



Gamification of production automation

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Abstract

Die Vermittlung technisch anspruchsvoller Lehrinhalte in Übungen ist oft an die Verwendung von Software geknüpft, die zur Bearbeitung benötigt wird. Gleichzeitig ist eine Vielzahl von Anforderungen und technischen Gegebenheiten zu beachten. Klassische Lehrveranstaltungen folgen dem Frontalunterrichtsprinzip. Der Lehrende zeigt an einem Beispiel alle zu erfüllenden Arbeitsschritte. Die Studierenden lernten auf diese Weise die Bedienung der Software und der benötigten Funktionen vorwiegend nach dem Prinzip „Vormachen und Nachmachen“. Leichte Variationen zum Beispiel erfordern dann noch eine gewisse Adaptionsleistung des Studierenden des Gesehene an die eigene Aufgabenvariante. Die Ergebnisse werden anhand festgelegter Kriterien und Fehlerkataloge bewertet.

Diese Vorgehensweise ist zum einen wenig motivierend und zum anderen weit von den späteren Anforderungen der realen Arbeitswelt entfernt. Der Zwang zur Online-Lehre infolge der Covid-19-Pandemie wurde als Chance genutzt, bei der Lehrveranstaltung Produktionsautomatisierung dieses nicht mehr zeitgemäße Lehrkonzept durch ein neues zu ersetzen. Es basiert auf den Prinzipien der Gamification und erweitert den Handlungsraum des Lernenden erheblich. Durch den Einsatz real wirkender Belohnungen und der Möglichkeit die eigenen Ergebnisse selbst kontrollieren zu können, wird eine intrinsisch motivierende Arbeitsumgebung geschaffen. Die Integration einer wettbewerblichen Komponente steigert die Motivation zusätzlich.

The teaching of technically demanding content in exercises is often linked to the use of software that is required for processing. At the same time, a large number of requirements and technical conditions must be taken into account. Classical lectures follow the principle of frontal teaching. The teacher uses an example to show all the steps to be taken. In this way, the students learn how to operate the software and the required functions primarily according to the principle of "show and tell". Slight variations, for example, still require a certain adaptation performance of the student of the seen to the own task variant. The results are evaluated on the basis of fixed criteria and error catalogs.

On the one hand, this approach is not very motivating and, on the other hand, it is far away from the later requirements of the real working world. The compulsion to teach online as a result of the Covid 19 pandemic was used as an opportunity to replace this outdated teaching concept with a new one in the Product Automation course. It is based on the principles of gamification and considerably expands the learner's scope of action. An intrinsically motivating work environment is created through the use of real rewards and the possibility to control one's own results. The integration of a competitive component further increases motivation.

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1. Initial situation

The course Production Automation is primarily aimed at students of mechanical engineering specializing in production technology. However, industrial engineers and computer scientists also take this course. The aim of the course is to teach automation technologies, production planning knowledge, common tools and workflows along the product engineering process (PEP). The focus is on manufacturing and its planning. Work preparation takes a special position in this context. The core content in the classic offline format was the planning of a milling operation with upstream design of the component to be planned using the CAD/CAM software PTC Creo. The process was strictly linear. Based on a given drawing, the component was designed and then its machining was planned. This was done successively in several practice hours, accompanied by the instructor. In this way, the students learned how to use the software and the required functions, mainly on the principle of "show and tell". Slight variations in the component geometry required a certain amount of adaptation by the student of what they had seen to their own variant of the task. The results were evaluated on the basis of defined criteria and error catalogs.

2. Something had to be changed

With the shift of teaching to the digital space, there was a unique opportunity to adapt both the content and the delivery methods of the course. The main improvement variable addressed should be student motivation. For years, this has been regarded across all fields of study and courses as in need of improvement and, at the same time, as a critical component for academic success. Problematic is the activation of students to avoid procrastination [1]. Self-efficacy, in particular, takes on a central role here, as it is "related to a higher interest in studying and a higher motivation to perform. As a result, students more strongly pursue the goal of being successful in their studies and achieve higher academic performance" [2]. In any case, lack of access to information and knowledge can no longer serve as

a reason for high dropout rates in the age of the Internet.

