

Innovation and Diffusion of the Swansoft CNC Simulator in CNC Learning and the Potential Development of Virtual Reality

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ABSTRACT

The advancement of manufacturing technology has increased the importance of Computer Numerical Control (CNC) competencies in engineering and vocational education. However, limited access to physical CNC machines and high operational costs remain significant challenges in CNC learning. The Swansoft CNC Simulator has emerged as an innovative solution that enables students to learn CNC programming and machine operation in a safe, flexible, and virtual learning environment. This study employed a quantitative approach using a survey method. Data were collected through a questionnaire administered to 32 students who had experience using the Swansoft CNC Simulator in CNC learning activities. The research instrument was developed based on Rogers' Diffusion of Innovation Theory, encompassing five key attributes: Relative Advantage, Compatibility, Complexity, Trialability, and Observability. The collected data were analyzed descriptively using frequencies, percentages, and mean scores. The results revealed that most students perceived the Swansoft CNC Simulator as highly beneficial in improving their understanding of CNC programming and machine operation. The findings also indicated a high level of technology adoption among students, although several challenges related to compatibility with individual learning preferences and perceived complexity were identified. Furthermore, the study demonstrated that Virtual Reality (VR) technology has considerable potential to enhance the effectiveness of CNC learning, as most students expressed strong interest in integrating VR into CNC simulation environments. The study concludes that the Swansoft CNC Simulator contributes positively to learning effectiveness, reduces the risk of errors during CNC training, and enriches students' learning experiences. The integration of Virtual Reality is recommended as an innovative approach to support more realistic, immersive, and effective simulation-based CNC learning.

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INTRODUCTION

The rapid advancement of digitalization and industrial automation has transformed manufacturing systems worldwide, making Computer Numerical Control (CNC) technology one of the

core competencies required in modern industry. CNC machines have replaced many conventional machining processes by providing higher precision, efficiency, consistency, and automation, thereby reducing human error and increasing productivity in manufacturing operations (Soori et al., n.d.). Consequently, engineering and vocational education institutions are expected to develop effective instructional strategies that enable students to acquire CNC programming and operational competencies aligned with industrial requirements.

Despite its importance, CNC education faces several challenges, particularly regarding accessibility to physical CNC machines. The high acquisition, operation, and maintenance costs of CNC equipment limit their availability in many educational and vocational training institutions (Berner, 2009). Furthermore, the number of machines is often insufficient compared to the number of students, resulting in limited hands-on practice opportunities and reduced exposure to actual machining operations. Such conditions may hinder the development of students' programming and machine operation competencies. In addition, programming errors during machining activities may cause damage to cutting tools, workpieces, or machine components, potentially increasing operational costs and safety risks. Incorrect G-code commands can lead to machining failures, workplace accidents, and costly equipment repairs. Therefore, innovative approaches are required to enhance CNC learning effectiveness while minimizing operational constraints and risks.

Software-based CNC simulation has emerged as a practical solution to overcome these challenges. Among the available simulation platforms, the Swansoft CNC Simulator has been widely recognized as an effective educational tool for CNC programming and machine operation training. The simulator enables students to practice CNC operations in a safe virtual environment while eliminating the risks associated with physical machining processes (Chen et al., 2026). Swansoft CNC Simulator incorporates features that closely replicate real machining conditions, including toolpath visualization, machining process simulation, program verification, and programming error detection (Arsenal et al., 2025). Through these features, students can freely experiment with CNC programming techniques without risking equipment damage. Moreover, the simulator provides flexible learning opportunities because it can be accessed independently of laboratory schedules and machine availability. As a result, simulation-based learning contributes to improved conceptual understanding, technical proficiency, and learner confidence before students engage in actual workshop practices.

Recent advancements in Virtual Reality (VR) technology have further expanded opportunities for innovation in technical and vocational education, including CNC training (Chiang et al., 2022). Unlike conventional screen-based simulation systems, VR offers immersive and interactive learning experiences through three-dimensional virtual environments. In CNC education, VR technology allows students to experience machine operation as if they were working in a real manufacturing workshop, providing realistic interactions with machine controls, tools, and machining processes. Such immersive experiences facilitate not only conceptual understanding but also practical skill development. Previous

studies have demonstrated that VR-based training can improve cognitive achievement, psychomotor skills, spatial understanding, and overall learning engagement (Hussain & Khan, 2024). Additionally, VR enables learners to practice complex machining scenarios and operational procedures that may be difficult, expensive, or unsafe to perform using actual equipment. Consequently, students can develop greater preparedness for real industrial environments while minimizing potential risks during the learning process.

The integration of Swansoft CNC Simulator with Virtual Reality technology presents a promising opportunity to enhance CNC education. Combining software-based simulation capabilities with immersive VR experiences enables students to engage in realistic machining scenarios while maintaining a safe and controlled learning environment (Zheng et al., 2024). This integrated approach facilitates the acquisition of programming, operational, and decision-making skills that closely resemble real-world industrial practices. Furthermore, immersive learning experiences may increase student motivation, engagement, and confidence, thereby improving overall learning outcomes. Such innovations have the potential to bridge the gap between theoretical instruction and industrial practice, ensuring that students develop competencies that meet current manufacturing demands.

Technical and vocational education institutions must continuously adapt to technological developments to prepare graduates for increasingly sophisticated industrial environments (Huang, 2025). Previous studies have demonstrated that CNC simulation tools such as Swansoft CNC Simulator can effectively address limitations in physical machine accessibility, improve student understanding, and reduce operational risks during CNC programming instruction (Huang, 2025). Meanwhile, Virtual Reality technology offers additional advantages by creating more immersive, interactive, and realistic learning experiences that can further enhance educational effectiveness.

