Does the Manufacturing Industry Also Need Gamification? - A Gamification Design Practice for CNC Machine Tool Skill Training

Tian-shu Li and Min-yang Liu

Abstract. In CNC (Computer Numerical Control) vocational colleges, the current traditional pedagogy has become conflicting with the learning preferences of the "Generation Z", resulting in their low sense of competence, low learning autonomy, and insufficient recognition of industry identification. Thus, gamification design provides novel ideas for addressing these issues. Based on the theories of self-determination theory and motivational affordances, this study analyzes the sore points and study needs of students who are majoring in CNC technology at vocational colleges. Hence, according to the 12 dimensions of motivational affordances, the "needs-affordances-features" framework and the course content of CNC technology, a set of gamification design strategies for CNC machine tool skill training is proposed. Consequently, a smartphone-based interactive design practice is completed. Following this design practice, a user experience test is executed, and a positive result is obtained. Theoretically, this study explores the feasibility of modified gamification design processes that combine the motivational affordance model and the "needs-affordances-features" framework. Practically, the integration of gamification design into CNC machine tool skill training is not only a bold attempt to boost the learning motivation of students, but also a practical research foundation for the innovative development and transformation of CNC technology vocational education.

Keywords. gamification; interaction design; motivation affordance; CNC machine tool skill training; user experience; Generation Z

In recent years, "manufacturing power" has become a key focus of China's national strategy. The intelligent transformation and development of the manufacturing industry inevitably require the reserve and cultivation of more high-quality talents. This also puts forward higher requirements for CNC technology vocational colleges that cultivate talents for the manufacturing industry[1]. However, as "Generation Z" becomes the main body in vocational colleges, the shortcomings of traditional vocational education are revealed. The learning experience is dull and uninteresting, resulting in low initiative in students' learning and poor learning outcomes. Since researches have shown that gamification has a positive impact on enhancing educational effectiveness[2], this study will take CNC machine tool skill training as an example to conduct research on gamification interaction design to improve the students' learning experience.

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1. Vocational Education of CNC Technology

1.1. National Encouragement for the Reform and Upgrade of Vocational Education

The manufacturing industry in China is in a period of comprehensive transformation and upgrading, aiming to achieve connectivity and integrated development through intelligent and innovative production methods. In order to carry out this strategic goal, the country is initiating to put much greater emphasis on vocational education, encouraging students to improve their skill levels, and injecting fresh power into enterprises. Vocational colleges as the main institutions for training front-line employees in the manufacturing industry, are also actively reforms and upgrades. It is exploring various teaching methods to cultivate versatile talents with excellent vocational skills, flexibility, creativity and continuous independent learning capabilities.

1.2. Technical Training for CNC Machine Tools

Nowadays, students in CNC technology vocational colleges generally belong to the "Generation Z", who refers to the generation born between 1995 to 2010, and grew up with the development of the internet. They show significant differences from their parents in terms of thinking patterns and behavioral habits, forming distinct learning preferences. They display a strong interest-driven learning motivation. Simultaneously, they seek enjoyable learning experiences and immediate feedback, as well as attaching importance to the realization of personal value. These learning preferences are not easily satisfied within the traditional pedagogy of vocational colleges, which has led to a series of problems in the current CNC technology vocational education.

Firstly, CNC machine tool skill training involves monotonous and challenging course content, often requiring high levels of manual dexterity. This results in students lacking confidence in their abilities, leading to feelings of reluctance and decreased motivation to learn. Secondly, the cramming education is still the main teaching approach in the classes of CNC technology, which contradicts the learning preferences of the Generation Z, and limits their learning autonomy to a great extent. Thirdly, the content taught in schools may not align well with actual factory application scenarios. Students may lack a clear understanding of the practical value and future prospects of CNC machine tool skill, resulting in a lack of ideals and a sense of purpose. This leads to a problem of insufficient recognition of industry identification.

