken to check that the part conforms to specifications. Finally, students should achieve the design parameters of the part.

5 Results and Discussion

For applying the model presented in Sec. 4, action research was conducted through direct observation (participation in meetings) and interview feedbacks. Action research is a methodology in which the researcher plans, implements, describes, and evaluates an improvement in current practice in a specific setting. In addition, researchers interfere in the object of study cooperatively with the participants to solve a problem and contribute to the knowledge base [19]. Also, a teacher acted as coach, a laboratory processor as a second coach, and two mechanical engineering students were apprentices. The machining process of the part was performed in a CNC laboratory of the Federal University of Santa Catarina. Initially, the teacher gave the following information to the students: the raw material, the 2D drawing of the part, with its dimensions and tolerances (Fig. 5).

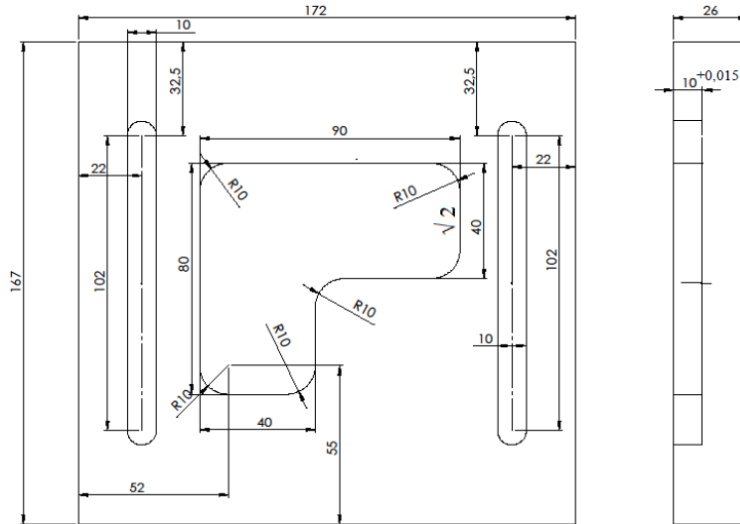


Fig. 5. 2D part drawing.

Each experimentation cycle was registered in the storyboard, presented in Table 1. The storyboard was located as close to the process as possible. First, the students registered the Current Condition, the Target Condition, and the Obstacles Parking a lot. After that, they would define what they planned to do to attack one obstacle at a time and what they expected from this action. After each cycle, students recorded what happened and what they learned before speaking with the coach again. The daily coaching sessions took place over seven days.

Table 1. The Improvement Kata PDCA Cycles Record.

Focus process: Machining process planning	Challenge: Fabricated part	
Current condition	Target condition	Obstacles Parking Lot
1 - Initial information defined and raw material supplied: <i>aluminum - prismatic block 345 x 167 x 28 mm</i> <i>Lot size: 1 piece;</i>	TC-1: Process plan;	1 - Lack of processing plan;
2 - Initial process plan elaborated;	TC-2: Machining conditions;	2 - Unknowledge of the machining parameters;
3 - Defined machining parameters;	TC-3: Modelling and G-Code;	3.0 - Lack of 3D part drawing;
4 - Modeled part and G-code developed.	TC-4: Machined part: <i>Tolerances of surfaces not shown = $\pm 0.1\text{mm}$; Roughness of surfaces not shown = $12.5\ 2\ \mu\text{m}$; Lot size: 1 piece 172 x 167 x 26 mm.</i>	3.1 / 3.2 - G-Code unknown;
		4.0 - Non-manufactured part.

PDCA cycles' notes

Step	What do you plan?	What do you expect?	What happened	What you learned
1	Develop an initial process plan that contains the entire machining operation (day 1).	Initial process plan (end of day 1).	We begin to shape the process plan by showing the machining operations with their respective elementary operations. We checked the infrastructure of the laboratory. Thus, it was possible within the options available in the lab, the machine tool, tools, devices, and which machining process would be used in the manufacturing.	It is necessary to start shaping a process plan containing its elementary operations. From there, we were able to develop the specific machining parameters. This cycle proved to be essential for our understanding of how the part will be machined.
2	Define machining parameters (day 2).	Setting the machining parameters: theoretical values for cutting speed, feed rate, and roughness (end of day 2).	We defined the main machining parameters from the technical drawing. The first parameter to be obtained was the speed (in <i>rpm</i>) for the tools: End mill with diameters <i>10 mm</i> and <i>12 mm</i> . For the first one, a rotation of <i>3000 rpm</i> was adopted, and for the second one, <i>2653 rpm</i> . The cutting speed for the first is <i>94.24 m/min</i> and for the second is <i>100.015 m/min</i> . The feed rate for the first will be <i>150 mm/min</i> , and for the second will be <i>132.65 mm/min</i> .	This cycle is essential because the parameters help us to achieve perfect machining through the rational use of the resources offered by a given machine tool.
3.0	Model the part to be fabricated (day 3).	3D part drawing (end of day 3).	We performed the modeling using a CAD system. We chose SolidWorks software because it is parametric CAD and because the group found it easy to use.	This cycle proved to be fundamental for the development and optimization of the project. The 3D model is a virtual prototype in which it is possible to perform dimensional analysis of the parts with much more precision, checking all the details.