Although numerous studies have investigated CNC simulation and Virtual Reality independently, limited research has explored their integration from the perspective of innovation and diffusion in technical and vocational education. Existing literature has largely focused on technical performance and learning effectiveness, whereas relatively little attention has been devoted to understanding how these technologies can be adopted, disseminated, and integrated into educational systems to support Industry 4.0 and the emerging Industry 5.0 paradigm. This gap highlights the need for further investigation into innovative instructional approaches that leverage advanced simulation technologies to improve workforce readiness and educational relevance.

Therefore, this study aims to explore the innovation and diffusion of the Swansoft CNC Simulator in CNC education and to examine the potential development of Virtual Reality-based learning environments for technical training. The study seeks to identify strategies for optimizing CNC instruction, enhancing students' technical competencies, and improving their preparedness for technology-driven industrial workplaces. Ultimately, the findings are expected to contribute to the development of more effective, efficient, and industry-relevant learning models that support the

evolving needs of advanced manufacturing and vocational education in the Industry 4.0 and Industry 5.0 era.

METHOD

This study employed a quantitative research approach using a survey method to investigate the innovation and diffusion of the Swansoft CNC Simulator in CNC learning and to examine the potential development of Virtual Reality (VR) technology in vocational education. A quantitative survey was considered appropriate because it enables researchers to systematically collect and analyze participants' perceptions regarding the adoption of educational technologies and their effectiveness in supporting learning processes.

The participants consisted of 32 undergraduate students enrolled in CNC-related courses who had prior experience using the Swansoft CNC Simulator during their learning activities. These students were selected because they had direct exposure to the simulator and were therefore capable of providing informed evaluations regarding its usefulness, usability, and potential integration with emerging technologies such as Virtual Reality.

Data were collected through a structured questionnaire developed based on Rogers' Diffusion of Innovation Theory . The instrument was designed to measure five key attributes that influence innovation adoption, namely Relative Advantage, Compatibility, Complexity, Trialability, and Observability. These dimensions have been widely utilized in studies investigating the adoption and diffusion of educational technologies because they provide a comprehensive framework for understanding users' perceptions toward innovation acceptance .

Table 1. Questionnaire Structure Based on Rogers' Diffusion of Innovation Model

No.	Attribute/Indicator	Questionnaire Focus	Number of Items
1	Relative Advantage	Benefits of using CNC simulation in learning; comparison with traditional learning methods; effectiveness of Swansoft Simulator in improving student understanding; potential benefits of VR integration in CNC learning	4
2	Compatibility	Suitability of the simulator with students' learning styles; relevance to actual CNC machine operations; willingness to adopt new technologies; interest in VR-based learning environments	4
3	Complexity	Understanding of simulator operation; ease of use; operational difficulty level; challenges encountered during simulator usage	4
4	Trialability	Duration of Swansoft usage; contexts in which the simulator is utilized; students' familiarity with VR technology	3
5	Observability	Frequency of simulator use; preferred learning methods; discussions with peers and instructors; accessibility of simulator-related information; information sources; suggestions for future simulator development	6

Table 1 presents the distribution of indicators and questionnaire items used in this study. The questionnaire employed a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) to measure students' perceptions regarding each innovation attribute. The use of a Likert scale allowed quantitative assessment of respondents' attitudes toward the adoption and effectiveness of the Swansoft CNC Simulator.

The collected data were analyzed using descriptive statistical techniques, including frequencies, percentages, means, and standard deviations. Descriptive analysis was conducted to evaluate students' perceptions of the simulator and to determine the extent to which the technology supports CNC learning. This approach also provided an overview of students' levels of technology acceptance and readiness for adopting innovative learning tools.

Furthermore, each dimension of Rogers' Diffusion of Innovation model—Relative Advantage, Compatibility, Complexity, Trialability, and Observability—was analyzed separately based on the scores obtained from the questionnaire responses. Comparative analysis among these dimensions was performed to identify the factors that most strongly influenced students' adoption of the Swansoft CNC Simulator. The results were subsequently presented through percentage distributions and graphical visualizations to facilitate interpretation of response patterns.

In addition, correlation analysis was conducted to explore potential relationships among the innovation attributes. This analysis aimed to identify interconnections between factors influencing students' perceptions and the effectiveness of CNC learning through simulation technology. The findings are expected to provide valuable insights into the adoption of CNC simulation technologies and their potential integration with Virtual Reality to enhance vocational and engineering education in the context of Industry 4.0 and Industry 5.0 (Guo, 2025).

RESULTS AND DISCUSSION

Perceived Relative Advantage

The assessment of the relative advantage attribute in the implementation of the Swansoft CNC Simulator was conducted by examining several aspects, including the perceived benefits of using the simulator in learning activities, its advantages compared with traditional instructional methods, and its effectiveness in enhancing students' understanding of CNC machine concepts. Relative advantage is considered one of the most important determinants of innovation adoption because users are more likely to accept a technology when they perceive it as offering greater benefits than existing alternatives .

The results regarding the perceived benefits of the Swansoft CNC Simulator are presented in Figure 1.

