

Optimization of Task-Centered Instructions in Computer Numerical Control Cutting Paths for Woodwork Technology Training

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Abstract

The main purpose of the study was to optimize Task-centered Instructions in Computer Numerical Control (CNC) Cutting Paths for Woodwork Technology Training. To guide the study three objectives, three research questions were formulated to guide the study. The study adopted Research and Development Design (R and D). The population was 66 respondents, comprising of 27 woodwork technology/wood product Engineering lecturers, 15 woodwork technology/wood product Engineering technologies, supervisors, and 12 woodwork technology/wood product Engineering technicians. The sample size for the study was 56, (86.2%) of the population. One instrument was used for this study was 63 researcher-developed instrument titled: Task Instructions in CNC Cutting Paths for Woodwork Technology Training Questionnaire was used for data collection for the study. The is a five-point Likert scale with response options scored thus: Highly Appropriate (HA), Moderately Appropriate (MA), Appropriate (A), Lowly Appropriate (LA), Not Appropriate (NA), with assigned values of 5,4,3,2, and 1 respectively. The instrument was validated by six experts for face-validation, content-validation and dacum-validation. Cronbach's Alpha statistical tool was used to calculate the internal consistency of the instrument which was established at 0.88. the Mean and Standard Deviation statistics was used to answer the research questions, while factorial analysis was used to determine the experts rating and Pearson Product Moment Correlation (PPMC) was used to test for the Inter-Rater Reliability of the Package. The study revealed that out of 63 task instructional items 3 were discarded and 60 were found appropriate for inclusion in the CNC task instructional package. The content validity ratio was high there the package was appropriate for use in training. In conclusion all Woodwork Lecturers, Technologies, Supervisors, and Technicians agreed that the identified Tasks and Subtasks had a high reliability coefficient, hence it was deemed fit for use.

Keywords: CNC, Cutting-paths, Task Woodwork Technology.

Introduction

Technical/technology education plays a crucial role in equipping individuals with practical skills and knowledge essential for job creation and economic growth. As industries evolve with advancements in automation, artificial intelligence, and digital transformation, there is a growing demand for a skilled workforce capable of innovation and entrepreneurship. The rapid technological advancements of the 21st century have significantly influenced technical and vocational education and training (TVET) programmes worldwide. These advancements, particularly in automation and digital manufacturing technologies such as Computer Numerical Control (CNC), have redefined the skill

requirements for industries such as building construction and woodworking. CNC technology, which allows for precise control of machinery through programmed instructions, has become a vital component of modern production processes, making it an indispensable part of training curricula for students in building and woodwork technology. (Prasetyo *et al.*, 2023). CNC technology has revolutionized manufacturing and construction processes by enabling high precision, efficiency, and repeatability. In the building and woodworking industries, CNC machines are used for various applications, including cutting, carving, drilling, and engraving complex patterns or designs. Unlike traditional manual methods, CNC operations rely on computer-aided design (CAD) and computer-aided manufacturing (CAM) software to create digital blueprints that guide machine movements, (Gunderson *et al.*, 2022).

This shift towards automation demands a workforce that is proficient in operating CNC machines, programming codes, interpreting designs, and equipment maintenance. Subsequently, the introduction of CNC training into building and woodworking education is critical for preparing trainees to meet these new demands. CNC training programmes must provide trainees with both theoretical knowledge and hands-on experience in methods of automatically operating a manufacturing machine based on a code of letters, numbers, and special characters (Chen *et al.*, 2024). Almost all current CNC controls use a word address format for programming except for certain conversational controls. Word address format, the CNC program is made up of sentence-like commands. Each command is made up of CNC words. Each CNC word has a letter address and a numerical value such as (X, Y, Z,) that tells the control the kind of word and the numerical value tells the control the value of the word. Words in a CNC command tells the CNC machine what type of operation to embark upon. These operations are to ensure that trainees are competent and ready for employment in modern industry settings. (Prasetyo *et al.*, 2023).