1.3. Gamification in manufacturing skill training

The application of gamification in the field of manufacturing is still in its nascent stages but has shown promising trends. Some studies apply gamification to manufacturing employee skill training. For example, Oliver Korn et al. gamified the process of mechanical assembly, making it easier for employees to perceive the accuracy and effectiveness of the assembly process. Jessica Ulmer et al. designed a combined point and leveling VR-based gamification system for assembly training (as shown in Figure 1a). Furthermore, gamification can also be used to learn manufacturing-related software. For example, the gamified teaching system...
"GamiCAD" helps guide new users of AutoCAD to become familiar with the operation of AutoCAD (as shown in Figure 1b)\(^{[10]}\).

To address the aforementioned issues and respond to the national call for talent development in the manufacturing industry, it is of great research significance to explore a CNC machine tool skill training strategy that aligns with the learning preferences of the Generation Z, of which the design practice should adopt innovative teaching methods, such as gamification, to provide students with clear and appealing learning objectives, adding interest to what might otherwise be a monotonous mechanical learning experience.

![a VR-based gamification system on assembly training](image1)

![b GamiCAD](image2)

**Figure 1.** Gamification applications for manufacturing skill training

### 2. Gamification in theory

#### 2.1. Gamification Concept and Applications

It has been recognized that gaming behaviors in the processes of production and daily life have driven human development and civilization. Therefore, people realize that the value of games is not only entertainment, and then put forward the concept of gamification. The term "gamification" was first coined in 2002 but gained widespread academic discussion after 2011. Sebastian Deterding et al. gave the first clear definition of gamification as "the use of game design elements in non-game contexts."\(^{[11]}\). Gamification related research aims to stimulate user motivation, enhance user experiences, and promote the achievement of expectations by combining various game elements\(^{[12]}\). Points, badges, and leaderboards, commonly referred to as PBL, exhibit distinct gaming characteristics and are frequently used game elements\(^{[13]}\).

Self-determination theory (SDT) serves as the theoretical foundation for research related to gamified motivation. SDT categorizes motivation into three types, namely, intrinsic motivation, extrinsic motivation, and amotivation. It also defines the fundamental psychological needs of humans are defined as autonomy, competence, and relatedness. Meeting these needs can enhance intrinsic motivation\(^{[14]}\) whereas individuals can also integrate experiences from their environment and gradually internalize them, resulting in the development of both intrinsic and extrinsic motivations.

#### 2.2. Motivation Affordances in Gamification Design

"Affordance" refers to the available action possibilities. Donald Norman defined the subject of affordance as "the combination of the actual properties and perceived properties of an object."\(^{[15]}\). Building upon this, Zhang introduced the term "motivation affordance"\(^{[16]}\), which refers to the properties of an object that determine whether and
how it can support one’s motivational needs. The theory of motivation affordance suggests that certain attributes of objects can serve to motivate users after meeting their needs. By controlling these attributes, motivation can be purposefully stimulated. Karahanna et al. proposed a comprehensive framework called "needs-affordances-features"[17], which enhances the practicality of the motivation affordance theory.

Gustavo Fortes Tondello et al. summarized 6 gamification design methods based on self-determination theory and motivation affordance theory, then proposed 12 dimensions of motivation affordance[18], classifying them into three major categories, namely intrinsic motivation affordance, extrinsic motivation affordance, and context-dependent motivation affordance (as shown in Figure 2).

![Figure 2. 12 dimensions of motivation affordances by Tondello et al.](image)

Intrinsic motivation affordances emphasize the enhancement of users intrinsic motivation through the fulfillment of three fundamental needs: competence, autonomy, and relatedness. Extrinsic motivation affordances serve as external incentives that can stimulate user behavioral motivation. Context-dependent motivation affordances will produce different motivation effects according to different situations. Intrinsic motivation affordances serve as motivators by satisfying needs, whereas extrinsic motivation affordances add further incentives, and context-dependent motivation affordances rely on the usage context to transform into either intrinsic or extrinsic. These three types of motivation affordances complement each other. In this study, the 12 dimensions of motivation affordances are used as a design guideline and integrated into the "needs-affordances-features" framework so as to conduct the design practice.