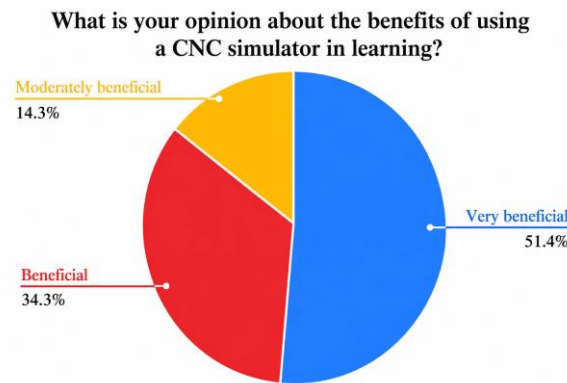


Figure 1. Perceived Benefits of Using the Swansoft CNC Simulator in Learning

Based on Figure 1, the majority of students perceived the Swansoft CNC Simulator as beneficial for learning, with 51.4% rating it as *very beneficial*, 34.3% as *beneficial*, and 14.3% as *moderately beneficial*, while no respondents considered it less beneficial or not beneficial. These findings indicate that the simulator effectively supports CNC learning by enhancing both conceptual understanding and practical skills through an interactive and risk-free virtual environment. The positive perceptions suggest that students can better visualize machining processes, verify CNC programs, and gain operational experience without the constraints and risks associated with physical CNC equipment. These results are consistent with the findings of (Yip-Hoi, 2013), who reported that simulation improves machine operation competencies while minimizing equipment-related risks, and found that simulation-based learning enhances independent practice and strengthens theoretical understanding. From the perspective of Diffusion of Innovation Theory, the high level of perceived usefulness reflects a strong relative advantage of the Swansoft CNC Simulator over conventional instructional methods, as innovations that provide clear and observable benefits are more likely to be adopted by users. Therefore, the simulator demonstrates significant potential as an effective technology-enhanced learning tool for vocational and engineering education.

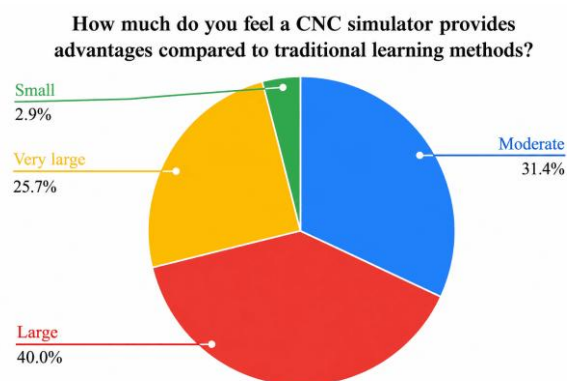


Figure 2. Perceived Advantages of the Swansoft CNC Simulator Compared to Traditional Learning Methods

Based on Figure 2, most students perceived that the Swansoft CNC Simulator offers greater advantages than traditional learning methods, with 40.0% of respondents rating the benefits as *high*,

25.7% as *very high*, 31.4% as *moderately significant*, and only 2.9% as *low*. These findings indicate that the simulator significantly enhances the effectiveness of practical learning by providing a flexible, interactive, and repeatable learning environment without the risk of damaging physical equipment. The high proportion of positive responses suggests that students recognize the simulator's value in facilitating skill development and improving learning outcomes through hands-on virtual experiences. This result is consistent with the findings (Talan, 2020), who reported that simulation-based technologies improve conceptual understanding and practical competencies more effectively than conventional instructional approaches. emphasized that technology-assisted learning environments contribute to the gradual development of technical skills through experiential learning. From the perspective of Diffusion of Innovation Theory, these positive perceptions reflect a strong relative advantage of the Swansoft CNC Simulator, which is a key factor influencing innovation adoption . Therefore, the integration of CNC simulation technology into vocational and engineering curricula should be further expanded to enhance the quality and effectiveness of manufacturing education.

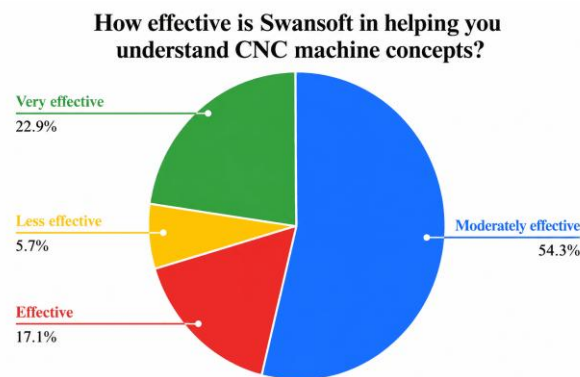


Figure 3. Perceived Effectiveness of the Swansoft CNC Simulator in Understanding CNC Machine Concepts

Based on Figure 3, the majority of students perceived the Swansoft CNC Simulator as effective in supporting their understanding of CNC machine concepts, with 54.3% of respondents rating it as *moderately effective*, 22.9% as *very effective*, 17.1% as *effective*, and only 5.7% as *less effective*. These findings indicate that the simulator plays an important role in facilitating CNC learning by helping students understand both theoretical concepts and machine operation procedures more easily through a virtual learning environment. The predominance of positive responses suggests that simulation technology enhances technology-based learning and provides valuable practical experience without requiring direct access to physical CNC machines. This result is consistent with the findings of Kadir and Xu (2011), who reported that simulation technologies can accelerate the learning process while improving both conceptual understanding and practical skills. Although a small proportion of students perceived the simulator as less effective, this may indicate the need for further optimization through enhanced interactivity, more comprehensive instructional modules, or integration with complementary teaching methods. From the perspective of Diffusion of Innovation Theory, the perceived effectiveness of the simulator reinforces its relative advantage as an educational innovation and supports its broader

adoption in vocational and engineering education . Therefore, the Swansoft CNC Simulator demonstrates considerable potential as an effective tool for improving students' understanding of CNC concepts and operations.

