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# Information integration over different educational levels and disciplines in a learning factory

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**Abstract**

Going beyond Bloom's traditional taxonomy, the RTTI model (reproduction, training, transfer, insight/innovation) allows for an educational approach in a learning factory that regards a learning process in terms of the ability to understand and reflect on a learner's progress and the learner's ability to take ownership of (and become autonomous in) the learning trajectory. This model facilitates the recursive master-apprentice approach that aims to establish a teaching and learning community, in which all participants directly and indirectly collaborate – irrespective of educational level, study programme and study progress. Every student can contribute – from their personal perspective - to the processes in the learning factory. Moreover, student will be master and apprentice at the same time, forcing them to internalise knowledge to the level that they can convey it to their 'apprentices' – where experienced staff provide safe, constructive, and contextualised environments. Extensive experience with project-led education underpins the feasibility of this approach, and the envisaged learning factory will extrapolate and mature, as the basis for a continually evolving environment that integrates information across multiple educational levels and disciplines. A cluster of projects acts as a case study to demonstrate how the RTTI model, together with the recursive master-apprentice approach can lead to a teaching and learning community – in this case leading to a distributed production demonstrator.


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*Keywords:* teaching and learning community; RTTI model; master-apprentice approach; project-led education

## 1. Introduction

Engineering students are confronted with a wide range of subjects during their studies. All these subjects are explicitly or implicitly related; they will influence each other in numerous ways, in different stages of development cycles and at different levels of aggregation or expertise. Consequentially, it is cardinal for students to fathom such relations and hence create synergy in their work. They need to understand the role of individual contributions in a larger context; as this cannot be rooted in theoretical treatises, students have to simultaneously understand, experience, digest and share knowledge to fully assimilate the knowledge itself, the impact of that knowledge as well as the implications of applying the knowledge. To achieve this in education, it is necessary for students to change perspectives throughout their studies. Moreover, students need to understand the role and value of other disciplines, and as academics they should be educated in making underpinned decisions, while reflecting on the effects they have on other stakeholders. Students should be (more) aware of the impact they (can) make based on their discipline or field of expertise, and how that influences and reacts with other disciplines. In switching perspectives and looking at the same, shared, subject from a different point of view provides students the opportunity to experience, and directly reflect on, the cause-and-effect that changes have on multiple different disciplines.

### *1.1. Switching perspectives and roles*

Education should change its focus from a goal-oriented sequence of courses/entities to a life-long-learning attitude. After all, students are being prepared to deal with the complex, ever-evolving circumstances and volatility of reality. Here, the value of a student's contribution depends on the relation and impact it has with other disciplines [1]. The starting point for this is the ability to understanding how collaboration can lead to synergy. In this, it is essential that students understand ('master') their own discipline to a certain extent first, before addressing (inter)dependencies and relations it has on other stakeholders. Yet, inherent to life-long-learning, there is never a moment that the 'own' discipline will be irrefutably mastered; consequently, uncertainty is inherent to engineering. Students, researchers, and educators should therefore not regard uncertainty as something that requires mitigation, but as one of the main drivers of engineering activities. As knowledge in a study programme varies with the educational progress and also increasingly with personal development paths and personal perspectives of students (from beginning bachelors to 'industrial' life-long-learners), this additional dimension is foremost about how learners conjointly acquire, share, convey, and consequently, fathom knowledge. Whenever an individual student is unaware of the context that knowledge is used in, nor can he identify with that context, any transfer of information or knowledge will be cumbersome or discordant [1]. To fully experience and understand these relations, education should transcend mere theoretical truths. To facilitate students in achieving this, the educational program wants to provide an environment that facilitates multi-stakeholder-decision making and conjointly reflects on those decisions at different levels of aggregation.

In order to keep track on how the intended learning outcomes in education are related to the cognitive domains of the students, Bloom's taxonomy is often referred to as a framework for classifying these learning objectives into levels of complexity and specificity [2]. Where this taxonomy has a strong focus on the internalisation of knowledge, it has little attention for fathoming knowledge or being part of the knowledge evolvement. Yet, in a learning factory, the latter aspects are especially relevant [3]. Developing and employing this awareness adds a dimension to Bloom's taxonomy, with a focus on interrelating the knowledge rather than on the knowledge itself.