3. Gamification Design for CNC Machine Tool Skill Training

3.1. Needs Analysis of CNC Machine Tool Skill Training

Through a preliminary analysis, it is observed that students in CNC technology vocational colleges generally exhibit low sense of competence, low learning autonomy, and insufficient recognition of industry identification. In order to gather a further understanding of these three aspects, a questionnaire is made and distributed to students who are majoring in CNC machine tool discipline. 1026 respondents are retrieved and 84.72% of the total are students from higher vocational colleges. Due to the nature of the CNC discipline, approximately 90% of the respondents are male, and their ages ranged from 18 to 25 years.

The questionnaire is centered on two primary aspects: academic performance and future employment prospects. Identify the most pressing issues among students separately. Ultimately, the top four concerns in the academic performance section and one concern in the future employment section were chosen (as shown in Figure 3), resulting in a total of five key sore points. These sore points allow for a comprehensive assessment of the current learning experiences of students.
The analysis of the questionnaire results is shown in Figure 4. After classifying the questionnaire results, 5 sore points are summarized and clustered into three problem dimensions as mentioned above. Some of the sore points can be triggered by multi-dimensional problems. For example, “the tediousness of the course content” can be mainly caused by the low sense of competence and low learning autonomy while “the lack of deep understanding of the industry” is more the result of insufficient recognition of the industry identification. Hence, in order to derive the solution to the problem in the later process, the sore points are transformed into the learning needs of students by the three problem dimensions and eventually 7 needs are proposed.

3.2. Gamification Design Framework for CNC Machine Tool Skill Training Based on Motivation Affordances

To fulfill the 7 needs clarified in the above analysis, a gamification design framework for CNC machine tool skill training was built (as shown in Figure 5), by adopting the well-known "needs-affordances-features" framework and utilizing the 12 dimensions of motivation affordances.

In this framework, suitable motivation affordances should be selected for each need, and then the design strategies are proposed with the features being clarified (as shown in Figure 5). Meanwhile, in order to ensure the rationality of the strategies and features, it was necessary to take the course contents as the guidelines. In this case, the curriculum of “CNC Machine Tool Operation and Programming” was chosen as the example, in which students were required to attain the knowledge of basic cognition of CNC machine tools, CNC machine tool processing operations, and CNC machine tool processing programming.

After the analysis according to the framework, this study obtains 5 design strategies and 13 features to guide the design practice.
"Accumulate knowledge and increase proficiency" can draw from the "completeness and mastery" motivation affordance as its motivational source, which emphasizes the importance of completing a series of tasks to improve the ability. "Manage effective academic progress" can draw from the "challenge and competence" motivation affordance, which emphasizes the improvement of the sense of competence by completing high-difficulty challenge tasks. Meanwhile, "challenge and competence" acknowledges the impact of tasks ranging from easy to extremely difficult on student motivation. This necessitates the implementation of a progressive difficulty level to boost student learning motivation. Both of these affordances underscore the importance of tasks completion. Consequently, "tasks and challenges with difficulty levels" design strategy is proposed. Its primary features include compulsory tasks facilitating students consolidation of knowledge, and challenges providing students with a gradual transition from easy to difficult learning experiences.

"Acquire immediate learning feedback" means that students expect feedback on learning results to gauge their level of skill development and achieve a sense of competence. Therefore, this study adopts the "feedback" motivation affordance as a motivational source and incorporates the "relatedness" motivation affordance within it. By feedback information, students subconsciously form competitive relationships, which encourage them and enhance their capabilities. As a result, the "clear and immediate feedback" design strategy is proposed. Students can clearly perceive their development and deficiencies based on learning feedback. The features of this strategy include task completion information, learning performance analysis and leaderboards.

"Have the possibility of choice and decision" means that students expect to have more autonomy, thereby strengthening their sense of independence in the learning process. To fulfill this, this study leverages the "autonomy and creativity" motivation affordance, emphasizing the importance of meeting students autonomy needs. Additionally, the mechanisms associated with "autonomy and creativity" offer high interactivity, thereby enhancing the enjoyment of activities and aligning with the goal of "increasing interests in the learning process." Ultimately, the "autonomous choices and customization" design strategy is proposed, which includes features like "free choices of tasks" and "customized props to upgrade game levels". These elements increase autonomy and interactivity during the learning process, alleviate learning pressure, and enhance interests in learning.