Compatibility

The compatibility attribute of the Swansoft CNC Simulator was evaluated based on several aspects, including the suitability of the simulator to students' learning styles, its resemblance to actual CNC machine operations, students' ability to adapt to new learning technologies, and their interest in using Virtual Reality (VR) for CNC learning. Compatibility is a critical factor in innovation adoption, as technologies that align with users' needs, experiences, and learning preferences are more likely to be accepted and utilized effectively .

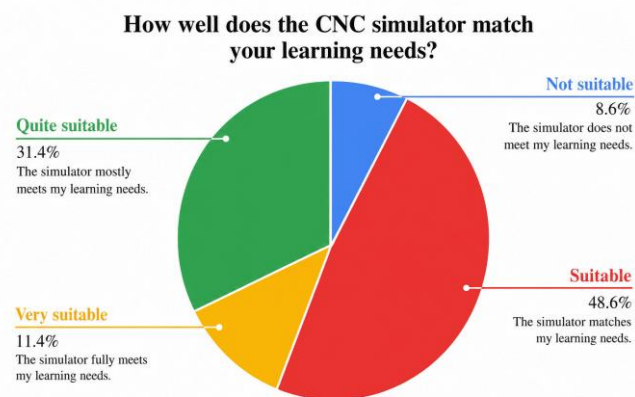


Figure 4. Compatibility of the Swansoft CNC Simulator with Students' Learning Styles

Based on Figure 4, the majority of students expressed positive perceptions regarding the compatibility of the Swansoft CNC Simulator with their learning styles, with 48.6% of respondents rating it as *compatible*, 31.4% as *moderately compatible*, and 11.4% as *highly compatible*, while only 8.6% considered it *less compatible*. These findings indicate that the simulator aligns well with diverse student learning preferences and can effectively support the acquisition of CNC knowledge through an interactive and practice-oriented learning environment. The predominance of positive responses suggests that simulation-based learning enhances student engagement and facilitates a deeper understanding of technical concepts. This finding is consistent with Talan (2020), who reported that simulation-based instruction improves student participation and learning outcomes, particularly in engineering and manufacturing education. Although a small proportion of students perceived the simulator as less compatible with their learning styles, this highlights the importance of incorporating diverse instructional approaches to accommodate different learner needs. Therefore, integrating the Swansoft CNC Simulator with complementary methods, such as hands-on practice and collaborative discussions, may further enhance learning effectiveness and create a more inclusive educational environment. From the perspective of Diffusion of Innovation Theory, the high level of perceived

compatibility supports the adoption of the simulator, as innovations that align with users' existing experiences and learning preferences are more readily accepted .

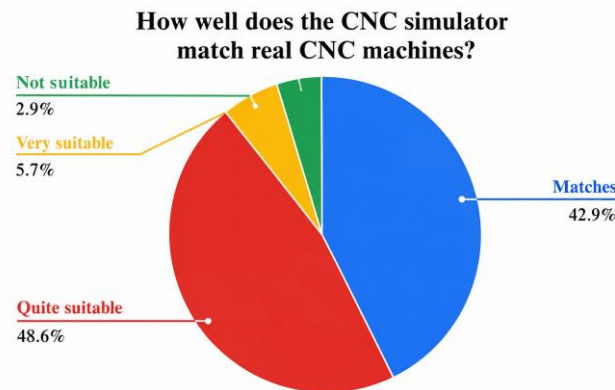


Figure 5. Compatibility of the Swansoft CNC Simulator with Actual CNC Machine Operations

Based on Figure 5, most students perceived the Swansoft CNC Simulator as reasonably representative of actual CNC machine operations, with 48.6% of respondents rating it as *moderately compatible*, 42.9% as *compatible*, and 2.9% as *highly compatible*, while only 5.7% considered it *less compatible*. These findings suggest that the simulator effectively replicates many essential aspects of CNC machining, enabling students to develop fundamental knowledge of machine operation, programming, and manufacturing processes in a safe learning environment. However, the relatively low percentage of responses in the *highly compatible* category indicates that certain elements of real machining, such as physical interaction, machine feedback, and workplace conditions, cannot be fully reproduced through simulation. This finding is consistent with (Talan, 2020), who reported that simulation technologies are highly effective in engineering education but cannot entirely replace hands-on experience with actual equipment. Therefore, the Swansoft CNC Simulator should be integrated with practical training using real CNC machines to ensure that students acquire both strong conceptual understanding and comprehensive practical skills aligned with industrial requirements (Wu et al., 2009). From the perspective of Diffusion of Innovation Theory, the high level of perceived compatibility with real CNC machines supports the adoption of the simulator as a valuable educational innovation in vocational and engineering education .