The pure transfer of specialized knowledge can therefore no longer be the sole main component of teaching. Students (rightly) expect an evolution of teaching. Basic motivational mechanisms that appeal to as broad a front of different characters as possible should be part of as many courses as possible. After all, people like to do what is fun, and they strive to get better at it. But it is precisely this enjoyment of learning that has suffered to a particular extent in the last two semesters, as a survey at the St. Gallen campus shows (Figure 1).

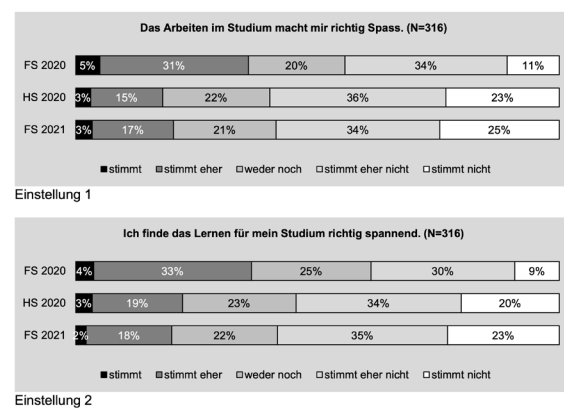


Figure 1: decreased learning fun during covid-19 [3]

Furthermore, the previous teaching concept was very much focused on practicing a specific solution. The solution was already partially available in the form of the finished design. It was only necessary to create a correct production plan for it. What had to be done for such a plan was demonstrated with a very similar example. In this way, the learner was already relieved of many action and decision-making steps. For example, he was shown functioning machining strategies, tool selection and setups that differed only slightly from those of the planning to be created. As a result, quite a few of the solutions created by the students were pure imitations of the procedure shown. On the one hand, this was not very motivating, since the solution space was basically limited by the given design. On the other hand, the learner was deprived of the actually interesting and challenging part of the task: finding a solution and procedure that works at all. For this, significantly more complex thought processes are necessary than for pure copying. For exam-

ple, the processing sequence requires numerous technical and technological conditions to be taken into account, all of which must be considered and thought through. In order to be able to take these into account, it is necessary to take a deeper look at the requirements and consequences behind them. Since these are often not monocausal, but result from a combination of design and selected procedure, the learner must also repeatedly reconsider his fundamentally selected processing sequence. The iterative procedure resulting from this in the actual workflow was largely prevented by the solution shown on the example part and the possible learning effect was prevented.

The fact that this assumption is correct was shown by mistakes made time and again, which can be classified as typical imitation errors. For example

- the use of the tools from the example, although they were rather inappropriate,
- Tool paths that do not produce stock removal (air cuts),
- unnecessarily many loop lashings (as in the example) or
- technologically incorrect machining sequences

could be observed.

Another obstacle was the way the consultations were organized. They took place physically in the computer pool. Although this meant that there was personal contact with the teacher, the interaction between teacher and learner was limited to direct conversation. The other learners were able to listen to this conversation. However, especially with technically demanding questions, the visualization of the problem situation and solution is more than useful from a didactic point of view. For example, it is very difficult to describe in words the selection of a suitable tool if it depends primarily on the geometry of the feature. In such cases the teacher went to the learner's place and both looked at his screen. Thus, the knowledge gain of this problem was limited to one learner. It was absolutely the rule that the teacher had to answer the same questions over and over again during a consultation or help solve very similar problems.

If all factors were taken together, the picture of a teaching event emerged, which was oriented towards the adoption and adaptation of demonstrated action steps to a very similar task. The transmission of the teacher's knowledge was close to the concept of frontal teaching. The possibility of recognizing and understanding one's own mistakes was hardly provided for. In connection with the limited scope for design, the motivation of the learners to deal with the actually interesting aspects of production planning was rather limited.

3. Gamification

To change this, the gamification approach has been adopted [4]. It is well known that "gamification can help support motivation to use these systems in a work-related way or to learn how to use software" [5]. To this end, gamified elements such as high scores, awards, virtual rewards, or different game levels are added to the underlying task.

