

# Impact of Virtual Prototype on the Academic Performance of Engineering Undergraduates\*

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The purpose of this study was to explore the effectiveness of the teaching program of integrating the virtual prototype technology for students majoring in mechanical engineering. An activity involving the engineering teaching ideas of applying the virtual prototype technology to the design of NC machine tools was implemented for the study. It constructs the context-based teaching design along with a self-developed virtual learning environment. To describe the improvements in the students' understanding of NC machining course, a comparison was performed with the class teaching based on different teaching modes to learn the designed task. We used the statistical hypothesis test to evaluate the validity of the proposed teaching method according to the survey data from 58 engineering students participating in this applied research, with a qualitative methodological approach using a combination of case study and survey. We also evaluated students' response towards the research topics to investigate its teaching-learning effectiveness and acceptance by student community. Findings from the study have implications for the improvement of NC machining course and provide a framework for the students to get comprehensive simulation and analytical optimization through NC machine tools designed by themselves. Students' feedback also revealed that students obtain more satisfaction and self-confidence, and demonstrated high positive attitude towards the proposed teaching method, and showed high perceived usefulness of the context-based teaching design to acquire the knowledge of NC machining.

**Keywords:** virtual prototype; human computer interface; NC machining; mechanical engineering; collaborative learning

## 1. Introduction

At present, the global manufacturing revitalization strategy is actively promoting the vigorous development of the fourth industrial revolution. Promoting excellence in manufacturing emerges as a strategic goal both for industry and society in the next few years. Manufacturing education has been identified as a major driver to achieving this goal. However, the pace of economic, social and technological change has increased the gap between the competences needed by industry and those provided by the universities' curricula [1]. Especially for NC (Numerical Control) machining technology, as the key field of advanced manufacturing industry, the global changes in NC machine tool require greater levels of NC machining competency in order for NC machining professionals to respond effectively to complex high-tech industries and equipment manufacturing situations [2]. To meet this internationally identified need, more reliable NC machining education strategies are required.

As the core course of mechanical engineering specialty, NC machining course pays more attention to the cultivation of comprehensive ability, with the change of training objectives and the different needs of society for the engineering science and technology talents [3, 4]. However, the course has strong characteristics of integrating theory with practice and engineering application, which makes

it difficult to learn and master. Therefore, NC machining course is often considered by teachers and students to be a difficult pursuit [5]. If only the pure narrative in the lecture-based classroom, students cannot fully understand the movement and work process of NC machine tools under actual working conditions. There exists a discrepancy between their claims of valuing creativity and the realities of their classrooms. At the same time, modern NC machining technology has been in constant progress, and the need for NC experimental conditions and equipments should be constantly enriched and improved along with the development of the times, and further strengthened. Therefore, in order to facilitate the teaching and learning, it is necessary to reform the teaching methods and practice activity of the course.

### 1.1 Characteristic Analysis of NC Machining Course

NC machining course is an important compulsory course for mechanical engineering specialty in colleges and universities in China, and has a unique position in training students' practical ability and comprehensive quality. It mainly studies the structural design, operation methods and working principles of NC machine tools. The typical NC system and fault diagnosis of NC machine tool are analyzed by taking common NC machine tools as examples [6].

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The teaching idea of this course used to adopt a step-by-step method, from part to whole, from simple to complex, so that the students could gradually grasp the key technology and the overall design idea of NC machine tool [7]. It attaches importance to the connection and cohesion with other curriculum framework in the course arrangement, involving many prerequisite courses such as “mechanical design foundation”, “mechanical principle”, “material mechanics”, “theoretical mechanics”, “mechanical system dynamics” and “hydraulic principle” and so on. This course not only covers a wide range of subjects, but also has many teaching contents and relatively few hours, including many basic concepts and principles and strong applicability.

### *1.2 Current Status and Existing Problems of NC Machining Course*

NC machining course is a professional basic course which combines theory with practice closely, involving many types of machine tools and complex spatial structure of the whole machine tool. Moreover, it is interrelated among different courses, and has a strong theoretical and practical significance. So it is a difficult course for teachers and students to teach and learn, and it makes students feel fear and boredom in teaching-learning activities. Through the preliminary investigation and analysis [8–10], three main reasons for the difficulty were identified. They are summarized as follows.

#### *1.2.1 The Relative Simplicity of Teaching Methods*

For a long time, the popular teaching methods of “instillation” and “cramming” have been unable to adapt to the learning interests of contemporary students. Traditional teaching methods such as blackboard writing, teaching aids, wall charts and physical objects are essential, but it is difficult to visually and dynamically demonstrate the relationship between the various structures and the movement process of the whole machine tool, which make it difficult for some students to understand the design process. For example, the mechanism motion device of NC machine tool is so complicated that some students can’t imagine its spatial movement trajectory and understand the entire design process profoundly. Over time, the students will be unable to understand, or even give up. With the accelerated development of modern science and technology, the advanced NC machining equipments are constantly appearing, and the corresponding amount of knowledge is increasing rapidly. The traditional teaching method cannot adapt to the demand of epoch development, so modern educational technology should be adopted to provide strong support for teaching practice.

#### *1.2.2 Poor Hardware Conditions of Colleges and Universities*

Because the course involves the spatial motion of working mechanism of NC machine tool, it is difficult for the students to understand the movement condition of NC machine tool profoundly only by the teacher’s language description, as well as drawing, hanging chart and other ways. Therefore, a certain number of three-dimensional entity teaching model and experimental equipment are needed to assist the teaching process. However, the current NC machine tools are high-price, high-precision automation equipment, but also have the characteristics of high maintenance costs. The teaching hardware facilities of colleges and universities in this area are generally lagging behind, and it is difficult to keep pace with the times. For example, the screw drive system and servo control technology of NC machine tools have always been the focus and difficulty in NC teaching. Because of the abstraction of the principle and the concealment of the technology, students often feel puzzled about many concepts and graphics in the teaching process. This brings a lot of inconvenience to teachers, and also puts forward higher requirements for teachers.