### *1.2. Anticipated learning factory*

A learning factory that is currently under development at the University of Twente embraces constant change. Where this environment is still in its development phase, it therefore (still) provides the opportunity to develop innovative educational approaches, in which a sound theoretical fundament and immediate application in a physical and virtual environment go hand in hand [4]. It will prepare students for challenges of the future with information integration over different educational levels and disciplines. For this, a shared environment is anticipated, where different levels of education (university, university of applied sciences, vocational education), different levels of experience (first year BSc. students up to final year MSc. students and beyond), and different disciplines (e.g., mechanical engineering, industrial design engineering and industrial engineering & management) conjointly work in a realistic environment. In simultaneously addressing the activities in the learning factory and the organisation/layout of the learning factory in correlation with (multiple) product development trajectories, there is an inherent focus on bringing together multiple disciplines at different levels of complexity. The impact of decisions from one discipline are experienced in, and influence, other disciplines. Students are confronted with the effect they have on the overall product development cycle, and gain insight in – and learn from – how their reasoning and decisions influence other perspective – as well as from the reciprocity in that.

## 2. Approach and method

Understanding the role of the individual in the larger context is best experienced if multiple disciplines are conjointly working in a shared (physical and digital) environment, on a shared assignment. The idiosyncrasy of collaboration is best explored and experienced in (nearly) real-time cooperation between different disciplines [4]. This calls for an environment, like a learning factory, that is inherently, continuously, and even unconsciously subject to change – a set of characteristics that in some, more traditional, learning factories might be seen as adverse and difficult to align with reproducible, deterministic, and cyclic activities in an established ecosystem. Since the activities of every stakeholder in the learning factory is based on information provided by other stakeholders in previous phases or simultaneously on different aspects, a reliable transfer of information between stakeholders is essential. Many available approaches focus on the resulting physical part of the learning factory, rather than on the underlaying educational methods. The implementation of new developments or trends in industry, such as industry 4.0 [5] covers some of the aspects of the desired information integration. This can be combined with the notion of reconfigurable systems or learning modules that allow a combination of teaching and applied research [6]. This involves finding a balance between available resources and the characteristics of a specific environment [7]. To keep track of the relationship between design elements, didactics and quality management, a maturity model and associated levels can be used [8]. For the development of the learning factory an approach is needed that supports these characteristics of the educational vision, where information integration relations between theoretical knowledge and practical application are essential.

### *2.1. Beyond Bloom's taxonomy: RTTI/OPSA*

Since the emphasis in the proposed deployment of the learning factory should be on the ability to fathom and transfer knowledge, the Bloom taxonomy cannot comprehensively cover all required aspects. For that reason, underpinning the didactical approaches in the learning factory is extended by adopting the RTTI/OPSA model [9]. This model addresses a learning process in terms of the ability to understand and reflect on a learner's progress and its ability to take ownership of (and become autonomous in) the learning trajectory. It distinguishes between developing intellectual capabilities (RTTI) and using that development as the basis for demeanour (OPSA). Moreover, the model does justice to the changing perspectives and volatility of the circumstances that are ingrained in the envisaged learning factory. In this, the acronym RTTI captures the levels as: Reproduction, Training, Transfer, Insight & Innovation. At the first level, *reproducing*, the emphasis is on the ability to remember and reproduce knowledge. The *training* level addresses the application of prepared and explicit procedures in a familiar context. The next level, *transfer*, focuses on applying such procedures in increasingly unfamiliar or new situations or contexts. The last level, *insight & innovation*, exemplifies analysing, understanding, and constructing solutions from different perspectives concurrently. This aligns closely with the essence of the envisaged learning factory; from that alignment, the preceding levels can be employed in defining preparatory educational activities and can even be used in establishing/developing the learning factory itself. Together, the four levels depict the way of thinking a student can experience and develop (both collective and individual) on certain knowledge, perspectives, or fields of expertise. Corresponding to these intellectual abilities, the OPSA (organise, participate, self-confidence, and autonomy) aim to embed the learnings in adequate competencies and reflective abilities. Together, the intellectual capabilities (RTTI, 'thinking pillar') and competencies (OPSA, 'behaviour pillar') support the envisaged learning factory in exciting e.g., peer-learning, master-apprentice approaches, integration of education and research, and dynamically incorporating multiple perspectives. Table 1 represents the RTTI/OPRA model.

