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INDUSTRIAL ENGINEERING EDUCATION – CHALLENGING COMPLEXITY BY SIMPLE MEANS

Bartlomiej Gladysz

Warsaw University of Technology, Institute of Production Systems Organization, Poland

Corresponding author:
Bartlomiej Gladysz
Warsaw University of Technology
Institute of Production Systems Organization
Narbutta 86, 02-524 Warsaw, Poland
phone: (+48) 22 234 81 26
e-mail: bartlomiej.gladysz@pw.edu.pl

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Abstract
Industrial engineers gather knowledge during their bachelor studies through lectures and practical classes. The goal of practical class might be an extension of knowledge and/or a consolidation and application of already gathered knowledge. It is observed that there exists a gap between theory learnt during lectures and practical classes. If practical classes require holistic approach and solving complex tasks (problems), students strive with understanding relations and connections between parts of knowledge. The aim of this article is to show an example of a simple practical assignment that can serve as a bridge between lectures and practical classes through discussion of interactions and relations between parts of theoretical knowledge. It is an example of in-class simulating of a line and cellular layout considering discussion of elements impacting and impacted by the type of layout (e.g. learning curve, changeovers, etc.). In-class verification of the presented approach confirmed its usability for teaching industrial engineers and bridging the gap between theory delivered through lectures and more advanced practical classes.

Keywords
Engineering education, industrial engineering, layout, line, cell.

Introduction

Industrial engineering is covering wide range of topics and activities. It is multidisciplinary, or even transdisciplinary, area. Therefore, it is crucial to understand relations and impacts between sub-areas of industrial engineering interest. This make industrial engineering education very challenging. Traditionally, lectures should provide students with knowledge, which later is applied during practical classes. Only limited part of theory may be effectively delivered by lectures, especially when considering industrial engineering, which is practical and interdisciplinary of its nature. Nitkiewicz and Ayen [1] identified key criteria in development of industrial engineering curricula through literature review. Those criteria are general program, educational methods and tools, cooperation and networks, industry-based training, competences and skills, and quality assurance and accreditation. There are no crisp boundaries between categories, which are overlapping (Table 1).

One interesting approach is the use of LEGO bricks are popular tool in practical teaching line balancing problem [2]. Such approach is very useful to train not only particular engineering skills as balancing, but also to train transferable skills, such as multidisciplinary work (e.g. including elements of software engineering and programming) and teamwork. This also enables flipped classroom approach, where active learning is applied and students spend more in-class time on problem-finding, collaboration, problem-solving [3]. There are also other interesting sophisticated concepts and applications of new technologies in industrial engineering education. It is noteworthy to mention educational games [4], modelling and simulations with their benefits in education. Efforts are also focused on introduction of:

- sustainability concepts into industrial engineering education [5–7],

- work-based learning [8],
- project-based learning [7, 9],
- developing business expertise [10],
- internationalization and frequent short mobility increase [7],
- distance learning [11, 12],
- learning factories [13].

Table 1
Development criteria for industrial engineering curricula based on Nitkiewicz and Ayen [2].

Criteria	Examples
General program	Cooperative and participative education
	Industry 4.0 and digitisation paradigms inclusion
	Outcome-based education structure
	Sustainability inclusion, triple bottom line paradigm inclusion
Methods and tools	Case studies
	Experimental, problem based, project based, experiential learning, design thinking
	Flipped classroom
	Interactive tools, VR/AR
	Learning/teaching factories
	Participative education
	Simulation modelling
	Sustainability assessment tools
Cooperation and networks	Cooperative and participative education
	Experience sharing
	Internationalision
	Telecollaboration
Industry based training	Cooperative training
	Evaluation of competences and skills
	Industrial talks and study visits
	Industry-based theses and projects
Competences and skills	Industry-based evaluation
	Transferable skills, including "soft" skills (p.e. communication and language) ICT and software skills managing innovation skills project management skills
Quality assurance and accreditation	Benchmarking of accreditation and quality assurance systems
	Certifying and adapting quality management systems
	Qualification frameworks (national, european)

Students are unaware of the industrial engineering field and does not recognize its transdisciplinary character. Dagget and Alptekin [14] pointed that the reason for this lack of knowledge is the complexity and variety (from banks and other services to different manufacturing industries) of industrial engineering applications.