Task analysis is a systematic process of breaking down a job or activity into its component tasks to identify the specific skills, knowledge, and tools required to perform it effectively. Task analysis is an observation method that divides goals into smaller subtasks. The task analysis process applies to numerous industries and can improve the efficiency of goal-setting, employee training and task completion. Learning what task analysis is and how one can apply it to work can help improve the daily operations of a workplace (OECD, 2019). In the context of CNC training, task analysis involves examining and identifying steps in: the entire workflow of CNC operations, interpreting CAD designs, setting up machines, executing programmed tasks and troubleshooting errors. Incorporating task analysis in developing skills for application for CNC the training programme of the woodworking technology.

Task analysis can be applied to improve CNC training in the following ways:
Curriculum Design: Using task analysis to identify and prioritize the skills required for CNC operations ensures that the curriculum covers all essential competencies in a logical sequence.

Training Modules: Breaking down CNC tasks into smaller components allows for the creation of focused training modules, such as machine setup, software programming, or safety protocols.

Assessment Criteria: Task analysis provides a clear framework for evaluating students performance based on their ability to complete specific tasks efficiently and accurately.

Resource Allocation: By understanding the specific requirements of CNC training centers can allocate resources more effectively, focusing on acquiring essential equipment and materials.

Instructor Training: Task analysis highlights the areas where instructors may need additional training, ensuring they are equipped to deliver comprehensive CNC education.

The incorporation of CNC training into the woodwork technology programmes offered by the schools has the potential to significantly enhance trainees' employability. Skilled CNC operators are in high demand across various sectors, including furniture manufacturing, construction, and industrial design. In addition to employment opportunities, CNC training equips individuals with the skills needed to establish their own businesses, promote entrepreneurship and contribute to economic development. (Nasir, 2022). Moreover, the implementation of CNC technology in the building and woodworking industries will improve production efficiency, reduce material waste, and enhance the quality of finished products. By preparing trainees to operate and maintain CNC machines, the schools can play a pivotal role in driving innovation and competitiveness within these industries. Task analysis serves as a vital tool in this process, enabling the development of targeted training curricula that equip students with the skills needed to thrive in the workforce. For the training centers, leveraging task analysis to enhance CNC training not only addresses the skills gap but also contributes to broader goals of reducing unemployment and fostering economic growth. By overcoming the challenges associated with infrastructure, curriculum development, and instructor training, the centers can ensure that its programmes remain relevant and impactful in an increasingly technology-driven world.

CNC machining woodwork offers numerous advantages over traditional woodworking techniques. One of the primary benefits is precision. CNC machines can execute intricate designs with incredible accuracy, ensuring that each piece is consistent and meets the desired specifications. This level of precision is challenging to achieve with manual woodworking methods. Efficiency is another significant advantage of CNC machining wood. The automated process allows for faster production times, reducing the overall time required to complete a project. This increased efficiency is particularly beneficial for large-scale production, where time is a critical factor. Consistency is also a key benefit of CNC machining wood. Each piece produced by a CNC machine is identical to the others, ensuring uniformity in the final product. This consistency is essential for projects that require multiple identical parts, such as furniture or cabinetry, (Gomez-Torres, 2021). When it comes to CNC machining wood, selecting the right type of wood is crucial for achieving optimal results

According to Peters, (2017) appropriate cutting tool selection task is the process of choosing the most suitable type, size, geometry, and material of cutting tools (such as router

bits, drills, end mills, and saw blades) to achieve the desired surface quality, dimensional accuracy, and production efficiency. The right tool choice ensures clean cuts, reduced tool wear, minimal defects, and optimal machining speed, while an unsuitable tool can cause tear-out, burning, chatter and excessive waste.

Appropriate header section selection task are the main sections or blocks in a CNC program that contain the setup instructions, operational parameters, and identification details required before the machining process begins. Selecting the appropriate header sections means ensuring that the CNC program includes all necessary preparatory codes, information, and structure relevant to the specific wood machining task. A CNC header section acts as the instruction front page of a machining program. It tells the CNC system what to prepare for, which tools to use, how to start operations, and the parameters under which the process will run. (Kalpkjian & Schimd, 2018).