Table 1. Thinking levels and corresponding behavioural levels. (adapted from [5])

| Thinking level | Behavioural level |
|---|---|
| **R**eproduction | **O**rganise |
| **T**raining | **P**articipate |
| **T**ransfer | **S**elf-confidence |
| **I**nsight & Innovation | **A**utonomy |

### *2.2. Value of project-led education*

The RTTI/OPRA model closely relates to engineering education; more than Bloom's taxonomy, it aligns with the simultaneous, iterative engineering approach of acquiring, understanding, applying – but also sharing and conjointly reflecting on - knowledge. Even without explicitly applying the RTTI/OPRA model, many engineering courses will implicitly use components or aspects thereof. This is certainly the case for the educational programmes in engineering at the University of Twente, which have a long tradition in in applying project-led education as a means to inspire and challenge students and to allow them to study and experience the relation between theoretical knowledge and (industrial) realistic practice [10]. In educational modules of ten weeks each, students follow theoretical courses that thematically cohere with a project. Varying with the module and the level of studies, projects constitute 20-50% of the overall study load, and students work in groups ranging from 4 to over 15 students per group. Students are challenged to take ownership of their own projects, take the responsibility for the outcome, but also for the processes that leads to that outcome – while continuously reflecting on the progress and learnings. With that, learners focus less on 'passing courses', rendering assessments more transparent and purposeful [11], as students themselves are involved in correlating activities to goals and deliverables. Learners thus not 'just' straightforwardly try to solve the problem at hand, but also look at the consequences of solution for other perspectives, to establish co-operation over different disciplines but also to question or reformulate the problem statement [10]. Inherent to this approach is the fact that learners are challenged to exchange knowledge, and that learners pro-actively communicate with experts in the field to seek knowledge, advice, coaching and feedback. Habitually, student groups have an assigned tutor, who helps the groups in formulating questions, directions, and approaches, but who will not always provide answers or solutions. This forces the learners to focus on the problem-solving approaches and underpinning of reasonings, rather than on merely arriving at an (unverifiable) factual answer.

### 3. Asynchronous Master-apprentice learning factory

It is evident that project-led education leads to better internalisation of knowledge, to better decision-making and decision-making skills, and to more profound understanding of and reflection on the reasoning that underlies the project progress and its outcome. With that, project-led education has shown many characteristics that much later were captured in the RTTI/OPSA model. The envisaged learning factory facilitates a strong integration between education and ongoing research; moreover, while serving as the basis for a teaching and learning community. In this community, there are no clear hierarchies nor predetermined roles for students, teachers, or researchers, but it foremost aims to be an environment that stimulates knowledge transfer. Every student can contribute – from their perspective - to the processes in the learning factory. All those perspectives add value in their own way, and not one solution will be the primed, sought-after, and expected one. With that, all participants in the learning community have comparable and equivalent roles, where advanced learners foremost have a head start over beginning learners – and where researchers can learn from (decision making by) even beginning learners. Yet, as beginning learners progress, they again will have an advantage over incoming novices. With that, the learning community is an amalgamation of consecutive generations of learners, that evolve in the process, and might eventually evolve into researchers or teachers. This flow is quite typical of a master-apprentice approach, where, traditionally, the transfer of knowledge, skills and interpretative ability is supported. In practical education, apprentices acquire technical know-how by working alongside experienced and qualified employees and receiving guidance from them during their work [12]. Throughout history this is commonly used as the preferred work-related learning approach. The apprentice starts with sheer observations, followed by 'reproducing', 'doing', 'being guided' and 'learning-by-doing' respectively. However, this traditional master-apprentice approach habitually relies on all parties being present at the same time at the same location while co-operating on the same task. This is in line with the first level, *reproduction* in the RTTI/OPSA model, and eventually can lead to the second level of *training*. In current industrial practice, and even more in learning factories, this rather artisanal approach is inapplicable, caused by the many different perspectives involved, the student-staff (or master-apprentice) ratio, but foremost by the constant change of persons involved. Furthermore, to reach the other two levels of the RTTI model, students should be able to *transfer* their knowledge to others and be stimulated to reach the level of *insight/innovation*, both of which are not covered in the traditional master-apprentice approach. To reach these levels, and for the conveyance of (tacit) knowledge, an interpretation of the master-apprentice approach is required that allows for differentiation in time and location of learners. This contemporary interpretation brings together different levels of aggregation and facilitates multiple perspectives in an integrated manner, while not imposing workflows or view-dependent approaches [13]. Beginning learners may be performing tasks that are defined/planned/optimised by graduate students, and these graduate students may be studying optimisation methods in the context of a PhD. research trajectory. At the same time, undergraduates may be studying assembly variations, or contribute to a product optimalisation performed by graduate students. Thus, what may be a challenging learning intent for some students, may be input for advanced learners. This allows different students to simultaneously work on similar topics at their own level, while concurrently – and perhaps even implicitly or unconsciously – providing a wealth of information, input, reflections, and creativity for students at different levels. In such scenarios, students and teachers can all be the instigator of learning, and all can inspire, guide, and motivate individuals to collaborate on peer learning at different levels and eventually engage in a master-apprentice relationship themselves. Figure 1 illustrates this for a number of different programmes that will participate in the envisaged learning factory.