#### *1.2.3 The Weakness of Practical Teaching*

Because the teaching content of this course involves the operation of NC machine tools under actual working conditions, it is necessary to let students feel at the experimental workshop or the processing site, which will be of great help to the teaching efficiency. However, the practice teaching links in most domestic colleges and universities are not perfect enough at present, so that students cannot really understand the intrinsic working principle of NC machine tools.

### *1.3 Research Objectives of the Proposed Teaching Strategy*

In recent years, with the great changes in the theories, methods and means in the field of mechanical engineering, the virtual prototype technology, integrating computation, design, analysis and simulation, has attracted wide attention and is increasingly used in engineering personnel training and engineering practice teaching [11]. Based on the teaching characteristics of the course and the actual needs of the students, with the aid of the latest research results of virtual prototype technology in the field of NC machining, this paper puts forward a dynamic teaching method for NC machining course. It firstly discusses the application of virtual prototype as an ideal modern assistant instructional tool in the classroom to make up for

the existing deficiencies. And then it describes the virtual prototype of NC machine tool developed by using the open-source integrated simulation and verification platform, which could enable students to truly feel the spatial structure and actual working conditions of NC machine tool. Under this circumstance, the students will be encouraged to take ownership of their own learning, and then construct their own virtual prototype of NC machine tool efficiently, quickly and accurately by using various functional modules of UG software. So the overall simulation can be carried out to optimize the design accuracy of NC machine tool in the context of human-computer interaction. The purpose of this study was to analyze the effectiveness of the teaching program that integrates virtual prototype technology from the perspective of the situational learning. In particular, it examines the students' perceived levels of satisfaction and performance in a virtual learning environment. This will be used to show that the educational environments based on virtual prototype technology will be conducive to promoting students to construct their own NC professional knowledge, and cultivating students' innovative thinking ability.

## **2. Teaching Method Based on Virtual Prototype Technology**

Technology is one of the most prevalent tools complementary to innovative instructional models [12]. Virtual reality offers vast possibilities to enhance the conventional approach for delivering engineering education, and is widely concerned in the community of engineering education [13, 14]. The introduction of virtual reality technology into NC practical teaching can improve NC machining curriculum by supplementing the traditional learning experience with the virtual situation materials [15]. Virtual prototype technology, as computer-aided engineering (CAE) technology in engineering field in recent years, has been widely used in mechanical engineering to replace the traditional mechanical design, test and research methods, which has become a trend of development [16]. Accordingly, it also continues to make an increasing impact on all aspects of engineering education, and thereby push the envelope of engineering education to cover much broader fields and attract many more students. Simply speaking, its main working principle is to establish a prototype model on a computer, analyze the dynamic performance of the model, then improve the prototype design scheme, replace the original physical prototype with digital form [17]. That is, the simulation assembly of product is carried out in 3D design environment to obtain 3D entity of the whole

machine tool, and then realize the motion simulation of NC machine tool, as well as the finite element analysis and optimization of production, computer aided manufacturing and animation generation in a visual environment [18]. As such, the virtual prototype technology could serve as an effective teaching-learning tool if used in an appropriate pedagogical setting. It also improves the students' understanding of the teaching-learning process by offering new possibilities, such as bringing the exciting and real-world-based curricula into the classroom, providing new tools to enhance teaching, and giving students and teachers more opportunities for interaction [19]. Meanwhile, the virtual prototype technology integrates many related technologies, such as computer graphics, multimedia, artificial intelligence, multi-sensor, network parallel processing, which will be incorporated into instructional activities. Such a capability provides students with opportunities and contexts to learn the connections among concepts across different scientific domains. In addition, the virtual prototype technology can use the computer generated three-dimensional spatial image to realize the target synthesis technology, and presents it in the form of graphics and animation through the visual, auditory, tactile and other organs. Therefore, as a powerful didactic resource, the virtual prototype technology has the advantages of stereoscopic and intuitive, that gives us the ability to focus our students' attention on the principles of NC machining, and further create an immersive experience for the students from the visual, auditory and behavioural feelings through well-organized knowledge structure of NC machining courses.

Virtual prototype could be regarded as a full-cycle process to explore the structure, function, and cost of a complete product on the computer using modelling and simulation techniques before actual manufacturing [20]. The application of virtual prototype technology in actual NC machining is realized by commercial software with friendly interface, powerful function and stable performance. The software could build the structure model under different conditions, and get dynamic simulation and finite element analysis results, and save them as animation format for presentation in class. This will enable students to truly observe the motion process of NC machine tools and form a teaching method with the features of integrating animation, image, text and voice into an organic whole, to help students effectively learn and master the course content. The working principle and actual working process of NC machine tools (such as lathe, milling and machining centre) are vividly displayed by computer multimedia technology such as animation and video, and the links and move-

ment relations among components are also dynamically displayed. Then the students can intuitively, stereoscopically and dynamically learn the knowledge in the field of NC machining. In this way, we would form a dynamic teaching method in full use of the actual environment, analogue simulation and situational teaching, which has outstanding advantages compared with traditional teaching methods.