Appropriate cutting parameters task are the specific machining settings, such as spindle speed (RPM), feed rate, depth of cut, and step-over, that control how the cutting tool interacts with the wood materials. Appropriate cutting parameter selection means determining the optimal combination of these variables to achieve high-quality finishes, dimensional accuracy, and efficient material removal while minimizing tool wear, heat buildup, and defects such as tear-out or burning. (Walker, 2018).

The selection of cutting tools is crucial for successful CNC machining wood. Different types of cutting tools are designed for specific tasks, and choosing the right tool can significantly impact the quality of the final product. Common types of cutting tools used in CNC machining wood include router bits, end mills, and drill bits. Router bits come in various shapes and sizes, each designed for specific cutting and carving tasks. For example, spiral bits are ideal for straight cuts, ball nose bits are perfect for 3D carving and contouring, and V-bits are preferred for lettering and engraving. End mills, typically used for milling operations, are available in different diameters, flute configurations, and cutting lengths. Choosing the right end mill depends on the material being machined and the desired finish. Drill bits are used for creating holes and come in various sizes and types, each suited for specific applications.

The material of the cutting tool is another critical factor to consider. Cutting tools made of High-Speed Steel (HSS) and carbide are commonly used for CNC machining wood. HSS tools are affordable and suitable for general-purpose machining, but they tend to wear out faster than carbide tools. Carbide tools are more expensive but offer superior performance and durability. They can withstand higher cutting speeds and are more resistant to wear and heat, making them ideal for machining hardwoods and other tough materials. For the best results, it is essential to choose cutting tools that are sharp and well-maintained. Dull tools can result in poor cut quality, increased heat generation, and potential damage to the work-piece.

Research Objectives

The study was to Optimize Task-centered Instructions in Computer Numerical Control (CNC) Cutting Paths for Woodwork Technology training. Specifically, the study was to:

- i. Determine task instructions in CNC Cutting Tools Selection for Woodwork Technology training.
- ii. Determine task instructions in CNC Header Section Selection for Woodwork Technology training.
- iii. Determine task instructions in CNC Cutting Parameters Selection for Woodwork Technology training.

Research Questions

- i. What are task instructions in CNC Cutting Tools Selection for Woodwork Technology training?
- ii. What are task instructions in CNC Header Section Selection for Woodwork Technology training?
- iii. What are task instructions in CNC Cutting Parameters Selection for Woodwork Technology training?

Methodology

Research and Development (R and D) design was adopted for the study. Developmental study is useful when developing new methods and processes for implementing existing models or using existing tools. The area of the study is South-South Nigeria. The geopolitical zone of southern Nigeria is the subject of the research it encompasses the geographical landmass of six states: Cross River State, Akwa Ibom State, Rivers State, Bayelsa State, Delta State, and Edo State. The study population were all lecturers, Technologists, Supervisors and Technicians in woodwork Technology units in Departments of vocational education, Industrial technology Education, Vocational and Technical Education, Technology Education, Wood product Engineering and Supervisors in woodwork training centers with a total population of 66 in South-South, Nigeria. The sample size was 56 from the three sample states; Lecturers 25, Technologists 13, Supervisors 7, and Technicians 11. Purposive sampling technique was used to sample the States. Thereafter, sample random sampling and Krejci Morgan table was used to select the respondents. One instrument was used for this study was 63 researcher-developed instrument titled: Task Instruction in CNC Cutting Paths for Woodwork Technology Training Questionnaire was used for data collection for the study. The is a five-point Likert scale with response options scored thus: Highly Appropriate (HA), Moderately Appropriate (MA), Appropriate(A), Lowly Appropriate (LA), Not Appropriate (NA), with assigned values of 5,4,3,2, and 1 respectively. The instrument was validated by six experts for face-validation, content-validation and dacum-validation. Cronbach's Alpha statistical tool was used to calculate the

internal consistency of the instrument which was established at 0.88. the Mean and Standard Deviation statistics was used to answer the research questions, while factorial analysis was used to determine the experts rating and Pearson Product Moment Correlation (PPMC) was used to test for the Inter-Rater Reliability of the Package.