Task rewards can motivate students to engage actively in learning and experience enjoyment. Therefore, both "increase interests in the learning process" and "stimulate learning initiative" draw from the external motivation affordance as their motivational
source, which encompasses "ownership and rewards", "scarcity" and "loss avoidance". "Scarcity" enhances motivation by making rewards harder to attain. "Loss avoidance" affordance requires that rewards be time-sensitive to improve learning efficiency and increase learning engagement. Hence, the "visualization and diversification of rewards" design strategy is proposed, incorporating features such as points, badges, levels and props to establish a system of learning incentives and penalties.

The "immersion" motivation affordance aims to create an immersive system to enhance user experience, with narrative mechanisms being a commonly used approach. "Learn more about industry information and values" can draw from the "immersion" motivation affordance as its motivational source by incorporating information about the CNC machine tool industry into the immersive system and presenting it using narrative mechanisms. Meanwhile, the "purpose and meaning" motivation affordance is further employed by setting meaningful task objectives to help students appreciate the values of the CNC machine tool industry. Consequently, the "interactive narrative" design strategy is proposed, which includes manufacturing-themed science fiction narratives and dialogue interactions to enhance user immersion.

4. Gamification Design for CNC Machine Tool Skill Training

This application is designed to assist students in consolidating and strengthening their knowledge in the course of CNC machine tool skill training. The main mechanism is to set question tasks so that students can practice exercises anytime and anywhere after class. This application is called "Divine Manufacturer Realm", which means to "create hope with machinery". The protagonist is designed with the image of a future mechanical engineer, and the interactive interface incorporates machinery and technology-related elements, which aims to enhance students’ sense of involvement and engagement in continuous learning, thereby achieving the expected study goals, a set of the UI designs is shown in Figure 6.

Figure 6: UI design of "Divine Manufacturer Realm"

- "Tasks and challenges with difficulty levels"

In this application, students can obtain virtual mechanical parts by completing tasks. The tasks are divided into three categories, namely mainline tasks, daily tasks and challenge tasks. The mainline tasks are carried out in conjunction with the narrative, and the storyline corresponds to the course learning content. The daily tasks aim to maintain students practicing in this application regularly and continuously. Challenge tasks require higher accuracy in answering the questions.

All tasks are set with difficulty levels. Students can receive different rewards based
on varying levels of correctness in answering the quiz. For example, daily tasks require students to achieve 60% accuracy to obtain mechanical parts while challenge tasks need to achieve 100% accuracy to have ultra-precision mechanical parts.

- "Clear and immediate feedback"
  Feedback can inform students of their current game status, interaction results, and subsequent operations that need to be operated. For example, students can understand their performances compared with others through game levels, mission progress, rankings, gained props and rewards. Meanwhile, they can also view the analysis of personal capabilities and customized strategies in aspects of competence, endurance, exploration, concentration, and enthusiasm.

- "Autonomous choices and customization"
  There are two types of choice mechanisms provided to meet students autonomous needs. The first type is that students are able to choose whatever tasks they desire to conduct and whenever they prefer to complete them.

  The second type is the customization of props that students gain from the game. In this application, the main mission is to unlock a series of virtual CNC machine tools and to manufacture high-level mechanical parts with them so as to upgrade the game levels. Each of the CNC machine tools has a unique appearance and processing capabilities. Students can choose their preferred CNC machine tools and upgrade the components of spindles, cutters, workbenches and the CNC systems to improve the processing precision of the equipment so as to obtain more game rewards.

- "Visualization and diversification of rewards"
  Visualization rewards allow students to receive positive feedback more intuitively, which motivates them to complete a greater number of tasks and alleviates the boringness of mechanical learning. This application includes four types of rewards, namely virtual mechanical parts, game energies, experience points and corresponding badges by completing tasks.

- "Interactive Narrative"
  The background of this application’s story involves a group of engineers who refuse to leave their homeland during doomsday. Instead, they attempt to save themselves by constructing a base, awaiting a new hope. Students can always grow up with the characters in the story and accumulate knowledge in the tasks as learners.

  Students can also drive the plot forward by completing the interactive dialogues with the characters, which may enrich their learning experience and improve their learning motivation by creating an immersive sense of learning, playing, and working.