### 3. Teaching Implementation Framework based on Virtual Prototype Technology

As the use of high-fidelity simulation increases in engineering education, it is important to have comprehensive, integrated simulation scenarios that can serve as supplements to NC machining practicum [21]. NC machine tool is a very complicated mechanical system, so after the establishment of its computer digital model, it is necessary to carry out a comprehensive simulation analysis, which involves kinematics performance, dynamics performance, mechanical structure performance and workpiece processing performance, etc. so as to help designers correct parameters in time during the design process, to achieve the complete realization of the virtual prototype of NC machine tool in the real sense. Hence, the teaching framework proposed in this paper is also based on the simulation construction and complete execution process of the virtual prototype of NC machine tool, as shown in Fig. 1.

#### 3.1 Conceptual Design of the Virtual Prototype of NC Machine Tool

The conceptual design mainly guide the students to engage in ascertaining the function requirements of NC machine tool, the allocation of motion functions and the structural layout design, finally determining the overall design scheme of NC machine tool and the main components (such as spindle components and feed system, etc.), and making comprehensive evaluation of general project.

Compared with the traditional design, the con-

ceptual design of virtual prototype is more flexible and conducive to innovative design, which helps the students reach a deeper level of conceptual learning of NC machine tool. It can effectively engage the students in the innovative design of the overall scheme of NC machine tools and facilitate the students to learn the trial, application and evaluation of the new-style driving mode or structure type of NC machine tools.

In order to achieve the manufacturing function of NC machine tools, it is necessary to specify the position-pose relationship of cutter and workpiece, so as to determine the basic motion scheme of NC machine tool. For the same motion scheme, there can be different machine tool structure layout, such as vertical, horizontal, symmetrical, etc. Through the three-dimensional digital model, the structure layout of the virtual prototype of NC machine tool can be preliminarily evaluated and take the best. Then, the general parameters of NC machine tool can be determined on the basis of the overall structure model of NC machine tool. It mainly includes the dimension parameters and kinetic parameters of the main components from a global point of view, as the basis for the subsequent detailed design.

While it is important for students to acquire conceptual understanding before being steered their designs in the right direction, conceptual understanding alone may not suffice to make specific decisions that are quantitative by nature. This needs to continue to take the following steps.

#### 3.2 Modelling and Assembling of the Virtual Prototype of NC Machine Tool

The virtual prototype technology has the potential to transform UG software from pure engineering tools into powerful learning environments that promise to boost engineering education. The precondition and basis of establishing the virtual prototype of NC machine tool is to set the digital models of all kinds of parts on computers, and

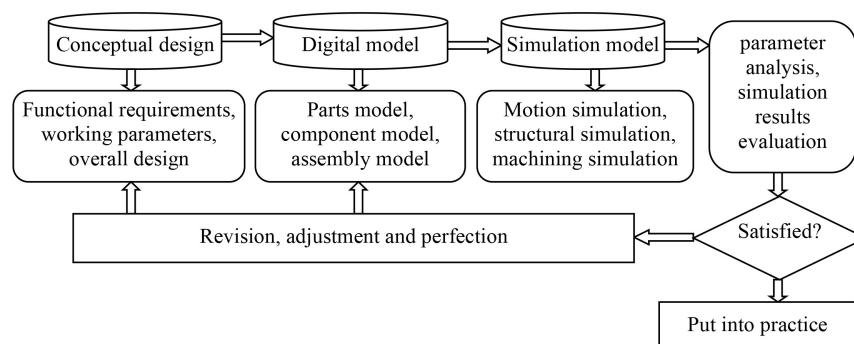


Fig. 1. Realization process of virtual prototype of NC machine tool.

establish a complete digital model of NC machine tool through virtual assembling. Besides, the digital model should be able to reflect the actual character like the appearance, colour, texture, quality and location of NC machine tool. The components of NC machine tool can be established quickly and assembled accurately according to their actual positions. After interference checking, NC machine tool can be completely reproduced in the computer. Moreover, the operator and NC machine tool can be best matched by establishing a man-machine environment. However, these essential elements for engineering education are often insufficiently provided in real classrooms. Because in many complex situations, even if there are teachers who can give comprehensive guidance, only through systematic analysis of students' existing work, can we accurately evaluate students' subtle design decisions and make appropriate suggestions for their next work, which may be too time-consuming to put into practice.

Therefore, taking the challenge of designing NC turning centre at the testing workshop site as an engineering example, this paper illustrates the learning and teaching opportunities created by the modelling, assembling and data mining capabilities of UG software. It is an interactive CAD/CAM tool developed along the direction of integrated digital solutions for engineering application to support the engineering research and education. Fig. 2 shows the digital model of NC turning centre. Students could make full use of the digital model to simulate, explore and imagine how it may work in the real world.

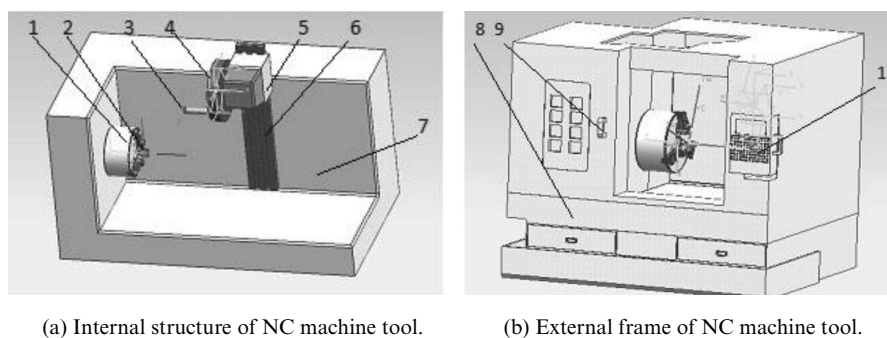
### 3.3 Motion Simulation of the Virtual Prototype of NC Machine Tool