Results

Table1: Summary of factorial analysis of expert's ratings of the tasks to be included in the Instruction in CNC cutting paths for Woodwork Technology training (N=56)

S/N	Task Area	Number of Items Selected	Number of Items Discarded	Remarks (Number of Items Included)
1	Cutting Tools Selection Task in CNC	23	2	21
2	Header Sections Selection Task in CNC	18	0	18
3	Cutting Parameters Selection Task in CNC	22	1	21
Total	All Task Areas	63	3	60 Coolant-Spindle Control Selection Task in CNC

Source: Field work (2025) SPSS generated. ($X \geq 2.5$ Appropriate, $X \leq 2.5$ Not Appropriate)

The result in Table 1 shows a summary of the Principal Component Analysis (PCA) experts' ratings of the developed instructional package. It indicates that out of 63 items, 60 items relating to Woodwork skills have mean responses above 2.50 and factor loading of 0.40 and above, signifying that they are considered by the respondents (experts) as being appropriate and are, therefore selected for inclusion. Three items had factor loadings below 0.40 and were thus, discarded. Thus 60 items were found to be appropriate for inclusion in the instructional packages.

Table 2: Summary of Mean and Standard Deviation of Responses on Items included in the Task instructions N=56

S/N	Item	Mean	SD	Remark
Cutting Tools Selection Task in CNC				
1	Selecting tools based on wood type	3.72	0.35	Appropriate
2	Selecting process based on operation type	3.65	0.42	Appropriate
3	Selecting carbide tools for durability	3.58	0.45	Appropriate
4	Selecting carbide tools for performance	3.68	0.38	Appropriate
5	Selecting high-speed steel for durability	2.85	0.62	Low Appropriate
6	Selecting high-speed steel for performance	2.35	0.68	Not Appropriate
7	Selecting diamond-tipped tools for durability	3.45	0.52	Appropriate
8	Selecting diamond-tipped tools for performance	3.55	0.48	Appropriate
9	Choosing flat-end ball-nose bits	3.78	0.30	Appropriate
10	Choosing V-bit based on cut type	3.65	0.42	Appropriate