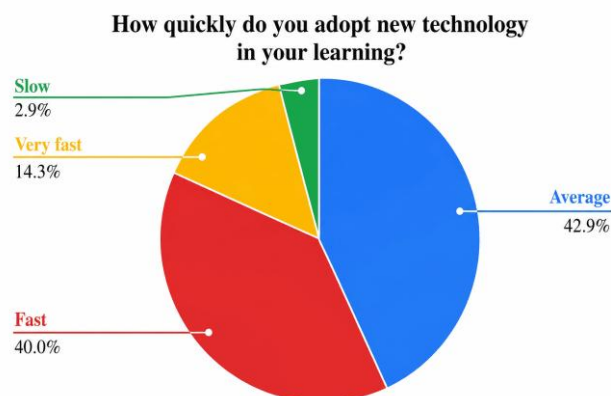


Figure 6. Students' Speed of Adapting to New Learning Technologies

Based on Figure 6, most students demonstrated a positive ability to adapt to new learning technologies, with 42.9% of respondents categorizing themselves as having an *average* adaptation rate, 40.0% as *fast*, 14.3% as *very fast*, and only 2.9% as *slow* in adopting new technologies. These findings indicate that the majority of students possess a relatively high level of readiness to engage with technological innovations in educational settings. The substantial proportion of respondents in the *fast* and *very fast* categories suggests that students can effectively adapt to technology-enhanced learning environments, which is essential for successful digital learning implementation in the era of Industry 4.0 (Hariyanto et al., 2022). Nevertheless, the presence of a small group of students who experience difficulties in adapting highlights the influence of factors such as technological literacy, access to digital resources, and prior experience with educational technologies. Therefore, educational institutions should provide adequate training, technical guidance, and learning support to facilitate a more inclusive and effective technology adoption process, ensuring that all students can fully benefit from technology-integrated learning environments (Liang et al., 2024). From the perspective of Diffusion of Innovation Theory, students' readiness to adopt new technologies reflects a favorable condition for the implementation and diffusion of innovative learning tools such as the Swansoft CNC Simulator .

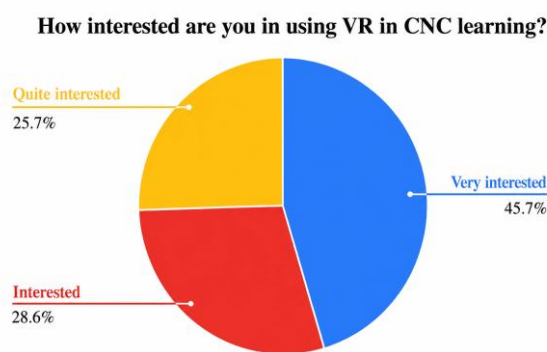


Figure 7. Students' Interest in Using Virtual Reality for CNC Learning

Based on Figure 7, students demonstrated a strong interest in the use of Virtual Reality (VR) for CNC learning, with 45.7% of respondents indicating that they were very interested, 28.6% interested, and 25.7% moderately interested, while none expressed a lack of interest. These findings suggest that VR has significant potential as an innovative learning medium in CNC education due to its ability to provide immersive, interactive, and realistic learning experiences that closely resemble actual industrial environments. The high level of student interest reflects positive perceptions of VR's potential to enhance conceptual understanding, technical skills, and the overall effectiveness of simulation-based learning. This finding is consistent with studies (Yang et al., 2024a), which reported that VR creates realistic simulation environments, accelerates learning processes, and improves safety and efficiency by allowing students to practice without the risk of equipment damage or workplace accidents. However, the successful implementation of VR requires consideration of infrastructure availability, investment costs, instructor readiness, and the development of industry-relevant learning modules. From the

perspective of Diffusion of Innovation Theory, the high level of interest observed among students indicates favorable compatibility and acceptance of VR as an emerging educational technology, supporting its potential adoption in future CNC learning environments .

Complexity

The complexity attribute was evaluated based on students' understanding of how the Swansoft CNC Simulator operates, the perceived ease of use of the application, and the challenges encountered during its implementation. In the context of Diffusion of Innovation Theory, complexity refers to the degree to which an innovation is perceived as difficult to understand and use. Technologies that are easier to learn and operate are generally more likely to be adopted by users .

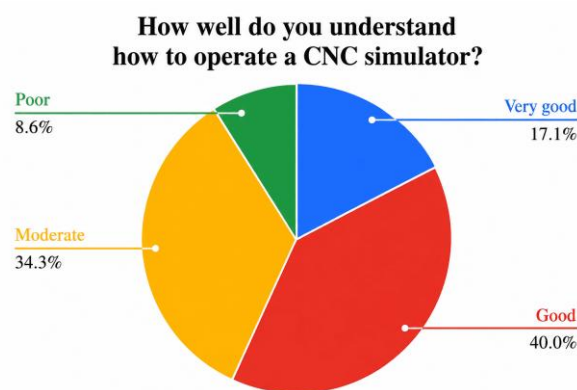


Figure 8. Students' Understanding of How the Swansoft CNC Simulator Operates

Based on Figure 8, most students demonstrated a good understanding of how the Swansoft CNC Simulator operates, with 40.0% of respondents reporting a *good* level of understanding, 34.3% a *moderate* level, 17.1% a *very good* level, and only 8.6% indicating a *low* level of understanding. These findings suggest that the majority of students were able to effectively comprehend the concepts and operational procedures of the simulator, with 57.1% reporting good or very good understanding. This result indicates that the simulator contributes positively to the development of students' technical knowledge and skills prior to engaging with actual CNC machines. Simulation-based learning provides a safe environment for practice without the risk of damaging equipment, thereby increasing students' confidence in CNC programming and machine operation (Yip-Hoi, n.d.). Nevertheless, a small proportion of students experienced difficulties in understanding the simulator, highlighting the need for additional support through training sessions, more comprehensive instructional materials, and enhanced interactive learning features. Therefore, optimizing the use of the Swansoft CNC Simulator through adaptive teaching strategies and adequate instructional support may further improve learning effectiveness and student competency development. From the perspective of Diffusion of Innovation Theory, the high level of student understanding suggests that the simulator possesses a relatively low perceived complexity, which positively supports its adoption in vocational and engineering education .