Computer simulations can be open learning environments that allow students to follow a process of hypothesis-making and idea-testing, isolate and manipulate parameters, employ a variety of repre-

sentations and investigate physics phenomena that would not be possible to study in a classroom [22]. UG motion module was used to implement the computer simulation in the teaching-learning process, through establishing the motion simulation model of NC machine tool based on its digital model, as well as adding necessary motion simulation information (like kinetic pair and constraints, etc.). It mainly carries out kinematic analysis and dynamic analysis for NC machine tool. With the help of a powerful simulation function, these analysis of NC machine tool which is difficult to teach and transfer can be made simpler and clearer. With the help of a powerful simulation function, these analysis of NC machine tool, which are difficult for students to understand in a real classroom, will become simple and clear.

With this capability, the motion module empower the students to explore the motion simulation of NC machine tool as illustrated by the examples in Fig. 3, so that the complicated procedure could be broken down into a few simple steps. After the definition of motion relation, contact pairs and drive mode, the movements of the worktable, sliding saddle and spindle box (in three directions of X, Y, Z) can be achieved on the digital model, to ensure that the movement of machine tool can reach the required limit position with no motion interference generated within the full travel range.

Considering that the moving parts of NC machine tool, such as worktable and sliding saddle, may appear two kinds of motion states, namely steady movement and unsteady movement. UG motion simulation module can also be used to analyze and evaluate the motion smoothness of the virtual prototype of NC machine tool, and then analyze the influence of driving speed, transmission stiffness, as well as the difference of dynamic and static friction coefficient on the motion smoothness of the moving parts of NC machine tools.



1. Principal axis. 2. Fixture assembly model. 3. Tool holder. 4. Tool carrier. 5. X directional feed module. 6. Z directional feed module. 7. Machine base. 8. Machine shell. 9. Displaceable access door. 10. Operation panel.

**Fig. 2.** Digital model of NC machine tool.

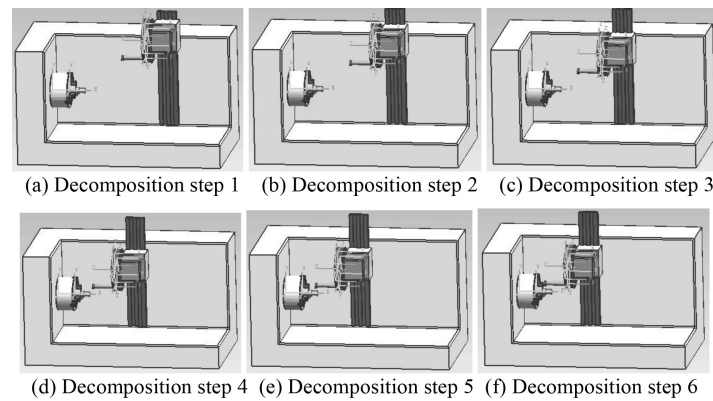


Fig. 3. The motion simulation of the whole NC machining process.

### 3.4 Structural Analysis of the Virtual Prototype of NC Machine Tool

The structural analysis help the students develop the abstract mental models and design thinking skills that empower them to imagine and reason about engineering systems that they are challenged to design [23]. Multiphysics simulation analysis is an important capability of modern computer-aided engineering software as it allows the students to study complex real-world problems in which multiple physics mechanisms jointly drive the processes [24]. To this end, the structural analysis used in this study was based on UG structure module, which has powerful structural finite element analysis function. It can perform various structural analyses on parts, components and even the whole machine tool, including static analysis, modal analysis, harmonic response analysis and thermal deformation analysis, etc., and then generate formative feedback to students based on real-time calculation and analysis of students' work. Feedback can be delivered through rich, operable visualizations and graphs that convey important information in a vivid and efficient way. Therefore, the calculation generation of the novel solutions using exploratory tools of UG structure module provides teachers a promising way to stimulate students in ideation and lead them to think outside the box.

In general, UG structure module can comprehensively analyze whether the mechanical properties of the designed parts and the whole machine tools meet the operating requirements. Its predictive power can provide quantitative results to help students make design decisions. When machining a workpiece on NC machine tool, the parts and components of NC machine tool are deformed due to force, resulting in relative elastic displacement between the tool and the workpiece, thereby affecting the machining accuracy and production efficiency of the workpiece. Considering that the base, sliding saddle, worktable, column and spindle box

of NC machine tool are important basic parts, their structure style and material composition will affect the static stiffness and anti-vibration performance of NC machine tool. However, the static stiffness and modal analysis can be carried out by using the structural module to evaluate the static characteristics and dynamic properties of these important components. Similarly, when NC machine tool is cutting the workpiece, there will be periodic exciting force acting on the workpiece. When the frequency of exciting force is the same as the natural frequency of worktable (including the fixture and workpiece), the resonance will occur. This can not guarantee the machining accuracy, but also will cause serious damage to the cutter and NC machine tool itself. Therefore, it is necessary to use harmonic response analysis to estimate the dynamic response of the worktable.

Put it simply, engineering design is not just about "how it works" (qualitative conceptual understanding), but "how much it should be" (quantitative decision making). Without the accurate results predicted by simulation-based analyses, students would not be able to evaluate their design choices and arrive at optimal solutions.