3.1	Create a drawing representing the tool paths and get G-Code (day 4).	The drawing with the tool paths containing the G-Code (end of day 4).	We try an integration with CAD software with CAM. We used STEP NC software. However, the software could not accept tools with a diameter greater than 4.029 mm , which was inconsistent with the available tools. Even so, a test was made by adding a 4 mm tool. When the cutting simulation was run, the program generated only one route for one of the slots, which made it impossible to use.	We realized the need to do this cycle again, considering using another software because the chosen one did not allow us to achieve what was expected.
3.2	Create a drawing representing the tool paths and get G-Code (day 5).	The drawing with the tool paths containing the G-Code (end of day 5).	We integrated CAD software with CAM again. SolidCAM made it possible to program the part and generate the G-code.	It is essential to use a CAM system to optimize the manufacturing process. SolidCAM allowed a significant gain in programming time. In addition, it was possible to test and virtually choose strategies without the need for physical testing.
4.0	Machine the part (day 6).	Fabricated part (end of day 6).	We measured the raw material and then performed the cut with the help of the processor. Thus, the block became the following dimension $172.5 \times 167 \times 28\text{ mm}$. The machining process performed was milling. The aluminum block was clamped in the vice. It allowed most of the operations involved in the process to be performed: facing, feature creation, and external contouring of the part. The end mill of 12 mm was used for the upper facing step and then to form the center cavity of the part. For the first step, a depth of 0.5 mm was set, performed in a single pass. And for the second, a depth equal to 1.5 mm and 6.5 passes for the operation. The end mill of 10 mm was used to form the two lateral grooves of the part with a defined depth of 1.5 mm and 4.5 passes for the operation. The external contouring of the part was not performed as originally planned. The contour was applied only on the	Understanding the importance of the machining process is an excellent stage. Once it became possible to transform raw material into a part. Safety is also an essential factor in this cycle. To achieve TC-4, another cycle is needed to check the quality of the part we produce, if it meets the design specifications.

			side where the part was cut. And for this step, the 10 mm tool was used with a depth set at 5.0 mm and six passes. This step took approximately three hours.	
4.1	Check the part's quality (day 7).	Part inspection (end of day 7).	We evaluate whether the final product conforms to the design specifications. We measure the following critical design dimensions: the internal roughness of the cavity, cavity depth, and sizes. We used a profilometer (Taylor Hobson Surtronic S-116). We identified that the limit (1.10 m) corresponds to the indicated limit ($2\text{ }\mu\text{m}$). We used a dial indicator (JR MAQ) to inspect the critical depth ($10\pm 0.1\text{ mm}$). The result was 10.006 mm , i.e., it meets the specifications. Finally, we measured the part with a caliper (Mitutoyo 522 Series). The values were $172 \times 166 \times 28\text{ mm}$, i.e., meeting the specifications."	This cycle is essential when problems are identified in the manufactured part. If they do, the process plan should be changed and the part re-machined.

Figure 6 shows the 3d part drawing and its sequential machining steps: facing (A), central cavity opening (B), sidewalls (C), and Fine grading (D).

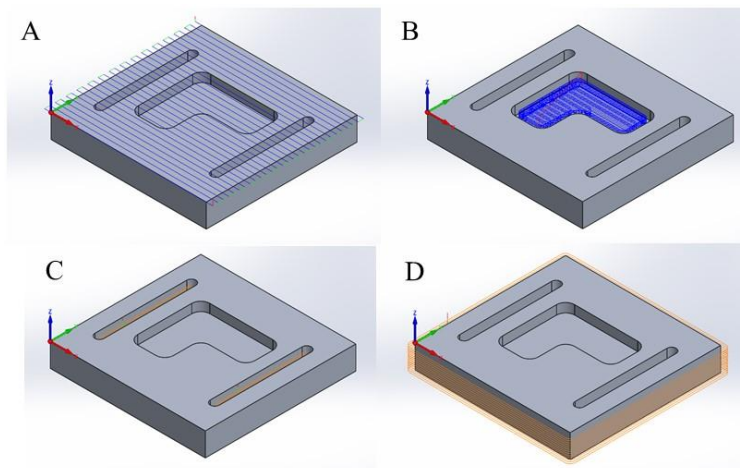


Fig. 6. Machining steps.