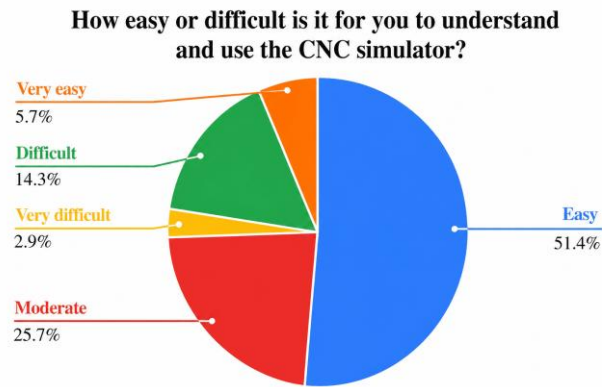


Figure 9. Ease of Use of the Swansoft CNC Simulator

Based on Figure 9, most students perceived the Swansoft CNC Simulator as relatively easy to understand and use, with 51.4% of respondents rating it as *moderately easy*, 25.7% as *easy*, and 5.7% as *very easy*. In contrast, 14.3% considered the simulator *difficult* to use, while only 2.9% rated it as *very difficult*. These findings indicate that 82.8% of students experienced a low level of difficulty when using the simulator, suggesting that it has been effectively designed to support the learning process. The perceived ease of use may be attributed to its intuitive features and its ability to present CNC programming and machine operation concepts within a safe and controlled environment (Suyetno & Yoto, 2021). This finding is consistent (Siryono et al., 2023), who reported that CNC simulation technologies can be utilized effectively by students with diverse backgrounds without requiring extensive training. Nevertheless, 17.2% of students still experienced difficulties, which may be associated with differences in technological literacy, prior experience, or user interface preferences. Therefore, further improvements, such as the development of interactive tutorials, adaptive learning approaches, and more comprehensive support features, could enhance the usability and learning effectiveness of the simulator. From the perspective of Diffusion of Innovation Theory, the high level of perceived ease of use indicates low complexity, which positively influences the adoption and acceptance of the Swansoft CNC Simulator in vocational and engineering education.

Table 2. Challenges Encountered by Students When Using the Swansoft CNC Simulator

Challenges Encountered by Students	Number of Students
Software and software feature issues	2
Hardware and software issues	5
Software issues	11
Hardware issues	6
Hardware, software, and software feature issues	1
Software feature issues	4
Hardware, software, and instructor-related issues	2
Hardware and software feature issues	1

Based on Table 2, software-related issues were the most frequently reported challenge in using the Swansoft CNC Simulator, affecting 11 students (37.93%). Additionally, 6 students (20.69%) experienced hardware-related problems, 5 students (17.24%) encountered combined hardware and software issues, and 4 students (13.79%) reported difficulties associated with software features. A

smaller number of students faced more complex challenges involving combinations of hardware, software, software features, and instructor-related factors. These findings suggest that although software remains the primary obstacle, the effectiveness of CNC simulation-based learning is also influenced by hardware quality, feature availability, and pedagogical support. Software-related difficulties may stem from user interface limitations, insufficient user familiarity, or system compatibility issues, whereas hardware-related challenges highlight the need to evaluate the adequacy of the equipment used in learning activities (Feng et al., 2025). Furthermore, the involvement of instructor-related factors indicates that successful implementation depends not only on technical infrastructure but also on effective instructional guidance and support throughout the learning process. Therefore, improvements in software and hardware quality, enhancement of user-friendly features, and strengthening of instructor competencies through training and comprehensive learning guidelines are essential to maximize the effectiveness of CNC simulator-based learning. From the perspective of Diffusion of Innovation Theory, reducing these technical and instructional barriers can decrease the perceived complexity of the innovation and support its broader adoption among students.

Triabilitas

Trialability was assessed by examining the duration of Swansoft CNC Simulator usage, the contexts in which the simulator was utilized, and students' knowledge of Virtual Reality (VR) technology.

Table 3. Trialability Assessment Data

Category	Frequency (n)
Duration of Swansoft Usage	
One Semester	30
One Month	1
One Week	1
Usage Context	
Classroom Practical Sessions	25
Self-Directed Learning	12
Competency Assessment or Examination	4
Training or Workshop	6
Knowledge of Virtual Reality (VR)	
Yes	30
No	2

Based on Table 3, the majority of students had used the Swansoft CNC Simulator for one semester, representing 30 out of 32 respondents (93.75%), while only one student (3.13%) had used it for one month and one student (3.13%) for one week. Regarding the context of use, classroom practical sessions were the most common activity, followed by self-directed learning (43.75%), training or workshops (18.75%), and competency assessments or examinations (12.5%). These findings indicate that Swansoft has been widely integrated into various CNC learning activities and serves not only as a practical training tool but also as a medium for independent learning and competency evaluation. Furthermore, most students (93.75%) were familiar with Virtual Reality (VR) technology, whereas only

6.25% had no prior knowledge of VR. This high level of awareness suggests considerable potential for integrating VR into future CNC learning environments. The findings indicate that the consistent and diverse use of Swansoft has supported students' competency development while creating opportunities for the adoption of VR to provide more immersive and realistic learning experiences |(Chernikova et al., 2020; Yang et al., 2024b). Nevertheless, additional educational efforts are needed for students who are less familiar with VR, and further studies should investigate the effectiveness of integrating VR with CNC simulation technologies to enhance learning outcomes and industrial readiness (Smith & Saunders, 2009). From the perspective of Diffusion of Innovation Theory, the extensive use of Swansoft across different learning contexts demonstrates a high level of trialability, which positively contributes to the adoption and acceptance of the technology among students .