### 3.5 Machining Simulation of the Virtual Prototype of NC Machine Tool

Based on UG IS&V module, the specific steps of turning operation are illustrated by tool path simulation of the designated NC turning parts, as shown in Fig. 4. Considering only the relative motion simulation between the cutter and the workpiece, It is necessary to extend its scope into the entire machine tool, so as to realize the comprehensive simulation of the whole system on the virtual prototype of NC machine tool. Under this circumstance, the whole simulation process can dynamically display the cutter, workpiece, fixture, and NC machine tool at the same time, rendering the integrated simulation of the whole machining system

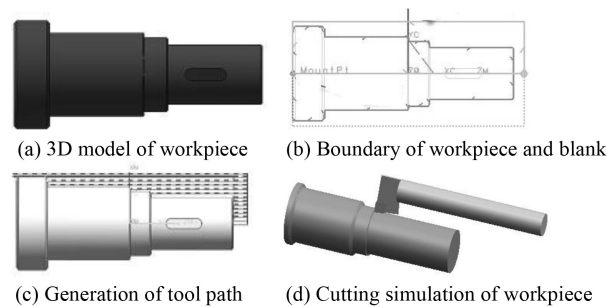


Fig. 4. Tool path simulation of the typical part in NC turning centre.

possible. This will enable the students to make an all-round evaluation of the machining capability of NC machine tool, and let them have practical skills in the virtual environments that can only be acquired on the real NC machine tool.

UG machining simulation module can simulate the tool path and the motion of NC machine tool respectively. During the simulation process, such operations as translation, scaling and rotation can be performed to observe the material removal process of the workpiece in the process of machining in an all-round way, so as to check whether the tool path of the workpiece is correct or not. Moreover, the time-consuming situation of different processing procedures and tool routes on the same workpiece can be evaluated to select the shortest and reasonable processing procedures, which will greatly improve the processing efficiency. Of course, the quantitative results predicted by the machining simulation module can help students make a precise decision about exactly how to design and manufacture the special fixtures for complex parts according to the special needs of users. Fig. 5 shows an example of establishing the workpiece model, verifying the tool path and simulating the whole NC machine tool.

Before executing the motion simulation of NC machine tool, the tool path of the workpiece must be generated correctly. In the process of tool path verification, the cutter will complete various machining operations in turn according to the generated NC code, and the operator can observe the movement track and trend of the cutter, with the removal process of the workpiece material displayed dynamically. So interactive visualizations like these allow students to see the qualitative effect of the governing NC machining principles. On the basis of generating the tool path and verifying the workpiece model, students could use the substitution command to transfer the established digital model of NC machine tool. The position relationship between the workpiece and NC machine tool is consistent with the actual machining situation. If necessary, manual relocation can be carried out. And then students set the necessary simulation options, such as material removal, the interference and collision detection, the tolerance range of machining accuracy, etc. So far, students will perform the related machining simulation operation on virtual prototype of NC machine tool, and then observe the machining state.

In simulation environments, students can build

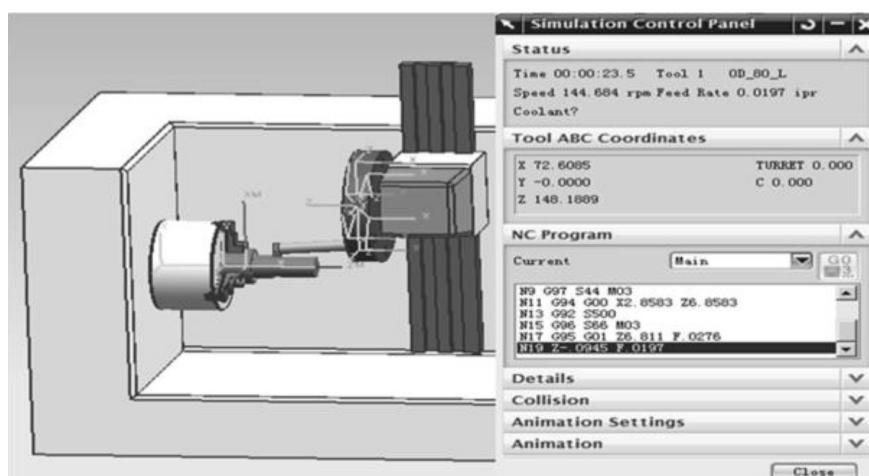


Fig. 5. Integrated simulation and verification of the virtual prototype of NC machine tool.

their own models, generate and test hypotheses, and observe the results iteratively. That is, the flexibility of computer simulations would encourage students to participate in their exploration processes. In this way NC machining courses are becoming a fun and immersive. This affects students' thoughts about NC machining and their courage significantly.

## 4. Evaluation

### 4.1 Experimental Approach

This article aims to explore the influence of virtual prototype teaching method on the teaching development of NC machining course with the aid of the rubrics. In view of the fact that the students have a certain degree of logical thinking ability and information literacy after two years of professional learning, the research has been carried out in 2015–2016 academic year spring semester at the author's university on 58 students who studied mechanical engineering in engineering department. Students are randomly divided into a control group and an experimental group, each group is 29 people, the control group uses the traditional teaching model, and the experimental group uses the virtual prototype teaching method. Before participating in this study, two groups of students will receive the same teaching guidance and learning goals in the classroom to ensure the consistency of the experimental premise. The teaching intervention of this study began two weeks after the students in the experimental group received classroom teaching on the related topics. It required the students in the experimental group to respond to the learning tasks they faced with the help of virtual prototype technology.