All those mentioned efforts address issues of complexity, what is very immanent to industrial engineering as the educational, professional and occupational area. Therefore, an approach presented in the following sections also relates to complexity. Obviously, single exercise, nor even subject, cannot address all the mentioned approaches. It has to embedded and fit into the whole curriculum. However, the novelty lays in addressing introductory classes and bridging theoretical (lectures) with practical (labs/exercises/projects) parts of classes and presentation of ready for use educational materials. Presented approach addresses directly methods and tools, and competences and skills from the set of criteria identified by Nitkiewicz and Ayen [2]. It also incorporates some principles of project-based learning and experiential learning.

Methodology

The overall methodology of the research consisted of consecutive steps (Fig. 1). The assumptions founding the presented exercise lays in cognitivism and it is assumed that cognition is the key for understanding. The learner is assumed to be learning not only the content, but also how to manipulate the environment. The student becomes the active subject of learning. The student experiments, researches, divulges, concludes and develops reasoning. The knowledge is assimilated through the intermediary of tasks, and learning is motivated through activity [16].

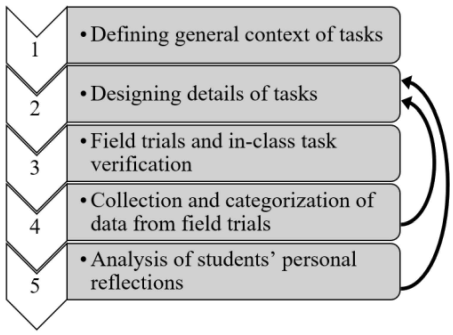

Fig. 1. Methodology.

General context of the task was defined considering such factors as:
- course degree (level),
- alumni profile,
- course curriculum, and
- subject curriculum.

Details of the task were analyzed considering:
- subject curriculum,

- especially lacking connections between its theoretical (lectures) and practical (labs/projects/exercises) parts.

Defined tasks were verified in classes. Data collection was the consecutive step and that resulted in categorization of possible topics and relations between knowledge areas to be addressed. Students personal reflections were analyzed in the last step to assess, if the goal of defined approach was achieved. The whole process was also controlled by feedback loops to apply findings into tasks definitions.

The main goal of presented approach was to illustrate how lectures and practical classes in the field of industrial engineering could be bridged using simple in-class tasks. For this purpose, a three-fold approach was adopted:

- Representative topic was selected;
- Educational task was designed;
- Educational task was verified in four different groups (two curricula of bachelor level, full-time and part-time).

Groups were consisted of 14–16 students.

Results

General context of tasks

General approach presented in the article was adopted from Daggett and Alptekin [14], who proposed simple in-class practical training to discover and discuss differences and contexts of line and cellular layout design. They discussed arguments that their approach is valid for high school students, who do not recognize industrial engineering and its applications. However, in the context of Polish education system, it is hardly possible to apply such application-oriented classes in high schools. Therefore, the approach may be valid in the early education at bachelor level in industrial-oriented study curricula, especially such as management and production engineering. It also can support basic organization and production management subjects in bachelor (of engineering) curricula, which are not industrial engineering, but relate to it e.g. machines construction.

The goal of presented task was to illustrate differences between cellular and line layout. It is assumed that presented task serves as simple illustrative example to the part of lectures dedicated to layout design. Students are taught about different types of layouts [15] and their use including:

- product-oriented layouts,
- process-oriented layouts,
- fixed position layouts, and
- hybrid layouts.

The selection of topic was done in a way, that the task is valid for different bachelor curricula and may be verified in different bachelor groups i.e. management and production engineering, mechanics and machines construction.

Proposed exercise is an extension of the lecture and way to memorize knowledge. The goal is to simulate and illustrate basic differences resulting from adopting line layout versus cellular layout design. At the same time, it is also introduction to more advanced practical classes on layout design including such topics as grouping parts, design of line layout, design of cellular layout, workstation design, line balancing, etc.