But the task itself must also be adapted to this concept or be suitable for it. To get the learner to care about the reward elements offered, both the achievable goals must be attractive and the steps necessary to achieve them must be sufficiently clear and achievable. However, what appears attainable to a learner depends heavily on that learner's individual skills and knowledge. With the ever-growing number of students, this spread has increased. The modularization of teaching has also ensured a very broad field of study. Thus, in addition to production engineers, students of economics, teaching and also computer science are regularly represented in this course. The technical fundamentals that these groups bring with them differ greatly. In some cases, they do not even have a basic knowledge of process engineering. In order to nevertheless enable these extremely heterogeneous levels of competence to engage in self-directed learning, several approaches are required. This increases the chance that even with only limited prior knowledge, an approach to the problem can be found.

Complicating matters further was the fact that Covid 19 restrictions meant that elements or tools requiring physical presence had to be dis-

pensed with. A shift of the entire course to virtual space was thus required. However, this also comes with some disadvantages. For example, it is known that some people need personal contact with the instructor or fellow students in order to develop a positive motivation to work. Still other people learn primarily through conversation and the accompanying exchange with another person. Gamification can help here to get into conversation with others.

The core of this is the task. This is designed so openly with regard to possible solutions that it can be considered impossible for two students to find the same solution independently of each other. This allows the students to exchange ideas without being inhibited in their motivation. Also, you cannot simply adopt the solutions of others. This promotes professional exchange, since the question of "why did you do it that way?" always resonates.

However, in order for the learner to get to this point where he is already fully engaged with the task, the initial entry threshold must first be overcome. This is often perceived as a "mountain" that one does not know exactly how to approach at first. This often leads to the fact that processing is not even begun

To solve this problem and increase the learner's motivation to enter the task, several measures were resorted to:

- a task that offers a projection surface and thus increases identification,
- a design task that can be understood by anyone without prior technical knowledge,
- a target that is immediately comprehensible and verifiable for everyone
- as well as a working and learning mode that invites discussion and exchange.

4. Implementation

The task introduces the learner to the situation as a newcomer at a fictitious innovative toy manufacturer. There he is responsible for the special order "Design and production of a marble run in small series". Concrete requirements are placed on the design (e.g. minimum length or minimum slope). However, there are no specifications as to how these are to be met.

Only a maximum unit price is given in order to ensure a certain minimum level for learners who are running this course with the minimum effort. Beyond that it is bound alone to the given manufacturing environment (tool catalog and machine tool). This gives the learner many degrees of freedom, which allows an almost infinite number of approaches and solutions. It is deliberately refrained from showing an example solution in order not to limit the solution and thinking space.

Fusion360 from Autodesk was chosen as the technical software basis. In addition to the mandatory features (executable on all relevant operating systems, available online, free of charge for teachers and learners) and functions (integrated CAD- CAM, CAM verification module), it offers a very intuitive operating concept. In addition, there are many learning resources available free of charge. This enables the learner to go through all steps in one software. Annoying interface work (e.g. exporting files, memorizing data) is no longer necessary. This promotes in particular the mutual play between design and manufacturing and thus opens up a very large scope of action, since the learner can concentrate on finding a solution and is not interrupted again and again by annoying cumbersome work. This also promotes the emergence of the so-called flow. This occurs when one is completely immersed in the task and is perceived as pleasant and desirable by the vast majority of people.

In order to counteract the sometimes arising overload due to the sheer number of options for action, the strong dependencies of both parts on each other, which are close to those of a real PEP, are used. At first glance, countless solutions are conceivable. However, when trying them out, it quickly becomes clear that many of them do not lead to the desired results for a wide variety of reasons.

In order to facilitate the start for as many users as possible with different levels of practice and behavior, videos were made available on OPAL with further links before the start of the exercise. This provided the opportunity to acquire and practice the necessary knowledge in advance. For other types of learners, a digital introductory event (goto meeting) was held with a hybrid structure (question part and subse-

quent provision as a video on OPAL). In addition, the forum was used and a weekly consultation (GoToMeeting) was held.

In addition to the technical specifications, the marble run must also meet economic requirements. This is where the strongest game element is implemented: a competitive situation for the lowest manufacturing costs. The best 25% of all final solutions submitted receive a staggered bonus on the overall score (Table 1).