11	Choosing bit types based on cut type	3.55	0.48	Appropriate
12	Matching tool diameter with design	3.82	0.28	Appropriate
13	Selecting upcut bits for chip evacuation	3.45	0.52	Appropriate
14	Selecting upcut bits for clean edges	3.58	0.45	Appropriate
15	Selecting upcut bits for both edges	2.38	0.61	Not Appropriate
16	Selecting tools machine can handle	3.75	0.32	Appropriate
17	Rating feed for optimal performance	3.65	0.42	Appropriate
18	Using coated tools for extended life	3.55	0.48	Appropriate
19	Using coated tools to reduce friction	3.45	0.52	Appropriate
20	Checking tool length for deep cuts	3.68	0.38	Appropriate
21	Performing test cuts	3.82	0.28	Appropriate
22	Adjusting settings for accuracy	3.72	0.35	Appropriate
23	Adjusting settings for finishing	3.65	0.42	Appropriate
Header Sections Selection Task in CNC				
24	Selecting the appropriate header for the operation	3.72	0.35	Appropriate
25	Selecting air-cooled spindles based on needs	3.65	0.42	Appropriate
26	Selecting water-cooled spindles based on workload	2.85	0.62	Appropriate
27	Selecting the cooling needs	3.58	0.45	Appropriate
28	Matching spindle horsepower with range	3.45	0.52	Appropriate
29	Matching materials with range	2.75	0.68	Low Appropriate
30	Matching tool type with range	3.55	0.48	Appropriate
31	Choosing appropriate collet holders	3.78	0.30	Appropriate
32	Deciding on tool changer need	3.95	0.38	Appropriate
33	Opting spindle for required tool diameters	3.68	0.38	Appropriate
34	Opting spindle for shank sizes	3.55	0.48	Appropriate
35	Sorting for built-in dust extraction ports	2.65	0.72	Low Appropriate
36	Selecting protective guards	3.82	0.28	Appropriate
37	Selecting header compatible with CNC controller	3.45	0.52	Appropriate
38	Selecting header compatible with CNC software	3.58	0.45	Appropriate
39	Running tests for spindle stability	3.75	0.32	Appropriate
40	Running tests for tool accuracy	3.78	0.35	Appropriate
41	Running tests for cutting efficiency	2.85	0.62	Low Appropriate
Cutting Parameters Selection Task in CNC				
42	Adjusting settings based on wood type	3.72	0.35	Appropriate
43	Setting parameters based on tool diameter	3.85	0.25	Appropriate
44	Setting parameters based on flute type	3.55	0.48	Appropriate
45	Setting parameters based on coating	2.65	0.72	Low Appropriate
46	Adjusting spindle speed for material hardness	3.78	0.30	Appropriate
47	Adjusting tool type for material hardness	3.65	0.42	Appropriate
48	Setting tool movement speed	3.45	0.52	Appropriate
49	Setting balancing speed	1.88	0.92	Not Appropriate
50	Setting surface quality	3.58	0.45	Appropriate
51	Marking depth per pass (machine power)	3.68	0.38	Appropriate
52	Marking tool strength per pass	2.75	0.68	Low Appropriate
53	Setting tool path overlap (30-50%)	3.82	0.28	Appropriate
54	Setting tool entry speed	3.55	0.48	Appropriate
55	Choosing smooth entry	3.45	0.52	Appropriate
56	Choosing climb milling	3.78	0.30	Appropriate
57	Choosing conventional milling	2.85	0.62	Low Appropriate
58	Calculating chip load to prevent burning	3.65	0.42	Appropriate
59	Calculating chip load to prevent chipping	3.58	0.45	Appropriate
60	Trial pass for burning/chipping	3.95	0.58	Appropriate

62	Trial pass for chipping	3.45	0.52	Appropriate
62	Trial pass for tool deflection	2.55	0.75	Low Appropriate
63	Refining cutting parameters	3.72	0.35	Appropriate

Source: Field work (2025) SPSS generated. ($X \geq 2.5$ Appropriate, $X \leq 2.5$ Not Appropriate)

Table2 shows the summary of teachers' experts and woodwork practioners responses on the suitability of the woodwork skills pool items for inclusion in the instructional package. The result shows that 60 items have mean responses above 2.50 while 3 items have mean responses below 2.50. Thus, majority of the woodwork practitioners agreed that all 60 items be included in the task instructions. The standard deviation of the items ranges from 0.25 to 0.92 and were not too far from the mean.

Conclusion

Based on the findings of the study, it was concluded that 21 out of 23 tasks that characterize Cutting Tools Selection Task in CNC were relevant for inclusion in the training package; Moreso, all the 18 Header Section Task in CNC were relevant for inclusion in the training package; and 21 out of 22 tasks that characterize Cutting Parameter Selection Task CNC were relevant for inclusion in the training instructions.

Recommendations

Based on the findings of the study, the researcher recommends the following:

- (i) Skill trainers, especially those teaching woodwork technology and other technical and vocational courses/subjects, should adopt CNC task instructional package woodwork to enhance trainees' psychomotor achievements of learning.
- (ii) Trainers and trainers should break away from the analog of instruction and ensure the instruction is digital and become trainee and computer aided learning oriented as exemplified in the use of CNC task instructional package in woodwork/furniture technology.
- (iii) Skill trainers should develop interest in the use of CNC task instructional package in woodwork/furniture technology.

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