Details of tasks

Tasks were adopted from Daggett and Alptekin [14]. Students are asked to form two teams i.e. eight people and four people. Team of eight students is assigned to a line layout and the other team (four students) forms a cellular layout. The definition of industrial engineering is understood as a “product” and handwriting using colored pens is understood as a “technology” (Fig. 2). The goal of presented exercise is to produce four handwritten definitions of industrial engineering per team, so altogether eight papers with rewritten definition are produced in the first run (Fig. 3). Then teams are asked to perform second run and produce 16 pieces per team (32 pieces altogether) (Fig. 4).

First student in the group, which form the line layout, writes only the first line of the definition on the first blank page, then pass this page to the second student sitting next to him, and then starts writing the first line of the second page. She/he writes her/his line on 4 pages (1st run) and 16 pages (2nd run).

Second student in the line layout, starts writing when the first page is delivered to her/him by the first student. She/he writes only the second line of the definition, and then pass the page to the third student. Then she/he starts writing on the next page delivered by the first student as soon as possible. She/he writes her/his part on each page delivered by the previous student. Third student works analogically to the second, i.e. she/her writes only 3rd line of the definition on each page received, starts writing as soon as the first page is delivered, and starts writing on next pages as soon as possible. This logic is applicable also to 4th, 5th, 6th and 7th student in the line layout. Last student works also analogically but puts finished pages on the finished goods pile (any designated area). Each student is equipped with the pen of appropriate color regarding the color of the part of the definition, that she/her rewrites.

„Product" – definition of industrial engineering	„Technology" operations and tools	
	„Material": blank piece of paper	
	„Operations":	„Tools":
"IE is concerned with the design, installation,	1. Write 1st line.	Black pen
and improvement of integrated systems of people, material,	2. Write 2nd line.	Blue pen
information, equipment, and energy by drawing upon	3. Write 3rd line.	Green pen
specialized knowledge and skills in the mathematical,	4. Write 4th line.	Red pen
physical, and social sciences, together with	5. Write 5th line.	Black pen
the principles and methods of engineering analysis	6. Write 6th line.	Blue pen
and design to specify, predict, and evaluate	7. Write 7th line.	Green pen
the results to be obtained from such systems."	8. Write 8th line.	Red pen

Fig. 2. "Product" and "technology".

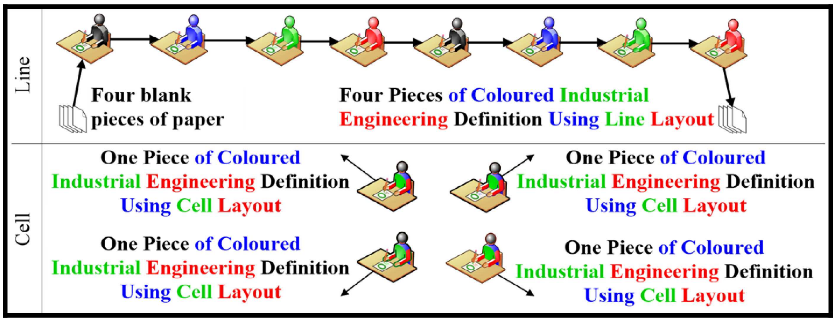

Fig. 3. Line layout and cell layout – first run, 8 pieces (4+4).

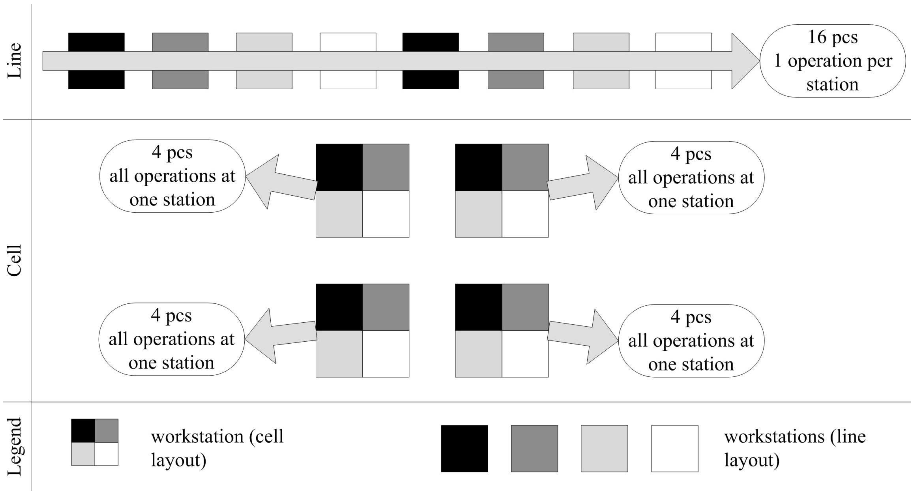

Fig. 4. Line layout and cell layout – second run, 32 pieces (16+16).

