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Lessons Learned from an Intelligent Tutoring System for Computer Numerical Control Programming (CNC Tutor)

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Advances in CAD/CAM software and CNC machining have made the transition of design and machining seamless. Once a part is designed in a CAD format and a user specifies the machine tool needed for each machining pass, the CAD/CAM software can generate the G-code and the G-code can be fed into the CNC machine directly without any delay. There is no need to write G-code for each machining job. However, understanding G-code is still valuable, especially when a machining job does not run smoothly. Intelligent tutoring systems (ITS) have been shown to be successful in helping students to learn about math and physics subjects. However, relatively few ITS have been used to teach engineering subjects. The objectives of the paper are to (1) create an intelligent tutoring system to teach basic understanding of G-code, and (2) evaluate the learning gains from the system, and (3) summarize lessons learned from the implementation. The system has been evaluated by 91 undergraduate students. Results suggest that the CNC Tutor design is instructionally effective and that students' subjective impressions of the system are positive. It appears that we may continue to develop similar types of Intelligent Tutoring Systems for other engineering subjects. It also appears that CNC Tutor's explanations and feedback are a good fit for active, visual learners. Possible enhancements include the addition of more video and/or simulations to help learners to visualize abstract concepts,

Introduction

Intelligent tutoring systems (ITS) are computer-based teaching environments that incorporate mathematics, cognitive science, natural language processing, and human-computer interaction [1]. In recent years, the use of ITS in classrooms and communities has increased and they have proved to be very effective. For example, the Cognitive Tutor developed by Carnegie Learning which aims to help students learn algebra was used by more than 1,700 schools in 2004 [2].

There are a few attempts in ITS development for programming. BITS [3] is a Bayesian intelligent tutoring system for computer programming. It uses Bayesian network to represent the structure of the problem as well as the students' knowledge. A Bayesian network consists of a directed acyclic graph (DAG) and a conditional probability distribution (CPD) table. The main functions that BITS provides are navigation support, prerequisite recommendations, and learning sequence generation. Another tutoring system for programming, QuizJET [4], is a system that supports authoring, delivery and assessment of parameterized questions for Java programming. Parameterized questions are a pattern of questions that are created initially by domain experts, and the pattern is replaced by randomly generated parameters at the presentation time. The advantage of this approach is that the authoring cost is significantly reduced and the possibility of plagiarism is also reduced. QuizPACK (Quizzes for Parameterized Assessment of C Knowledge) [5], is a similar system for the C programming language. JO-Tutor [6] is another ITS for Java. It can generate problems automatically based on randomly instantiated templates. The topics of the problem include functions, classes, inheritance, polymorphism, and so on. It also has an expert module to solve these problems so as to judge the response and provide feedback. So far, relatively few Intelligent Tutoring Systems have been developed in the engineering domain. Hsieh [7] used an ITS authoring tool called XAIDA to develop a tutorial on how to use a computer numerical control (CNC) machine. Cheng [8] developed Intelligent Tutoring System for Programmable Logic Controller ladder logic programming. CNC Tutor adds a “Hint module” to provide necessary information to inform the users about the questions and how to solve the problem presented - developing CNC G-code to complete a task.

System Development

In the domain of computer numerical control, there are two types of knowledge students need to learn. One is concepts and facts, and the other is problem solving skill. CNC Tutor consists of a learning module, a quiz module, and an exercise module. The learning module and the quiz module are focused on teaching concepts and facts, while the exercise module focuses on improving the students’ problem solving skills. Under these three modules are two data models: one is the domain model and the other is the student model. The domain model manages all the data related to the domain knowledge, for example, what is the prerequisite of a lesson, how to generate questions for a lesson, what are the answers and feedback for a question, and so on. The student model traces the students’ state, such as whether a student has passed a quiz and how many facts a student already knows. In addition, in order to evaluate the students’ CNC code and generate hints and feedback, there is a model called CNC interpreter under the exercise module. Figure 1 shows the opening screen of CNC Tutor. It is open to everyone who registers and obtains an access key. Figure 2 illustrates the overall system architecture of CNC Tutor and modules involved in the system.