Observabilitas

Observability was assessed based on students' preferences for CNC learning methods, the frequency of discussions regarding the use of the Swansoft CNC Simulator with instructors and peers, the accessibility of information related to the simulator, and students' recommendations concerning the use of CNC simulation and Virtual Reality (VR) technologies in learning.

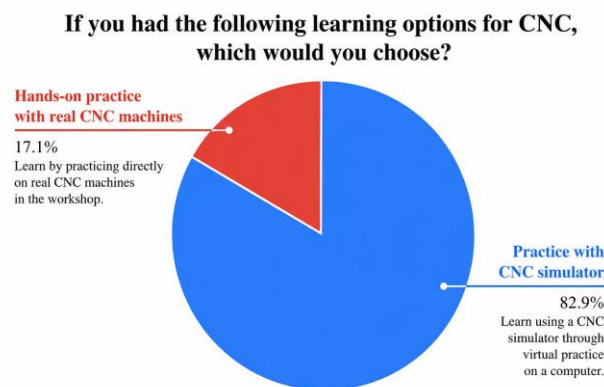


Figure 10. Students' Preferred CNC Learning Method

Based on Figure 10, the majority of students demonstrated a strong preference for practical learning methods in CNC education, with 82.9% of respondents selecting practical training, while only 17.1% preferred other learning approaches. These findings indicate that students favor learning experiences that provide direct hands-on engagement, as such approaches are perceived to be more effective in developing conceptual understanding and technical competencies related to CNC machine operation. The strong preference for practical learning is consistent with experiential learning theory, which emphasizes that technical skills are acquired more effectively through active practice than through purely theoretical instruction. This finding is supported by (Kubat Assoc, 2025), who reported that hands-on learning significantly contributes to competency development in engineering and manufacturing education. However, implementing practical training often involves challenges related

to equipment availability, operational costs, and safety considerations. Therefore, integrating practical learning with supporting technologies such as CNC simulators and Virtual Reality (VR) may provide an effective alternative for improving the quality, accessibility, and efficiency of CNC education (Sucipto, 2024). From the perspective of Diffusion of Innovation Theory, the preference for practice-oriented learning highlights the importance of observable learning outcomes, suggesting that simulation technologies capable of demonstrating tangible benefits are more likely to be accepted and adopted by students.

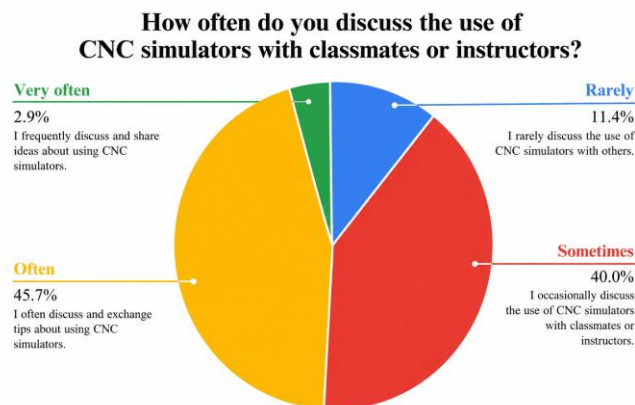


Figure 11. Frequency of Students' Discussions on the Use of the Swansoft CNC Simulator

Based on Figure 11, most students actively discussed the use of the Swansoft CNC Simulator with their peers and instructors, with 45.7% of respondents indicating that they *frequently* engaged in discussions, 40.0% *occasionally*, 2.9% *very frequently*, and only 11.4% *rarely* participated in discussions. These findings suggest that academic interaction related to CNC simulation has become an important component of the learning process, supporting both conceptual understanding and technological skill development. The high frequency of discussions reflects a collaborative learning environment in which knowledge sharing and experience exchange contribute positively to learning effectiveness (Scager et al., 2016). However, a small proportion of students reported limited participation in discussions, which may be associated with restricted access to information, lower motivation, or insufficient awareness of the benefits of academic collaboration. Therefore, educational strategies such as discussion-based assignments, collaborative learning activities, and interactive teaching approaches should be strengthened to maximize the educational benefits of CNC simulation technology and further enhance student competencies (Freeman et al., 2014). From the perspective of Diffusion of Innovation Theory, frequent communication among students and instructors increases the observability of innovation outcomes and supports the wider adoption of educational technologies .