"Product" –	„Technology" operations and tools	
definition of industrial engineering	Input material: blank piece of paper	„Tools":
"Industrial Engineers determine the optimal	1. Write 1st line.	• Black pen
way to get a job done	2. Write 2nd line.	• Blue pen
considering methods, people, time,	3. Write 3rd line.	• Green pen
money, material, and equipment."	4. Write 4th line.	• Red pen

Fig. 5. "Product" and "technology" – for limited number of students [colour online].

Each student, who form the cellular layout, is equipped with the full set of four color pens (black, blue, green, red). Each of them, rewrites the whole definition at once, line by line as listed on Fig. 2, changing pens between consecutive lines. In the first run, each of the four student rewrites one whole definition (4 pages in total per group), while in the second run she/he rewrites the definition four times on separate pages (16 pages in total per group).

Before first run, students are asked, what do they need to organize themselves accordingly, what will be their logistics, workstation design, equipment, etc.

Before first and second run a question is asked, which team (line or cell) will be faster. Majority of answers is that line should be faster, both for 1st and 2nd run. All instructions are pictorial and follow rules of visualization (Figs 2–5).

The minimum class time required to execute the exercise for two teams (minimum 14 students i.e. line team – 8 students + timekeeper, cell team – 4 students + timekeeper) is 90 minutes. Necessary resources for the basic version of the task are listed in Table 2.

Depending on available class time and the number of students, the number of teams may be multiplied, or tasks may be modified to balance the size of a group and class duration and to extend/limit duration of the exercise or to enable its execution with less/more numerous groups (Fig. 5).

Table 2
Necessary resources – basic task.

Resource	LINE	CELL	Sum
Pens	2 black	4 black	6 black
	2 blue	4 blue	6 blue
	2 green	4 green	6 green
	2 red	4 red	6 red
Students	8 workers	4 workers	14
	1 timekeeper	1 timekeeper	
Blank papers	4 (1st run)	4 (1st run)	40
	16 (2nd run)	16 (2nd run)	

Table 3
Results of exemplary groups – batch 4 pcs.

Group	LINE [min]		CELL [min]	
	1st piece	last piece	1st piece	last piece
1	3:00	3:56	2:37	3:20
2	2:55	4:01	2:40	3:25
3	3:06	4:04	2:44	3:32
4	2:50	3:50	2:35	3:35
Average	2:57	3:57	2:39	3:29

Both sets of “products” and “technologies” (Figs 2 and 5) were verified in class. Both delivered expected results i.e. manufacturing of 4 pieces per team is faster applying cell layout and manufacturing of 16 pieces per team is faster applying line layout (Tables 3 and 4).

Table 4
Results of exemplary groups – batch 16 pcs.

Group	LINE [min]		CELL [min]	
	1st piece	last piece	1st piece	last piece
1	2:40	8:06	9:20	11:30
2	2:30	8:00	9:25	11:20
3	2:45	8:15	9:45	11:50
4	2:26	7:55	9:15	11:45
Average	2:35	8:04	9:27	11:33

Discussion

Results were discussed with students. The focus was moderated on answering general questions: why cell was faster in the first run and why line was faster in the second run? Results of the first run were not in line with predictions of majority of students. Therefore, they had to challenge question, what is the reason of their mistake.