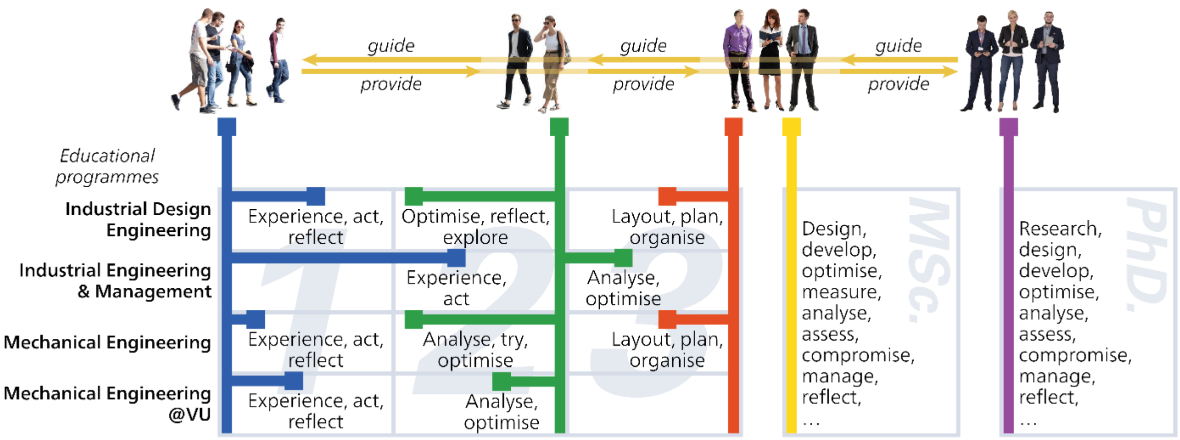


Fig. 1. Consecutive levels of maturity that co-operate over different education programmes in the envisaged learning factory.

A student will thus be master and apprentice at the same time, provoking all learners to internalise knowledge to the level that they can convey it to their ‘apprentices’ – where experienced staff provide safe, constructive and contextualised environments and guidance. This makes learning more active, and challenges learners to replicate, use, reformulate, reflect on, and creatively use the expertise they are building and conveying. With that, explicit and tacit knowledge are less disparate, allowing learners and educators to focus more on the rationale in and of decision making than on the sheer ‘correctness’ of solutions. In line with the RTTI/OPSA model, the recursive master-apprentice approach challenges learners to continuously involve in the teaching and learning community. The proposed learning factory will not have any standard invariable lay-out or setup. Students are expected to compose the environment to their needs, based on new insights, try-outs, expectations, and the outcomes of (previous) student/researcher work. They will encounter the perspectives of other disciplines, as well as being confronted with the consequence of their decisions over multiple lifecycle stages. Alongside, researchers and educators from different backgrounds will contribute to the environment. This will stimulate motivated learning, self-initiative, and self-organised learning; moreover, it supports students to meet the programme intended learning outcomes (PILOs) of their educational programme, while explicitly reflecting on those outcomes, and on the way in which they are reached. With that, learners will be challenged to transcend and outshine the knowledge offered at their level, by interacting with the ‘masters’ for their level. Moreover, every participant in the teaching and learning community is inherently challenged to think out-of-the-box, because of the ever-changing lay-out, setup and conditions in the learning factory. With this, learners need to integrate the notion uncertainty in every step of their work. Whereas staff will be supportive in dealing with such incertitudes, it foremost means that every learner is essentially a researcher: the learning factory will not reward learners with unequivocal answers if predefined process steps are executed. Rather, the learning factory will become a versatile environment to explore solution directions, to reach, underpin and evaluate decisions and to reflect on the value and impact of concepts, approaches and working methods with peers, in master-apprentice relations and with staff members.