The students' grades are mainly composed of process evaluation and result evaluation. Students should not only submit the periodic learning results in the teaching process of NC machining, but also the final required deliverables include the dynamic display of the whole NC machine tool and the virtual machining process of typical parts, as well as technical reports and demonstration reports. According to the differences in students' cognition for NC machining courses, this study could give a comprehensive and reasonable grade division for students' academic performance. Meanwhile, This study will draw on the analytic rubrics in the literature [25] to test the evaluation items and skill indicators of different learning types, mainly involving the two attributes of concept design and object design. The score of each item in curriculum evaluation form is shown in the relevant rubrics (see Appendix 1). The analysis indicators are divided into three levels to give students more opportunities to make better results, and also helps the teachers to evaluate students' performance accurately.

### 4.2 Empirical Analysis

In general, the basic differences of students' early learning may affect the teaching effect of NC machining course. In this study, covariance analysis would be used to eliminate the impact of basic differences, and further improve the reliability of evaluating the virtual prototype teaching method. As far as mechanical engineering specialty is concerned, the course of mechanical manufacturing technology can be said to be the basic course in the field of NC machining [26]. In order to eliminate the influence of the basic differences in the early learning of the research object, the final grades of the research subjects' mechanical manufacturing technology in the previous semester were transferred from the official authoritative educational administration system of the authors' university, to explore the basic course would have an impact on the virtual prototype teaching efficiency. That is, this study uses the bivariate correlation analysis in multivariate statistical analysis to obtain the correlation between the mechanical manufacturing technology and the virtual prototype teaching efficiency. And then the basic course scores are used as covariates to correct the statistical mean of the virtual prototype teaching method, to eliminate the impact of the basic differences in the previous learning. Finally, covariance analysis is used to evaluate the teaching effect of virtual prototype teaching method.

In view of the fact that each student has his own personality characteristics and growth background, the comparison of academic performance alone cannot show enough persuasion. Therefore, after completing the teaching plan, this study uses questionnaires to conduct in-depth research in order to grasp the students' more comprehensive views on the teaching method. The open questionnaire used in the article was put into practice in the subsequent 2016–2018 school year, which involved five criteria (1 = low; 5 = very high). It requires students to give answers based on their views on the teaching method, and provide the necessary reasons for the corresponding answers. Finally, the questionnaire survey was used to collect the students' cognitive evaluation of NC machining course. The statistical analysis results are shown in Table 1.

## 5. Results

In the evaluation stage of classroom instruction, the students' marks of the experimental group ( $M = 85.229$ ,  $SD = 3.00$ ) were significantly higher than that of the control group ( $M = 80.455$ ,  $SD = 4.00$ ). In order to test whether there is a statistically significant difference between using and not using



**Table 1.** Survey questionnaires for three consecutive academic years

The survey questionnaires and results for the three consecutive academic years								
Questionnaire item	2015–16		2016–17		2017–18		Three years	
	Mean	SD	Mean	SD	Mean	SD	F	P
1. Impact of the virtual prototype teaching method on learning efficacy	<b>4.274</b>	<b>0.426</b>	<b>3.642</b>	<b>0.471</b>	<b>3.56</b>	<b>0.497</b>	<b>19.221</b>	<b>0.001</b>
(Why? Please specify)								
i. The virtual prototype teaching method offers the possibility of optimal design scheme	4.25	0.585	3.704	0.823	3.36	0.757	10.182	0.004
ii. The virtual prototype teaching method offers the possibility of interactive evaluation module	4.286	0.659	3.667	0.961	3.6	0.645	6.547	0.024
iii. The virtual prototype teaching method offers the possibility of quick feedback, history keeping and inquiry mechanisms	4.286	0.763	3.556	0.892	3.72	0.792	6.039	0.004
2. Impact of the virtual prototype teaching method in motivation	<b>3.881</b>	<b>0.397</b>	<b>4.148</b>	<b>0.509</b>	<b>3.92</b>	<b>0.337</b>	<b>3.159</b>	<b>0.048</b>
(Why? Please specify)								
i. students enjoy engagement in the virtual prototype teaching environment	4.286	0.763	3.778	0.892	3.6	0.957	4.497	0.142
ii. The virtual prototype teaching method offers the possibility of active learning and experimentation for NC machining course	3.571	0.504	4.259	0.764	4.24	0.723	9.330	0.001
iii. The virtual prototype teaching method is an important innovative training program for a future NC technician	3.786	0.957	4.407	0.747	3.92	0.812	4.065	0.021
Number of students	28		27		25		80	

1–Poor; 2–Fair; 3–Average; 4–High; 5–Very High.