Students needed to understand the meaning of startup period in case of a line, what makes it less productive in the 1st run. The advantages of higher number of workers in the line layout and no changeovers (each student in a line operates only one pen to write its own part of a definition) were less significant than the impact of the startup and lead time for the 1st piece. There was also no moment, when all the line members are working in the same time (four workers are working in the same time when line is fully filled with work in progress). This implied a decrease of workers productivity as they were unoccupied for the significant part of the whole batch lead time. Results of the 2nd run are opposite to the 1st run. Cellular layout delivered batch of 16 pieces significantly later than the line. This situation originated from a significant waste of changeover in the cell. Each product needed seven changeovers (see Fig. 2). Productivity and throughput were discussed concerning differences between line and cellular layout.

Other topics that were discussed included learning curve and power law. Learning was faster for the case of line layout comparing to the cell, what was achieved through job simplification. On the other hand, job simplification has some contras, that can be discussed on example of quality. Tasks assigned to students in the line were to simple, what is routine and is error prone. Job enrichment might be a solution for this problem. On the other hand, tasks assigned to students in cellular layout were too large, so the learning (experience) curve in this case was significantly worse. This analysis may be supported by data, calculation of learning rate, forecasting times for i-th piece, etc. Another topic to be discussed with groups was product quality and process stability. This can be discussed by eye-ball comparison of repeatability of final products (definitions), which was better for the line, as each worker in the cell had different handwriting style.

Students paid a lot of attention to changeovers and possible improvements to limit their times in the case of cellular layout. This was discussed considering assumptions of SMED (Single Minute Exchange of Die) technique.

Some of the other proposed improvements and issues were tackling:

- Workplace design concerning:
  - Sitting position,
  - Vision type of work,
  - Intermediate storage of work in progress (papers),
  - Storage of tools (pens), etc.;
- Visual management (recognition) of tools;
- Changeover decrease by:
  - Preparation of tools in advance,
  - Division into external and internal activities as known from SMED technique (e.g. taking pen caps off),
  - Placing pens just in sequence, design of tooling fixtures (pen holders);
- New tool – multicolor pen;
- Technology improvement related to workplace design (placing model definition in front of student instead of displaying from overhead beamer);
- Constraints in a line;
- Calculation of takt time and its relation to identified constraint in a line;
- Line balancing (equal parts of definition to be rewritten);
- U-shape line possibilities;
- Robotization;
- Role of standardization concerning:
  - Improvements,
  - Takt time,
  - Line balancing;
- Technology upgrade (e.g. copying, typing plus printing).

The presented list is compiled from all the groups. However, it is the role of the teacher to raise topics, which were not noticed by students themselves. It has to be mentioned, that the tutor also needs to tailor the scope of discussion depending on the knowledge, which is assumed to be delivered upfront of discussed exercise, considering lectures related to the given course, but also other courses in the curriculum. Therefore, in fact this simple exercise may serve as an illustration of many topics simultaneously, but the knowledge has to be delivered upfront.

The above discussed list of topical areas may be extended accordingly to interests of involved students. Conclusion should include relations between product volumes, product variety, specialization of organizational (manufacturing) unit and type of layout.

There were no significant differences observed between groups. Each group made similar observations and elaborated similar proposal as a group. All expected problems (when designing tasks) were addressed and discussed by each group. This confirms some repeatability of achieved educational effects in terms of illustrating relations between different types of layout.

Conclusion

Presented practical exercise is an example of a simple task, which can be utilized to show interrelations and complexity of industrial engineering. This may serve as a good bridge between lectures and practical (more advanced) classes, as it allows discussion of many topics, their connections and somehow may summarize (in a simple and fast manner) a set of topics theoretically covered during lectures. Execution of the task and interviews with students confirmed its potential to introduce holistic approach and understanding of its meaning among students. Presented example is just one of many possibilities. There is big potential in creation of such simple and costless exercises or extending it. For example, simple stopwatch, time and motion study may be included in presented class or it may be presented on example of building (assembling) constructions from bricks. The latter case may also include design of a process, workplace design and line balancing. Obviously, those activities are not an alternative for advanced tools like simulation modelling, etc. However, they can serve as a bridge between lectures (illustrating and summarizing them) and advanced practical classes (being introductory for them). Therefore, this is possible way to increase students' preparedness to advanced practical classes by raising their understanding of the industrial engineering complexity.