**4. Example & case study**

Over the last five years, multiple students, student groups, and researchers, worked (simultaneously and sequentially) on several projects that (pre-)define, establish, and evaluate future components of the envisaged learning factory [13]. This approach ensures that the envisaged learning factory is not designed as an invariable entity, it also oversees the realisation of the learning factory as an evolving, scalable trajectory, rather than as a turn-key project. A cluster of such projects developed into a setup that became a distributed production demonstrator. Where participants worked on their projects from different perspectives (ranging from process control, via logistics to user interface design), no overarching approach, design, or project plan lies at the core of the demonstrator. This was explicitly omitted, to gain experience with peer-learning and master-apprentice learning in the context of introducing the RTTI/OPSA model. Moreover, in anticipating the changing circumstances of the envisaged learning factory, a learning-by-doing approach is part of this case study; solutions are developed while directly validating them [14]. This prepares the students for future challenges where collaboration is essential, while becoming more resilient by gaining experience in dealing with partial, irresolute, or unexpected outcomes. This approach not only challenges students to be critical in the application of their knowledge but will also lead to changing conditions for others.

At the core of the distributed production demonstrator are, instigated by sheer availability, a CNC-milling machine, a 3D printer, and a robot arm, all at desktop scale (see figure 2). As such components will be representative of the envisaged learning factory, they provide an exemplary environment to test principles for the learning factory, and foremost for assessing elements of the master-apprentice approach. Moreover, in involving students, researchers, and staff in both the development of the demonstrator and its application as an element in a larger learning factory environment, the case study can be used to confirm the ability to apply recursive learning approaches in engineering education for different perspectives. In the development cycle of the distributed production demonstrator, a master-apprentice affiliation even grew autonomously, as ‘developers’ of the

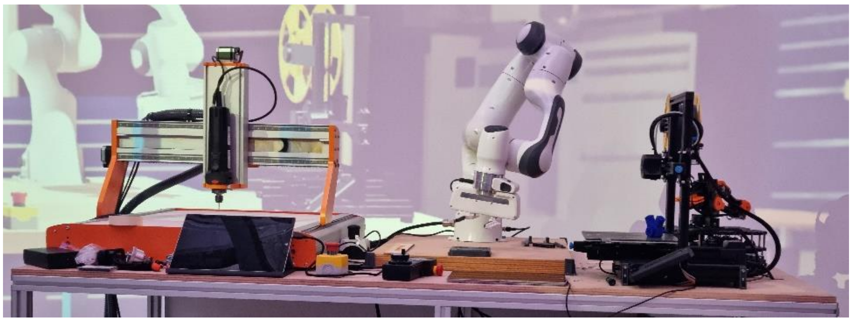

Fig. 2. Evolving setup for the distributed production demonstrator.

demonstrator recruited beginning learners to use and test the setup. Not only did the 'users' provide feedback on e.g., the usability and efficiency of the system, the operation of the demonstrator sparked discussions with the different types of 'developers', but foremost between these developers themselves. As anticipated, many of such discussions lead to active involvement of the 'users' – to the benefit of the masters and the apprentices. The case study is not limited to engineering disciplines, but also integrates social, behavioural and management studies into the same set-up, e.g. in the area of knowledge capture and transfer, ergonomics, human factors and sustainability. Students are responsible for documenting the rationale and information in such a way that others can (re-)use it for their project. The cluster of projects showed the added value of combining different study programs and study year; not only did the students manage to realise a working demonstration, over time the functionality of the setup is growing. This cluster of projects proves that peer-learning and master-apprentice relations are certainly feasible, effective, and efficient ways to obtain knowledge and gain experience in realistic environments, and that the RTTI/OPSA approach facilitate the educational approaches that underly these projects. Moreover, the case study shows that students pro-actively establish their own projects with demonstrable ownership of the projects – with limited staff support and entirely without plans, workflows, or guides predetermined by that staff.