**Table 2.** Results of independent samples t-test based on student marks

Nr.	Evaluation of NC machining courses (0–10)	*Gr.1		**Gr.2		M1-M2	t	p	Note
		Mean of marks M1	SD1	Mean of marks M2	SD2				
<b>A</b>	<b>1. Presentation of concept design</b>	<b>85.209</b>	<b>5.000</b>	<b>83.214</b>	<b>4.000</b>	<b>1.995</b>	<b>1.724</b>	<b>0.045</b>	<b>&lt;5%</b>
1	Approach to project requirements (40%)	85.483	6.947	83.793	5.144	1.690	1.053	0.149	>5%
2	Critical research and analysis (30%)	86.103	7.128	84.103	6.597	2.00	1.109	0.136	>5%
3	Teaching information support (15%)	82.448	8.369	79.655	7.504	2.793	1.338	0.093	>5%
4	Diagrams, figures, tables, expressions (15%)	85.448	6.947	83.448	5.075	2.000	1.252	0.108	>5%
<b>B</b>	<b>2. Presentation of object design</b>	<b>85.240</b>	<b>5.000</b>	<b>78.969</b>	<b>6.000</b>	<b>6.271</b>	<b>4.711</b>	<b>0.001</b>	<b>&lt;2%</b>
1	Implementation of planning progress (20%)	85.690	9.540	79.345	10.631	6.345	2.392	0.010	<2%
2	Quality of operational assignment (30%)	83.724	10.392	77.690	10.177	6.034	2.234	0.015	<2%
3	Analysis of operation assignment (15%)	86.931	9.483	81.448	10.102	5.483	2.131	0.019	<2%
4	Diagrammatic presentation of the operational scheme (10%)	86.517	9.902	81.172	10.727	5.345	1.972	0.027	<5%
5	Technical report (15%)	83.724	10.830	77.172	10.674	6.552	2.516	0.007	<2%
6	Oral presentation(10%)	86.517	9.902	78.828	12.312	7.690	2.621	0.006	<2%
<b>C</b>	<b>Final mark (1+2) (concept design = 35%) (object design = 65%)</b>	<b>85.229</b>	<b>3.000</b>	<b>80.455</b>	<b>4.000</b>	<b>4.774</b>	<b>5.168</b>	<b>0.001</b>	<b>&lt;2%</b>

\* Development of NC machining course using only conventional designing methodology. Number of students 29.

\*\* Development of NC machining course using the virtual prototype teaching method as an innovative training program. Number of students 29.

the virtual prototype teaching method, this study conducted an independent sample t-test based on the relevant statistical data of two groups, to explore the differences between two group of students in the cognition of NC machining course.

From part A of Table 2, Levene's F test showed that the hypothesis of homogeneity of variance meets all the requirements of restriction conditions, and the independent sample t-test was related to the statistical significance test, indicating that there is no significant difference between two group of students in for the presentation of concept design ( $t = 1.724$ ,  $p = 0.045 < 5\%$ ). It also accounted for high similarity of performance between two groups, mainly because the students of two groups have received the same guidance on the teaching objectives and design methodology. The virtual prototype teaching method has not been involved at this stage. In part B, as the cognitive part of object design, the average value of the experimental group was significantly higher than that of the control group due to the energy efficiency produced by the virtual prototype teaching method, and the difference between two groups was significant ( $t = 4.711$ ,  $p = 0.001 < 5\%$ ). Finally, in order to reflect the comprehensive response of students' cognition on concept design and object design of NC machining courses, the final score was composed of 35% of Part A and 65% of Part B. The results of data analysis here also expounded the high efficiency of the students in the experimental group, indicating that the average value of the students using the virtual prototype teaching method in NC machining course is significantly higher than that of the traditional teaching mode ( $t = 5.168$ ,  $p = 0.001 < 5\%$ ). This further proved that the virtual prototype teaching method does have a positive effect on improving students' academic performance and innovation ability.

In the stage of covariance analysis, the final score of students' basic course (mechanical manufacturing technology) is taken as the covariate in this study. By modifying the mean value of the dependent variables, the impact of basic differences in students' early learning could be eliminated as much as possible. This will make the mean value of the modified dependent variable be compared at the same covariate level. Under the premise of guaranteeing that the sample data of each group satisfies the application requirements of covariance analysis (including the normality and homogeneity of variance), the covariance analysis would be obtained by GLM module of SPSS10.0 software, as shown in Table 3, the results show a strong correlation between the analyzed variables. The results showed that there is a strong correlation between the analyzed variables. That is to say, qualitative factor (teaching efficiency) and quantitative factor (covariate, i.e. mechanical manufacturing technology) had a significant impact on the dependent variable (NC machining course). It indicated that there are significant differences in the teaching performance of different teaching methods ( $F = 17.820$ ,  $P < 0.001$ ), and there is a significant linear regression relationship between the dependent variable and the covariate ( $F = 96.418$ ,  $P < 0.001$ ), that is, the final grades of mechanical manufacturing technology have an impact on the performance of students in NC machining course. Through the analysis of covariance of the two courses' scores, after excluding the influence of the covariate on the dependent variable, the average scores of the students in the experimental group were significantly higher than those in the control group ( $84.821 > 81.479$ ), as shown in Table 4. The conclusion further proves the effectiveness of the virtual prototype teaching method.

In the third stage, the statistical analysis results of

**Table 3.** ANCOVA for two experimental groups

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1577.698	2	788.849	144.139	0.000
Intercept	418.184	1	418.184	76.411	0.000
Final Grade of Mechanical Manufacturing Technology	527.681	1	527.681	96.418	0.000
Student Group	97.526	1	97.526	17.820	0.000
Error	311.952	57	5.473		
Total	416725.000	60			
Corrected Total	1889.650	59			

**Table 4.** The corrected means of NC machining course

Student Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	84.821	0.498	83.824	85.818
2	81.479	0.498	80.482	82.476

the questionnaire for three consecutive years are shown in Table 1. F-test shows that there is no statistical significance at the level of 0.05 about the average statistics of virtual prototype teaching method on students' learning efficiency ( $F = 19.221$ ,  $p = 0.001$ ). And the same result is obtained in the aspect of learning motivation ( $F = 3.159$ ,  $p = 0.048$ ). This shows that the teaching environment based on virtual prototype technology is helpful for students to overcome the cognitive constraints and misunderstandings on NC machining course. When students perceive that the virtual prototype teaching method has a positive impact on their learning efficiency and motivation, the scores will be close to the high value area of the scoring system used.