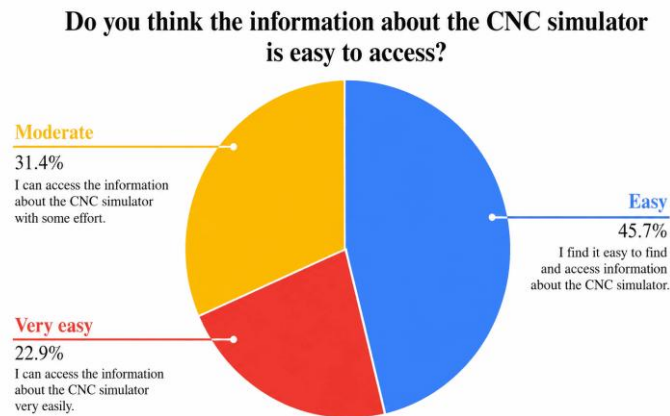


Figure 12. Accessibility of Information Related to the Swansoft CNC Simulator

Based on Figure 12, most students perceived information related to the Swansoft CNC Simulator as readily accessible. Specifically, 45.7% of respondents rated information accessibility as *easy*, 31.4% as *moderate*, and 22.9% as *very easy*. These findings indicate that the majority of students encounter few difficulties in obtaining information about the simulator, suggesting that relevant learning resources are generally available and accessible. This result is consistent with advancements in digital technologies that facilitate access to technical information and educational resources (Bond et al., 2021). The high proportion of students who rated accessibility as *easy* or *very easy* suggests that both online and offline learning materials are sufficiently available to support CNC learning. Nevertheless, the presence of respondents who selected the *moderate* category indicates opportunities for improvement, particularly in expanding access to localized learning resources, increasing formal training opportunities, and enhancing information dissemination strategies. Therefore, further efforts should focus on strengthening digital learning platforms, developing more structured instructional materials, and improving outreach activities to ensure broader and more equitable access to CNC simulation resources. From the perspective of Diffusion of Innovation Theory, the availability and accessibility of information contribute to the observability of an innovation, facilitating greater awareness, understanding, and eventual adoption among potential users.

Table 4. Sources of Information on the Swansoft CNC Simulator

Source of Information	Frequency
YouTube	Very Frequently
Official Simulator Website	Frequently
Peers/Classmates	Frequently
Instructors Only	Moderately Frequently
Social Media	Moderately Frequently
Other Sources	Rarely

Based on Table 4, students obtained information about the Swansoft CNC Simulator from various sources, with YouTube emerging as the most frequently used source, followed by the official simulator website, peers, instructors, social media, and other sources. These findings highlight the significant role of digital platforms in supporting learning and disseminating information related to CNC simulation technologies. The dominance of YouTube suggests that students prefer audiovisual resources because they facilitate a more practical and accessible understanding of simulator functions and CNC concepts, which is consistent with trends in technology-enhanced learning (Greeves & Oz, 2023). However, reliance on online resources that may not always be verified can increase the risk of misinformation or incomplete understanding. Therefore, the continued involvement of instructors, peer discussions, and official sources remains essential to ensure the accuracy and reliability of learning materials. Integrating digital learning resources with structured academic guidance can further enhance the effectiveness and credibility of CNC simulator-based learning (Wu et al., 2009). From the perspective of Diffusion of Innovation Theory, the availability of multiple information channels increases the observability of the innovation and facilitates its dissemination among potential users .

Students' Recommendations for the Implementation of Virtual Reality and CNC Simulation Technologies in Learning

Based on the survey results, students provided several recommendations to improve the effectiveness of CNC simulation-based learning. The most common recommendation was to combine simulator-based learning with hands-on practice using actual CNC machines to reduce the gap between virtual simulation and real industrial environments. Students also expressed strong interest in integrating Virtual Reality (VR) and Augmented Reality (AR) technologies to create more immersive, interactive, and industry-relevant learning experiences aligned with the requirements of Industry 4.0. Additional suggestions included providing institutionally licensed versions of the simulator, developing more structured learning modules, extending simulator usage time, and organizing dedicated classes or discussion forums to support deeper learning. These findings indicate that students generally hold positive perceptions of the role of CNC simulators in education but recognize opportunities for improvement in terms of technological features, learning facilities, and instructional strategies. Therefore, educational institutions should consider integrating simulation technologies with practical training, providing access to official software resources, and developing more comprehensive technology-based curricula to maximize the educational benefits of CNC simulators and VR technologies in manufacturing education. From the perspective of Diffusion of Innovation Theory, these recommendations reflect students' expectations for innovations that are more compatible with their

learning needs, easier to observe in practice, and capable of providing greater relative advantages in technical education .

CONCLUSION

This study evaluated the effectiveness of the Swansoft CNC Simulator in CNC learning by examining its relative advantage, compatibility, complexity, trialability, and observability based on Rogers' Diffusion of Innovation Theory. The findings indicate that the simulator provides substantial benefits in supporting CNC education through its ability to accurately simulate machining processes, enhance students' understanding of CNC programming and machine operation, and offer a safe learning environment without requiring direct access to physical CNC equipment. Students generally perceived the simulator as beneficial, compatible with their learning needs, easy to use, and effective in improving both conceptual understanding and technical skills. The widespread use of the simulator across various learning contexts and the positive perceptions regarding information accessibility further demonstrate its strong potential for adoption in vocational and engineering education.

The study also revealed that the primary challenges associated with the simulator involve software-related issues, hardware limitations, and the need for adequate instructional support. Although the simulator effectively facilitates learning, it cannot fully replicate the tactile experience, machine feedback, and complex operational conditions encountered when using actual CNC machines. Consequently, simulation-based learning should be complemented by hands-on practical training to ensure the development of comprehensive technical competencies and problem-solving skills required in industrial environments.

Furthermore, the high level of student interest in Virtual Reality (VR) suggests promising opportunities for integrating immersive technologies into CNC education. The incorporation of VR has the potential to enhance learning experiences by providing more realistic, interactive, and industry-oriented training environments. Therefore, educational institutions should consider integrating CNC simulation technologies with practical training, expanding access to official software resources, and developing technology-enhanced curricula that incorporate VR and other emerging technologies. Overall, the Swansoft CNC Simulator represents an effective and accessible learning tool that can contribute significantly to improving CNC education and preparing students for the technological demands of modern manufacturing industries.

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