Figure 7 presents the main steps of the machining process performed by the students (Milling). In addition, it shows the final part manufactured according to the project specifications. The machine tool used was the Charles MVC-955 (with Siemens Sinumerik 840Di CNC).

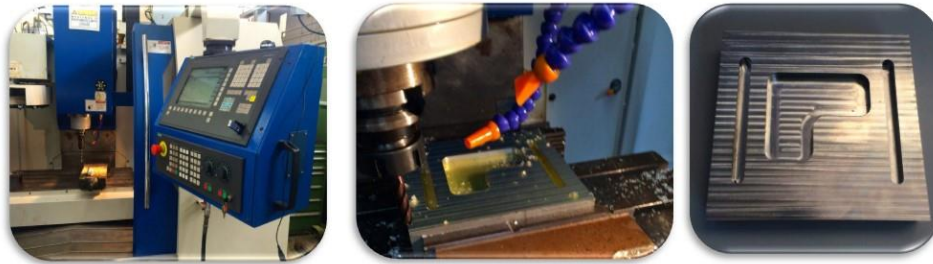


Fig. 7. Main machining steps.

5.1 Discussion

The difference of this study to others is that it focuses on Industrial Engineering and the use of Toyota kata to operationalize the PBL methodology. Most of these works focused on Chemical Engineering courses [4, 7, 12]. The use of the Toyota Kata approach made it possible to record and follow up on the activities performed and the development of the participants.

In this study, the moments of reflection occur during the Kata Coaching sessions, in contrast to other works [4, 12] that hold a session at the end of applying the PBL methodology. The teacher as Coach was not restricted to being a questioner. He guided the students to achieve their goals. As findings, the students highlighted integrated learning and decision making as central elements, in agreement with the results of other works [12], which emphasize the importance of reflections on applying the methodology. Some tasks and parameters foreseen in the initial cycle were changed due to the CNC laboratory infrastructure restrictions.

Initially, the students had difficulty reporting what was learned in each round. Sometimes they talked about what happened and not what they learned. Then, the students reported that recording the PDCA cycles using the Toyota Kata standards provided an organized source of information. They could easily visualize what they needed.

6 Conclusion

This study aimed to apply a theoretical PBL model to teach Process Design using the Toyota Kata approach. A theoretical model actively structured the students' learning, seeking their engagement, value focus, and a problem-solving routine.

This work provides a more excellent knowledge about Process Planning, PBL, along with the Toyota Kata patterns. The usual methodologies used for Process Planning conduct a flow of activities [5]. There is a greater engagement of students in the Process

Design activities using the PBL methodology. The theoretical model points out the deliverables for each step. Once the students understand what has to be delivered, the Target Condition for each step plans their activities to achieve it. Thus, students can understand the importance and impact of each machining activity at the end of planning. In this way, besides structuring and operationalizing PBL, the Toyota Kata Approach highlights the learning of each experimentation since students should fill in the storyboard with what happened and what they learned concerning the activity performed.

This study is representative of the body of literature covered. However, the authors point out that it is not without any limitations. The limitation is associated with the fact that the study was conducted with only a few undergraduate mechanical engineering students. The following are aspects that were identified during the elaboration of this work and can guide future research. In this context, the following research agenda is suggested: the methodology proposed in this study can be extrapolated to other areas of training in mechanical engineering, and it can be applied with undergraduate students from different semesters.