## 6. Discussions

Virtual prototype technology is the frontier issue developed rapidly in the field of international engineering technology, which has been widely used in mechanical engineering. It is also a new teaching method in the field of education technology in the era of artificial intelligence. In recent years, it has become a hot topic in the academic circles at home and abroad. Based on the practical experience and research results of European and American universities to integrate the idea of virtual simulation into engineering education, the teaching design of integrating virtual prototype technology proposed in this paper will be a breakthrough. It will build a novel kind of teaching reform path with the characteristics of deep cross-integration between engineering disciplines and virtual prototype technology, to strengthen the engineering practical teaching programs with the aid of its powerful intelligent interaction. Through multi-functional, interactive and integrated instructional scheme design, it will provide a learning cognitive environment with discovery and exploration functions, help learners to use the appropriate information processing and knowledge construction methods, to build their own cognitive system, and then comprehensively stimulate the students' cognitive skills and thinking process. By and large, this study will provide theoretical guidance and method reference for virtual prototype teaching method in training cognitive thinking ability of engineering innovation talents all over the world.

Although the virtual prototype technology allows students to enter the actual usage from NC machine tool and overlay this information on top of the simulation results so that they can compare the outputs of their designs with the goal more easily, there are some drawbacks in the virtual prototype teaching method. That is to say, everything is virtual and can not be touched in the virtual

learning environment, and it is difficult for students to combine with the real situation and establish a perceptual understanding of things. To this end, in view of the practicality and engineering applicability of this course, it is necessary for the authors to carry out research in combination of virtual and reality in the follow-up study, so as to unleash student's creativity, break their fixation and spur their exploration.

The present study provides empirical evidence for better understanding of students' evaluation of virtual prototype teaching method. Considering that some aspects of students, study conditions and the specific teaching context could partially explain our results, further research should be conducted with a greater number of questionnaire investigations. Also, we consider it necessary to analyze other investigation factors as input variables that enable us to acquire further knowledge for continuous improvement in NC machining course, since the level of students' satisfaction are largely determined by how they experience their learning environment and how they act. That is, how students approach their learning ultimately determines how well they learn. All of these aspects will be investigated in future work.

## 7. Conclusions

This study demonstrates the positive effects of the integrated simulation courseware developed based on the theoretical frameworks of the virtual prototype on the students majoring in mechanical engineering. The paper firstly discusses the educational implications of the teaching program of integrating the virtual prototype technology on NC machining course, and then describes the teaching methods and the specific teaching implementation framework based on the virtual prototype technology. Finally, the corresponding pretests, teaching activities and posttests are implemented based on the proposed teaching and experimental designs. The experimental results suggest that students could get comprehensive simulation and analytical optimization through NC machine tools designed by themselves, which is helpful to deepen the students' understanding of the course content, and finally exhibits superior results for mostly the learning performances. The survey results also show a great acceptance of virtual prototype as a tool for teaching concepts of NC machining course, and the students get higher satisfaction and self-confidence after teaching practice. The findings of this study indicates that the instructional approach presented here would serve as a framework in course design and give important ideas on improving NC machining course. It is significantly found that the use of

the virtual prototype technology in NC machining course has opened up an important research issue for engineering education. It is our belief that the overview of this study would be valuable for academic institutions and educators to design the virtual situational classroom for engineering specialties to enhance students' performance.

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## Appendix: Analytic rubrics used for the teaching evaluation

The analytic rubrics mainly involves the two attributes: conceptual design and object design of NC machining course, which includes all the elements that make up the student's evaluation. There are typically 10 rubric scores converted into three grades in the rubric scoring system.

Criteria	High (from 8 to 10)	Medium (from 5 to 7)	Low (from 0 to 4)
<b>1. Presentation of conceptual design of NC machining course</b>			
Approach to project requirements (40%)	The overall capability target of NC machining course is comprehended. The presented design conception is well formed	The overall capability target e is comprehended. The presented design conception needs to be reviewed	The overall capability target and the presented design conception are poor
Critical research and analysis (30%)	Excellent definition and comprehension of rules, laws and conceptions of theory	Good definition and comprehension of rules, laws and conceptions	Poor comprehension of rules, laws and conceptions
Teaching information support (15%)	all-round, accurate and relevant information for teaching process based on extensive investigation	Relevant information for teaching process based on a certain investigation	Provide the limited information for teaching process
Diagram, figure, table, expression (15%)	Excellent presentation supported by adequate diagrams, figures, tables and expressions	Good presentation by adequate diagrams, figures, tables and expressions	Poor presentation and poor diagrammatic support
<b>2. Presentation of object design of NC machining course</b>			
Implementation of planning progress (20%)	All tasks are assigned concretely and adapted to the planned time. Activities are well connected	Most of tasks are concretely distributed and appropriate. Activities are related	Activities undefined and/or non-differentiated. Activities very isolated
Quality of operational assignment (30%)	Excellent operational scheme according to requirements of NC machining course. Operational details are well presented	Good operational scheme according to the course requirements. Operations are not well detailed	Poor operational scheme. Details are not sufficient
Analysis of operation assignment(15%)	Very good presentation of process analysis, operational methodologies and controlling demands under study	Good presentation of process analysis, operational methodologies and controlling demands	Poor presentation of process analysis
Diagrammatic presentation of the operational scheme (10%)	Excellent presentation of diagrammatically operational scheme	Good presentation of diagrammatically operational scheme	Poor presentation of diagrammatically operational scheme
Technical report (15%)	Excellent technical report is written comprehensively, accurately and clearly	Good technical report, written clearly but need to be enhanced	Poor content of technical report
Oral presentation (10%)	Excellent oral presentation of operational methodology, diagram and computes	Good oral presentation of operational methodology, diagram and computes	Poor oral presentation of operational methodology, diagram and computes

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