Table 1: Distribution cost bonus

Percentile (bigger is better)	Bonus
100 - 96	0,5
95 - 91	0,4
90 - 86	0,3
85 - 81	0,2
80 - 76	0,1

For example, the learner can exchange time for quality - as in real life - and additionally receives information about the ranking of his performance in comparison to others. The calculation of the production costs is done via a standardized Excel file, which has to be filled in by the learner and handed in next to the project file (Figure 2). In addition, there is also a technical evaluation of the solution according to the classic point deduction principle in case of errors.

material costs	3,70 €
machining time	65 minutes
machine hour rate	100 € / h
machine setup	10 minutes
number of setup changes	2 pcs
duration setup change	5 minutes
hourly rate machining technician	60 € / h
manufacturing costs	161,67 €
overhead	50 %
production costs	242,5 €

Figure 2: Screenshot of the calculation sheet for the production costs.

In order to reflect the iterative improvement process typical in real working life, the learners can submit interim results and have them evaluated. For this purpose, 4 stages of 14 days each are planned.

The intermediate results are made available on a web page¹ (Figure 3).

¹ <https://paevatool.webspaces.tu-dresden.de>

This allows learners to track their progress self-directed and online. At the same time, the competitive situation for receiving the bonus points is visualized.

rank	percentile	cost bonus	matriculation number	cost of sales	data valid
1	100 - 96	0.5	4895635	50.32	✓
2	80 - 76	0.1	4549230	67.17	✓
3	-	0	4536143	76.95	✓
4	-	0	4894632	91.57	✓
5	-	0	4989512	290	✓
6	-	-	4905466	-	✗
7	-	-	4904285	-	✗
8	-	-	4886528	-	✗
9	-	-	4834684	-	✗
10	-	-	4905358	-	✗
11	-	-	4839781	-	✗

Figure 3: Highscore of the current intermediate results

The creation of the homepage as well as the maintenance and evaluation of the data are automated. The students upload their intermediate and final results as a ZIP file via OPAL into the corresponding submission module. Thus, all results can be downloaded by the instructor with a few clicks, regardless of the number of participants. A python script unpacks the files, parses the contents, extracts the data from the individual files and makes them available as assets. Missing or erroneous data is displayed so that the instructor is informed about this. Then, using the Angular framework, a homepage is automatically created from the assets provided. This then only needs to be delivered. This almost automatic build pipeline reduces the effort for the teacher to a few minutes. What remains, however, is the manual control of the production planning itself. Since the students have to hand in the entire project file, the results achieved can be compared very well with the underlying planning. Here Fusion360 supports with a comfortable NC verification (Figure 4). Thanks to the digital implementation of the exercise throughout, consultations can also be realized correspondingly easily, for example via screen sharing.

The weekly consultations serve as a learning and exchange space. These take place online

in the meeting environment. The resulting opportunities for interaction not only largely compensate for the lack of physical contact, but even create new possibilities. For example, learners can share the screen, which makes it possible to discuss and visualize a problem in the group. The assistance then offered by the instructor can be comprehended by everyone and, if necessary, used to solve a problem of their own. The consultations are recorded. In this way, individual topics can be viewed again afterwards.

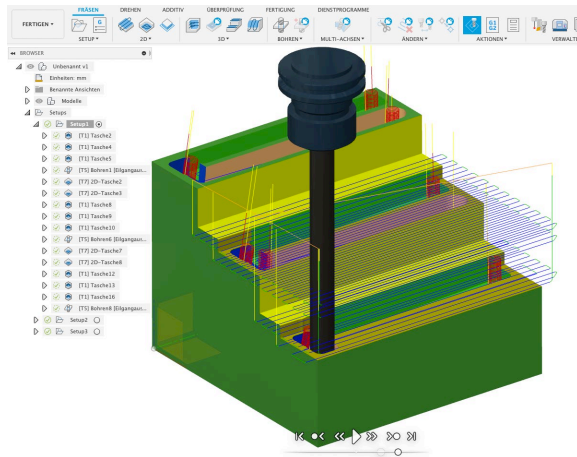


Figure 4: NC verification in Fusion360

Not a single sheet of paper is needed for the entire exercise.