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References

1. Alting L, Zhang H: Computer-Aided Process Planning: the state-of-the-art survey. *Int J Prod Res* 27:553–585 (1989). <https://doi.org/10.1080/00207548908942569>
2. Aranzabal A, Epelde E, Artetxe M: Monitoring questionnaires to ensure positive interdependence and individual accountability in a chemical process synthesis following collaborative PBL approach. *Educ Chem Eng* 26:58–66 (2019). <https://doi.org/10.1016/j.ece.2018.06.006>
3. Chang YI, Miller CL: PLM curriculum development: Using an industry-sponsored project to teach manufacturing simulation in a multidisciplinary environment. *J Manuf Syst* 24:171–177 (2005). [https://doi.org/10.1016/S0278-6125\(06\)80005-1](https://doi.org/10.1016/S0278-6125(06)80005-1)
4. Cifrian E, Andrés A, Galán B, Viguri JR: Integration of different assessment approaches: application to a project-based learning engineering course. *Educ Chem Eng* 31:62–75 (2020). <https://doi.org/10.1016/j.ece.2020.04.006>
5. Delolme L, Antomarchi A-L, Durieux S, Duc E: Decision-making for multi-criteria optimization of process planning. *Mech Ind* 20:806 (2019). <https://doi.org/10.1051/meca/2020040>
6. Jollands M, Parthasarathy R: Developing Engineering Students' Understanding of Sustainability Using Project-Based Learning. *Sustainability* 5:5052–5066 (2013). <https://doi.org/10.3390/su5125052>
7. Margallo M, Dominguez-Ramos R, Aldaco A: Incorporating life cycle assessment and ecodesign tools for green chemical engineering: A case study of competences and learning outcomes assessment. *Educ Chem Eng* 26:89–96 (2019). <https://doi.org/10.1016/j.ece.2018.08.002>
8. Ministry of Education: National Guidelines for the Undergraduate Engineering Programs' Curriculum (2018),

- http://portal.mec.gov.br/index.php?option=com_docman&view=download&alias=93861-texto-referencia-dcn-de-engenharia&category_slug=agosto-2018-pdf&Itemid=30192 , last accessed 2021/03/2
9. Pan G, Seow P-S, Koh G: Examining learning transformation in project-based learning process. *J Int Educ Bus* 12:167–180 (2019). <https://doi.org/10.1108/JIEB-06-2018-0022>
 10. Reedy AK, Guerrero Fariás ML, Reyes LH, Pradilla D: Improving employability skills through non-placement work-integrated learning in chemical and food engineering: A case study. *Educ Chem Eng* 33:91–101 (2020). <https://doi.org/10.1016/j.ece.2020.09.002>
 11. Ribeiro DRS, Werner SM, Forcellini FA, Pereira M: Project-Based Learning's Model for Teaching Process Planning through the Toyota Kata Approach. *J Lean Syst* 5:19–37 (2020).
 12. Ricaurte M, Vilorio A: Project-based learning as a strategy for multi-level training applied to undergraduate engineering students. *Educ Chem Eng* 33:102–111 (2020). <https://doi.org/10.1016/j.ece.2020.09.001>
 13. Rother M: *Toyota Kata: Managing people for improvement, adaptiveness and superior results*. MGH, New York (2009).
 14. Suárez-Barraza MF, Miguel-Dávila JA, Morales-Contreras MF: Application of Kaizen-Kata methodology to improve operational problem processes. A case study in a service organization. *Int J Qual Serv Sci* 13:29–44 (2021). <https://doi.org/10.1108/IJQSS-07-2020-0113>
 15. Thomas J, Utley J, Hong S-Y, Korkmaz H, Nugent G: *A Review of the Research*. Routledge (2000). http://www.bobpearlman.org/BestPractices/PBL_Research.pdf , last accessed 2021/03/2
 16. Uhlmann IR, Frazzon EM: Production rescheduling review: Opportunities for industrial integration and practical applications. *J Manuf Syst* 49:186–193 (2018). <https://doi.org/10.1016/j.jmsy.2018.10.004>
 17. United Nations: Sustainable Development Goals, <https://sdgs.un.org/goals/goal4>, last accessed 2021/03/21
 18. Wang W, Li Y, Huang L: Rule and branch-and-bound algorithm based sequencing of machining features for process planning of complex parts. *J Intell Manuf* 29:1329–1336 (2018). <https://doi.org/10.1007/s10845-015-1181-y>
 19. Westbrook, R: Action research: a new paradigm for research in production and operations management. *Int J Oper Prod Manag* 15:6–20 (1995). <http://doi.org/10.1108/01443579510104466>
 20. Xia Q, Etienne A, Dantan J, Siadat A: Reconfigurable machining process planning for part variety in new manufacturing paradigms: Definitions, models and framework. *Comput Ind Eng* 115:206–219 (2018). <https://doi.org/10.1016/j.cie.2017.11.010>
 21. Zacharia Z, Barton AC: Urban middle-school students' attitudes toward a defined science. *Sci Educ* 88:197–222 (2004). <https://doi.org/10.1002/sce.10110>