## 5. Concluding remarks

In academic education, continuously a balance must be struck between industrial reality and advanced scientific engineering insights. Or, stated differently, where beginning learners benefit from exposure to industrial practice, advanced learners and researchers can use that same industrial practice as a springboard for new insights, theories, and developments. Over the last decades, project-led education at the University of Twente has indeed proven instrumental in bringing practice to beginning learners; addressing theory while simultaneously applying the knowledge gained in realistic projects has become the core of undergraduate education in engineering. Based on this, educators and researchers have, implicitly as well as deliberately, developed initiatives to further capitalise on new ways of learning. Over time, various initiatives, projects, approaches, and paradigms have been explored, culminating in the development of a learning factory that brings together researchers, teachers and learners from different perspectives and that inherently embrace volatility and uncertainty as attributes of a realistic environment. In doing this, the RTTI/OPSA model provides the educational backbone to exceed traditional learning schemes, and it underpins the ability to use peer-learning and recursive master-apprentice approaches in engineering education. Over the years, many student projects have served as a testbed or sandbox for improving learning experiences. With that, the envisaged learning factory is not a turn-key autonomous entity with predictable behaviour – it rather is a scaled-up and matured extrapolation of such testbeds. As a teaching and learning community, all participants will experience and influence the learning factory, in a safe environment, where the primary process of production and assembly is subordinate to the ability to experience, understand, improve/optimise, and design/develop such primary processes. This will require staff to re-focus on the content of their courses, as well as on their role as educators. As most teaching staff has research responsibilities as well, they can also employ the learning factory as a living lab, where they can actively participate in the teaching and learning community, together with all levels of learners, and only with a head start over beginning learners.

## References

[1] R.G.J. Damgrave, E. Lutters, Designing Individual Education in a Group Setting, Procedia CIRP, 50 (2016) 733-738.
[2] A. Sharunova, Y. Wang, M. Kowalski, A.J. Qureshi, Applying Bloom's taxonomy in transdisciplinary engineering design education, International Journal of Technology and Design Education, 32 (2022) 987–999.
[3] E. Abele, G. Chryssolouris, W. Sihn, J. Metternich, H. ElMaraghy, G. Seliger, G. Sivard, W. ElMaraghy, V. Hummel, M. Tisch, S. Seifermann, Learning factories for future oriented research and education in manufacturing. CIRP Annals - Manufacturing Technology, 66/2 (2017) 803-826.
[4] R.G.J. Damgrave, E. Lutters, Student driven learning in Synthetic Environments, Procedia CIRP, 84 (2019) 341-346.
[5] Plorin D., Jentsch D., Hopf H., et al., 2015, Advanced Learning Factory (aLF) – Method, Implementation and Evaluation. Procedia CIRP, 32:13-8.
[6] Quinn W., Cionca V., Witheephanich K., et al., 2022, A Learning Factory Framework: Challenges and Solutions for an Irish University*. IFAC-PapersOnLine, 55:631-6.
[7] Leal L.F., Fleury A., Zancul E., 2020, Starting up a Learning Factory focused on Industry 4.0. Procedia Manufacturing, 45:436-41.
[8] Enke J., Glass R., Metternich J., 2017, Introducing a Maturity Model for Learning Factories. Procedia Manufacturing, 9:1-8.
[9] M. Drost, P. Verra, Sturen van leerprocessen met RTTI - Handboek RTTI, (2019), Uitgeverijplus
[10] W. Dankers, H.M. Schuurman-Hemmer, A. van den Boomgaard, E. Lutters, Bringing practice to the theory: Project-led education in Industrial Design Engineering, DRS//CUMULUS Oslo (14-17 May 2013) 29-43.
[11] J. Biggs, C. Tang, Teaching For Quality Learning At University, (2011) McGraw-Hill Education.
[12] E.F. Crawley, J. Malmqvist, S. Östlund, D.R. Brodeur, Rethinking Engineering Education - The CDIO Approach, (2007) Springer.
[13] E. Lutters, J. Massa, R.G.J. Damgrave, S. Thiede, L. Gommer, Integration of learning and research in a multi-perspective learning factory, 18th International CDIO conference (13-15 June 2022) 551-562.
[14] M. Tisch, J. Metternich, Potentials and Limits of Learning Factories in Research, Innovation Transfer, Education, and Training, Procedia Manufacturing, 9 (2017) 89-96.