5. Concept & Effect

In the way described, the students can experience a holistic planning process with all the relevant elements that make something like this really interesting in real life. At the same time, they are positively extrinsically motivated by the competitive situation for the bonus points. The task, which is comprehensible to everyone, promotes intrinsic motivation, which is also maintained during the course of the project due to the transparency of the underlying evaluation. The deliberately open solution space reduces the numerous specifications of the old exercise, which are often perceived as restrictive, and causes a paradigm shift in the unconscious perception of the task. Where previously a "find the solution desired by the teacher" dominated, space has now been created for creative and at the same time innova-

tive solutions. By complying with the simulated customer requirements explained in the assignment, students learn to translate external specifications into technical processes. The fact that they can check their results on a small scale and independently using the tools provided enables a self-directed learning process. This is supported by the avoidance of hard limits as far as possible. This gives students the opportunity to compensate for disadvantages at one point with advantages at another. Frustrating "I can't get any further" moments are thus largely absent.

All elements together create a positive motivation to learn.

6. Findings

The possibilities of virtual learning spaces were very useful. The frequency of duplicate questions decreased significantly compared to previous years. It was also possible to get many learners out of the anonymity and passivity of virtual lectures after an initial hesitant phase. From the third consultation at the latest, there was a lively exchange of ideas and approaches to solutions among the students as well.

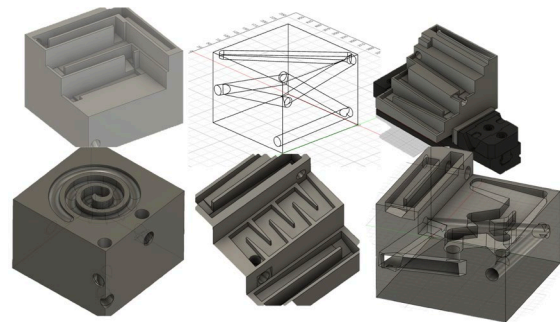


Figure 5: Different marble run designs by students.

The solutions devised by the students suggest that this exchange was also successful. Thus, numerous very different and creative marble run designs were created (Figure 5). Not only did these meet the requirements, but also the frequency and severity of errors of the associated production planning were at most as high as in the old exercise. This is all the more remarkable because the milling operations applied and geometries machined were in some cases significantly more complicated than in the old exercise.

Success can also be seen in the cost of sales (Figure 6). These are close together in the upper - i.e. points-effective - range. On the one hand, this indicates functioning competition and, on the other, that the framework conditions are working successfully.

rank	percentile	cost bonus	matriculation number	cost of sales
1	100 - 96	0.5	12345679	47.88
2	95 - 91	0.4	12345677	47.97
3	90 - 86	0.3	12345673	48.07
4	85 - 81	0.2	12345678	49.75

Figure 6: Top4 of the cost of sales

The example presented shows that the transformation of classic exercises into digital and motivating formats can succeed. Modern technologies and learning approaches can be used very well here. The effort required of the teacher can even be reduced, as repetitive activities can be automated.

OPAL can be used well for this purpose, although the interface is not very intuitive. Also the function to download all submitted solutions requires a certain detective intuition.

However, setting up the web space where the homepage is hosted was much more time-consuming. Numerous rules and regulations required several hours of training. The TU's internal checklist for web applications alone included well over 100 - in some cases very specific - questions on technical implementation. For the average computer user, the vast majority of these are likely to be difficult or impossible to understand. A reduced or pre-filled list for different types of applications as well as a wizard would help enormously. The obligatory imprint, but especially the accessibility statement, is also a challenge for the typical teacher due to the legal requirements for it. It is true that the TU-internal web support assists here to the best of its ability. But these are not sufficient to reduce the effort to an acceptable level. This issue is very important for a university that wants to take the step into the digital age. There is an urgent need for a central and appropriately equipped office to support

teachers in the barrier-free design of homepages, both technically and legally. Otherwise, many such projects are in danger of failing because of the effort involved - or they are not even started.

8. Literature

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