5. User experience test

To assess the applications ability to fulfill the educational needs of students and stimulate their learning motivation, a test is conducted. Six participants (males/females=4:2) are recruited to complete testing task and fill out a user experience questionnaire. The questionnaire utilized a 7-point Likert scale to rate 9 items, which are based on the Gameful Experience Questionnaire developed by HOGBERG J[19], and integrated with the content of the application.
The test is structured into three phases; 1) Familiarization with the application, where the experimental personnel provided an overview of the applications features and assigned tasks; 2) Completion of the primary tasks within the first part of the CNC machine tool recognition content, where participants are required to complete a minimum of two groups of daily tasks and challenge tasks, while other functions are explored at random intervals; and 3) Verification of task completion by the experimental personnel, followed by a demonstration of the personal information, honors, and rankings pages, and finally, completion of the user experience questionnaire. The results of this testing are presented in Table 1.

<table>
<thead>
<tr>
<th>Dimension/Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Learning needs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>5.77</strong></td>
</tr>
<tr>
<td>I feel an increase in ability by completing tasks</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6.17</td>
</tr>
<tr>
<td>Let me have a clear learning goal</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>4.83</td>
</tr>
<tr>
<td>Receive positive feedback on the completion of tasks</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>6.33</td>
</tr>
<tr>
<td><strong>Learning autonomy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>6.00</strong></td>
</tr>
<tr>
<td>I want to strive to be better</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6.00</td>
</tr>
<tr>
<td>Completing tasks without feeling forced</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>5.67</td>
</tr>
<tr>
<td>I feel like I could explore new something</td>
<td>7</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>6.33</td>
</tr>
<tr>
<td><strong>Learning experience</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td><strong>5.89</strong></td>
</tr>
<tr>
<td>I have a deeper understanding of the value of CNC</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5.67</td>
</tr>
<tr>
<td>machine tool industry in the process of learning</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I hope my role can bring more hope to mankind</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>5.50</td>
</tr>
<tr>
<td>I have an interesting learning experience</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6.50</td>
</tr>
</tbody>
</table>

Upon conducting a preliminary analysis of the user experience questionnaire, positive feedback was received across all indicators (Average>4). The average score for each dimension was approximately 6.0. The test results indicate that the application is capable of effectively meeting the educational needs of vocational college students learning CNC machine tool skill courses and enhancing their overall learning experience. However, certain limitations were observed during the testing process. The scope of the test was limited to the relatively basic CNC machine tool recognition content, and the duration of the test was brief, with the participants lacking the opportunity to gain an in-depth understanding of the applications functionality through extended usage. Additionally, the sense of achievement was relatively low, resulting in lower scores for some indicators. During the testing process, the participants exhibited differing opinions regarding the same game mechanics, highlighting the need for further research to personalize the application in the future.

6. Conclusion

The students in CNC technology vocational colleges generally exhibit low sense of competence, low learning autonomy, and insufficient recognition of industry identification. Based on the motivation affordances, this study transforms sore points of students into design demands and then forms a set of gamification design strategies for CNC machine tools skill training in a smartphone-based application, which achieves relatively positive results in a user experience test. Accordingly, this study clarifies the feasibility of using motivation affordances in gamification design and fulfills the innovative exploration of gamification in the field of CNC machine tool skill training. Normally in the context of the manufacturing industry, the concept of gamification typically stands as an outlier. This anomaly can be primarily attributed to the industries...
inherent conservatism and its adherence to rigid protocols. In an effort to challenge this status quo, this study goes beyond the conventional approach of employing standard gamification elements. Instead, it delves into the utilization of narrative as a gaming element, a less explored avenue in prior research, ultimately achieving improvements in both psychological and behavioral outcomes. This provides new design insights and lays a corresponding research foundation for the gamification development of CNC machine tool skill training.

Acknowledgments. This work was supported by Qin Xin Talents Cultivation Program, Beijing Information Science & Technology University (QXTCPC202013); Supply and Demand Matching Employment Program of Ministry of Education of the people's Republic of China (“Human Factors and Ergonomics Specialization”, 2021); General Project of Beijing Municipal Commission of Education Research Plan (KM20201123013).

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