PM-ET METHOD: A PRODUCT-BASED ENGINEERING TRAINING PROGRAM IN UNIVERSITIES

1Jing ZUOa, 2De-Yu WANGb \*, 3Ju GAOc, 4Xiu-Hai ZHANGd

1,2,3,4Tsinghua University, Beijing, China

azj.joe@tsinghua.edu.cn, bwdy@tsinghua.edu.cn, chaochun@tsinghua.edu.cn, dzhangxiuhai@tsinghua.edu.cn

ABSTRACT -In this paper, we will discuss about a engineering training program for organizing challenge-based learning activities which emphasizes the integration of process/project management into engineering training (so we call it PM-ET method). *Background*: By setting up product-based learning objectives and applying matrix management format to organizing teachers and teams of students, we enabled students to customize the learning path and the content according to their interests. *Method*: 1) the PM-ET method is designed based on parallel training sessions within fixed time slots where students can choose from, which enhances connection between teams, 2) we establish a product-based learning objective, which means connection within teams, 3) we integrate process management methods and tools, such as MES, into course management, which visualizes the learning progress for the sake of both instructors and learners. *Conclusion*: As has been shown during the course and by student feedback, students are more involved and their creativity is well demonstrated in products they made. We also found that it is an effective and efficient method for conducting and managing hands-on learning activities. Learners’ are motivated to work in collaboration to achieve higher goals.

KEYWORDS - engineering training; product development; matrix management; challenge-based learning; project management

1.1 INTRODUCTION

Engineering training, or sometimes called industrial training, are widely adopted by engineering universities and colleges worldwide as a program for students to gain competency in industries they are about to face. Since the process of automation has fundamentally transformed many industries, companies are no longer hiring college and university graduates for their operant skills. Instead, a broader view for system-level engineering challenges and a strong ability to work in teams are becoming key indicators for new employees.

In this study, we implemented a different engineering training approach for undergraduate students. We prepared several sample products for students to work in teams to design their own customized counterparts. The manufacturing processes they would use are the same ones as previous programs, where each student completed them in a consecutive fashion. The approach we took will require students to divide their work and collaborate intensively. During the progress, the students use tailored MES system to keep track of their working documents and product specifications. These electronic documents are assessed together with product design and product finishing as an evaluation of team performance.

The feedbacks from participating students are collected and analysed. The most frequently mentioned opinion is requesting for deeper customization, which coincides with our expectation for them.

1.1.1 Engineering training program as of now

In many years of engineering training practices, skill-based curriculum has proved its advantage in training the students’ operant skills. A traditional engineering training program includes about 10 different sessions, each lasting for one day or two. These sessions allow students to practice by hand how to operate lathe and milling machines and how to do forging, casting, welding, basic bench work etc. In recent years, after introducing NC machines such as milling, electric wiring cutting, laser cutting, and 3D printing, the students are able to practice CAD and CAM within one day. Since the traditional way of doing engineering training is totally skill oriented, there is little connection between different processes. Yet, this kind of training program is becoming less persuasive for the changing demand of the society for engineering students today.

From the student perspective, simple, direct way to practice operant skills is not necessarily more appealing than lectures. Although some students agree with the idea that learning how to operate machines and to do basic handcrafts is attractive, this opinion only represents the kind of students who are inherently fond of such activities. On the contrary, there are a significant number of students claiming that practicing handcraft skill is no better than listening to lectures. The major concern here is that the students usually fail to connect practicing operant skills to engineering training. In fact, even for novice engineers, it is not always easy to find engineering problems in basic engineering tasks. The consequence is that the students are not fully involved in the assigned programs, and that they are not actively thinking about the engineering concerns hidden behind. In such cases, it requires that the technician is very experience and very active in encouraging his or her students to discover the potential principles. Set aside the operant skills, since traditional training programs are not designed to group the students into teams, generic skills such as team working, communication, critical thinking, etc., are usually not adequately trained.

1.1.2 Basic design of a product-based engineering training program

The objective of this new kind of engineering training approach is to enhance the students’ generic skills, to broaden their view of industry systems, to enable them with computer-aided engineering abilities. Correspondingly, the basic design of the program will include the following features: 1) product-based, 2) manufacturing-execution-system-enabled, 3) consist of NC machines, 4) team work, 5) perform one and know all, and 6) challenge-based. Given these characteristics, the program is named process/project management integrated engineering training (PM-ET).