References

[1] Nitkiewicz T., Ayen Z., *Identifying key criteria in development of Industrial Engineering education*, MATEC Web of Conferences (12th International Conference Quality Production Improvement), 183(04008), 1–4, 2018, doi: 10.1051/matecconf/201818304008.

[2] Bailey T., Hurst A., *Teaching Line Balancing through Active and Blended Learning*, Decision Sciences Journal of Innovative Education, 2, 82–103, 2018, doi: 10.1111/dsji.12148.

[3] Kerr B., *The flipped classroom in engineering education: A survey of the research*, EEE International Conference on Interactive Collaborative Learning (ICL), pp. 815–818, 2015.

[4] Braghirolli L.F., Ribeiro J.L.D., Weise A.D., Pizzolato M., *Benefits of educational games as an introductory activity in industrial engineering education*, in Computers in Human Behavior, 58, 315–324, 2016, doi: 10.1016/j.chb.2015.12.063.

[5] Nazzal D., Zabinski J., Hugar A., Reinhart D., Karwowski W., Madani, K., *Introduction of Sustainability Concepts into Industrial Engineering Education: A Modular Approach*, Advances in Engineering Education, 4, 4, 1–31, 2015, available at: https://files.eric.ed.gov/fulltext/EJ1077845.pdf [Accessed 10 Feb. 2019].

[6] Colombo C., Alves A., Moreira F., van Hattum-Janssen N., *A study on impact of the UN Decade of Education for Sustainable Development on Industrial Engineering Education*, Dirección y Organización, 56, 4–9, 2015, available at: http://ww.revistadyo.com/index.php/dyo/article/view/469 [Accessed 10 Feb. 2019].

[7] Gladysz B., Jarzebowska E., *International project-oriented training of engineers based on the example of the European Engineering Team*, in e-mentor, 74, 2, 63–72, 2018, doi: 10.15219/em74.1354.

[8] Norgaard B., Nolan D., Polman T., Delfsma A., Parviainen E., Upanne I., Bayard O., Areskoug, M., *Work-based Learning –in Industrial Engineering*, 43rd Annual SEFI Conference, [online] Orléans: Société Européenne pour la Formation des Ingénieurs, available at: https://www.sefi.be/wp-content/uploads/2017/09/56595-B.-NORGA-ARD.pdf [Accessed 28 Jan. 2019].

[9] Alves A.C., Leão C.P., *Action, practice and research in project based learning in an industrial engineering and management program*, ASME 2015 International Mechanical Engineering Congress and Exposition, Houston: American Society of Mechanical Engineers, pp. V005T05A013–V005T05A013, 2015, doi: 10.1115/IMECE2015-51438.

[10] Lynch P.C., Bober C., Wilck, J., *An integrated approach to developing business expertise in industrial engineering students*, 122nd ASEE Annual Conference and Exposition, Seattle: American Society of Engineering Education, 2015, doi: 10.18260/p.23530.

[11] Stefanovic M., *The objectives, architectures and effects of distance learning laboratories for industrial engineering education*, Computers & Education, 69, 250–262, 2013, doi: 10.1016/j.compedu.2013.07.01.

[12] Stefanovic M., Matijevic M., Cvijetkovic V., *Remote Controlled Laboratory Experiments on the Web*, International Journal of Industrial Engineering – Theory Applications and Practice, 18, 3, 130–139, 2011.

[13] Jaeger A., Mayrhofer W., Kuhlang P., Matys K., Sihn W., *Total Immersion: Hands and Heads-On Training in a Learning Factory for Comprehensive Industrial Engineering Education*, International Journal of Engineering Education, 29, 1, 23–32, 2013.

[14] Daggett D., Alptekin S., *Industrial engineering made simple*, Calpoly Website, 1999, available at: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1011&context=ime_fac [accessed 31 Jan. 2019].

[15] Hosseini-Nasab H., Fereidouni S., Ghomi S.M.T.F., Fakhrzad M.B., *Classification of facility layout problems: a review study*, International Journal of Advanced Manufacturing Technology, 94, 1–4, 957–977, 2018.

[16] Azambuja M.J.C., Grimoni J.A.B., Coelho L.G., *Learning Theories applied in Engineering Education: a case study*, 7th IEEE World Engineering Education Forum (WEEF), pp. 915–919, 2017.