Six kinds of machining process were selected to design the program, including CNC lathe, CNC milling, CNC laser cutting/surface engraving, 3D printing, CNC wire EDM, and laser internal engraving. In developing the program design, three distinctive gadgets were proposed to serve as kickstarters for the students to further innovate: 1) Designer’s clock, 2) artist’s LED lantern, and 3) collector’s trophy. The components and the corresponding processes used are listed in Table 1. As each product is consist of at least three components, the team of students must split their work and work in parallel so as to finish the final assembly in time. On the other hand, for each manufacture unit, there will be students from different teams with their distinctive designs coming in during the course, the production management for customized orders is also realized with the participation of the students.

**Table 1** Products, components, and processes involved in the training session

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Lathe | Milling | Laser cutting | 3D printing | Wire EDM | Laser internal engraving |
| Designer’s clock | Clock stand | - | Clock surface | - | Clock hands | - |
| Artist’s LED lantern | Lantern base | Case slot | Lantern case | Lantern top | - | - |
| Collector’s trophy | - | Name plate | - | Trophy base | - | Trophy pattern |

The product-based training session lasts for two days. Students use MES system to maintain the related data. At the end of the two-day session, each team will present their work together with a series of documents to demonstrate how they would mass-produce the product. Evaluation of each student is based on both the performance of the team as well as their own involvement. Meanwhile, a parallel session will take place where students are regrouped into six and perform a feedback and comment session in a tailored 635-method fashion. Each team will brainstorm and write down their comments on either how to make the product more appealing, what kind of new product that can be made, or what are the key features of the program.

1.2 MATERIALS AND METHOD

1.2.1 Students

There are 278 students in total who participated in the product-based engineering training program. 96.8% of the students are undergraduates who are about to enter their sophomore year in Tsinghua University, 2.9% are entering their junior year, and one student is about to graduate. None of the students has had significant industry experience. The students are either from engineering departments or from science departments, as shown in Table 2. The students are grouped into teams of three or four to accomplish the product.

**Table 2** Proportion of students from each department

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Major | Aerospace | Automotive | Industrial Engineering | Mechanics | Material | Chemistry | Mechanical Engineering | Electronic Engineering |
| Number | 90 | 79 | 71 | 31 | 3 | 2 | 1 | 1 |
| Percentage | 32.4 | 28.4 | 25.5 | 11.2 | 1.1 | 0.7 | 0.4 | 0.4 |

1.2.2 Resources and learning objectives

The training program is part of the industrial training course. This course is listed as required course by departments in their curriculums. According to the course design, the program will last for two days.

In each of the six units, there is at least one full-time technician specialized in the corresponding machining process. The technician will give guidance to the students on how to implement design-for-manufacturing, what potential problems will arise in manufacturing, etc. The teams carry out their work under the guidance of an engineer who is dedicated to managing the manufacturing execution process. Another engineer will take care of all the units to make sure all the procedures are on time and all the resources are available.

The MES system used during the course is deployed on a local server.

Course management infrastructure

1.2.3 Method of PM-ET

The two-day training program is consist of introduction lectures to each manufacturing unit, practice sessions, and product presentation. The lectures are each 1.5-hour long, packed into the first day. The purpose of the lectures is to give the students a general view of what manufacturing capability they can utilize to accomplish their product.

During the following day, 30 students are grouped into teams of three or four. Then each team is briefed about the objectives, rotation procedure between each unit, outcome evaluation criteria, and product specifications. Afterwards, each team goes to their breakout room and plan for their own product. They have 5 hours to decide the strategy of making and carry it out. To fully utilize the potential of each manufacturing unit and to enhance within team collaboration, the students are organized as product teams as well as functional group. The engineers in each unit are responsible for evaluating the student performance.

For better collaboration, they would use a manufacturing execution system to keep track of the production documents. Besides, they need to prepare several other descriptive documents including a set of slides elaborating how they design and make the product.

The last hour of the second day would witness the final product of each team. They bring the product together for engineers from each unit to make assessment. The judges work as focus group to evaluate each product in terms of design, creativity, and product finish. Meanwhile, the students are regrouped into teams of 6 to perform a paper-based brainstorming. Each brainstorming team choose one of the three topics: 1) how to transform current products into more appealing and more challenging goal, 2) considering the current manufacturing capability, what other kinds of product could be made, and 3) use the most impressive parts of the program to depict the hosting institution. The discussion will be written down on paper for further analysis.

1.3 RESULTS

1.3.1 Product realization

Each product team starts with the sample product provided, but comes up with new kind of designs in terms of pattern, shape, feature location, and/or dimension. The students can also bring their life into the designs. For example, one student in a team is a member of Tsinghua Dance Ensemble. Her team delivered a stylish clock in the shape of a dancing ballerina. In other cases, students are willing to bring traditional Chinese culture and global culture symbols to their designs.

In terms of product finish, since each team uses MES to control the production documents, and functional team leaders, the engineers in charge, take the responsibility of the finish quality, the parts produced are assembled with little difficulties. Throughout the second, teams are working around the clock to make it on time to deliver the final product. Most of the teams bring their product to the gathering room on time, with only around 3% teams fallen behind the clock.

1.3.2 Student involvement

During the second day of teamworking, the observed result indicates that every student is busy doing their own part of the job. Any idleness will be a potential hazard for the progress of the team. The product team organization effectively forms a norm among the students, which regulate their behavior. The matrix management not only enhanced the communication between students within same manufacturing unit and also increased collaboration within a product team. To make it easier to do the final assembly, each part of the product must be made in accordance with other parts. The students also work intensively with engineers and learn to make full use of the machining power. As the students come up with their own designs by themselves, they are more motivated to realize these designs than in case where they are required to make something.

1.3.3 Feedback

Analysis of the comments made by students indicates that deeper customization of the product is preferred by most of the students. They are interested in using other kinds of material and in making other combinations of parts from various machining processes. Introducing other kinds of products, especially those with more functions, is also a preferred improvement. Products such as small robotic arms, programmable lantern, or cuckoo clock are mentioned as candidate products to be made. A general tendency is that the product is preferred to be more complex, functional, and integrated with electronic controllers. Correspondingly, the students also suggest that more time is spared from lecturing for making and machining.

1.4 DISCUSSION AND CONCLUSIONS

Original goals of this new kind of training program are fulfilled according to the observations and the results collected from the students. The process/project management enabled course workflow is an effective way to provide comprehensive training for students. Since the diversity of challenges is increased from original serial individual tasks of different machining units, the students are given more chances to explore a real-life engineering problem.

The objectives of implementing the transformed engineering training program is to emphasize the purpose of student generic skill training while maintaining the essence of machining work practice. The matrix form management is the key organizational structure to fulfil this purpose. As the students are working in teams to realize their own design of the product, the peer pressure takes its effect. Meanwhile, students also challenge their peers for their ideas or decisions, which is a good way to practice critical thinking among them. However, as proposed by some students, the product complexity may somehow limit the student innovation. The problem solving skill may not be fully practiced if the course is not challenging enough. How to tailor a product specially designed for this kind of two- or three-day training program, while establishing sufficient complexity, is left for us to explore.

One potential challenge for the instructors of such product-based training program is how to keep each of the students on what he or she is expected to do. The fact that students have diverse interests and preferences should not be neglected. This means we need to utilize other social forces than norm to act as catalyst for students to get motivated. From this study, we discovered that students are well capable of finishing a product with acceptable quality even when they are still novices. The next step is to find out how to introduce the force of market to the training program so as to stimulate the students to go further and explore their boundaries. One possibility is to hold expositions or exhibitions of student works. Alumni, faculties, peer students, visitors can purchase these products as souvenirs or gifts. Although the payback of a market takes effect after the training program, the idea of making a high-end product with extraordinary quality is expected to have instant effect over the students when they design and make their products.

Trans-disciplinary collaboration is also a good way to increase student involvement and promote the diversity of student works. The scope of the learning of a group of people will largely augmented when knowledge from multiple disciplines join together in one project. The next step is to discover how to guide the students to form trans-disciplinary teams and how to take the advantage of that.

As the engineering training program is targeted at both generic skills as well as operant skills, the balance in-between is the key to deliver expected improvement to the student proficiencies. The matrix management format helps the instructors to fine adjust this balance. In this study, we find out that the evaluation plan over the student performance is a very useful tool to guide the students to decide priorities. What is left for us to make further exploration is how we can emphasize the individual performance in operating the machine by setting up proper evaluation authorities for engineers in each unit. A more comprehensive evaluation plan will also help students to form ethical assessment in the co-opetition environment during the training program.

The last but not the least, infrastructure is the guarantee for the implementation of this program. The manufacturing execution system is working well in this educational context. Yet given the very limited time the students can use to do hands-on work, they are usually upset to take effort in preparing the document, which is a necessary procedure in industries. Thus we need to further develop simpler systems for students as well as the instructors to use so that the management cost is lowered to a more acceptable level. There are potentials in networking the equipment, implementing automated process control systems, enhance the management proficiencies of faculties, etc.

To sum up, students are more willing to be challenged than to be assigned with tasks. Providing a context for them to define problems and solve them is how we should design next generation engineering training program. The scheme of training programs will keep evolving, as education is already an engineering problem itself.

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