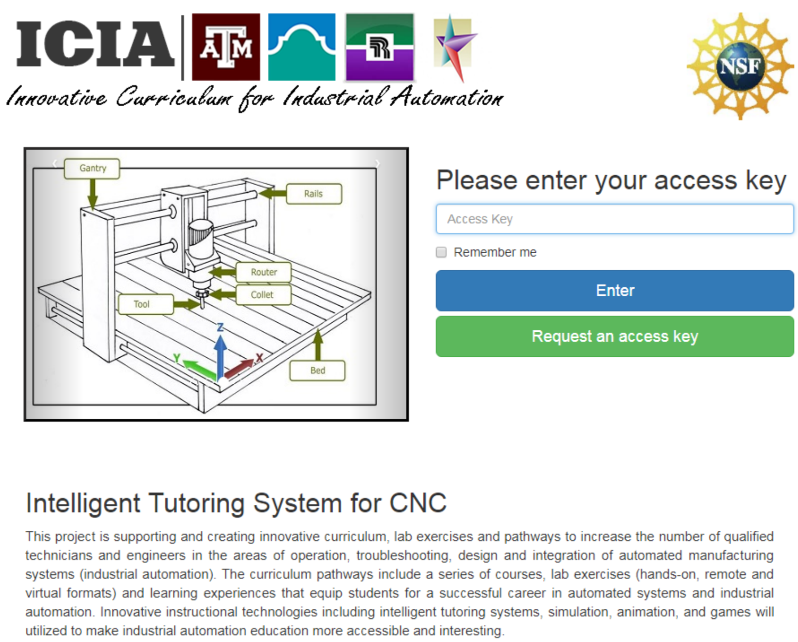


Figure 1. Opening screen of CNC Tutor.

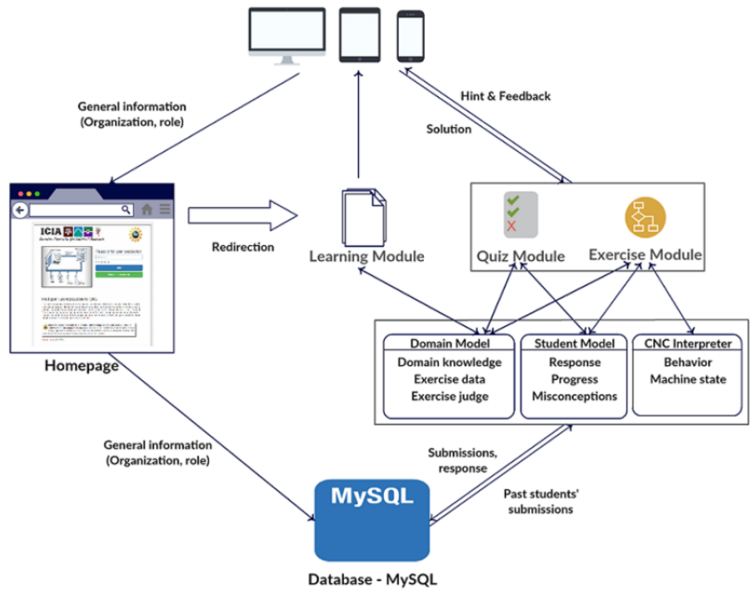


Figure 2. CNC Tutor system architecture.

Methodology

The developed CNC Tutor was evaluated by two group of undergraduate students to determine:

- Does CNC Tutor help students to learn more about CNC programming?
- Student opinions about various aspects of the tutor, such as its ease-of-use and relevance to their education.
- Student comments

Participants. CNC machining is covered in a CAD/CAM and Production System course with emphasis on different kinds of CNCs and functionality during lecture. The lab exercises focus on CAM software and the use of various machining tools. G-code is taught briefly after the code is generated using CAM software (FeatureCAM). CNC Tutor is used to supplement the course. Two groups of undergraduate students participated in this study. The first group consisted of junior-level students who took the CAD/CAM and Production System course about one semester prior and the second group consisted of senior level students who took the CAD/CAM and Production System students about one year prior. Evaluation activities took place during the last lab of the semester and participation was voluntary. There were nine labs of students.

Materials. Evaluation instruments included two parallel eight-item tests with seven multiple-choice and one programming questions and an opinion survey. The survey asked students to rate various characteristics of the prototype on a 7-point Likert scale. Figure 3 contains two sample questions—one from the test and one from the opinion survey.

SAMPLE TEST QUESTION

1. The G code for clockwise arc profiles is ______.

a). G0 b). G1 c). G2 d). G3

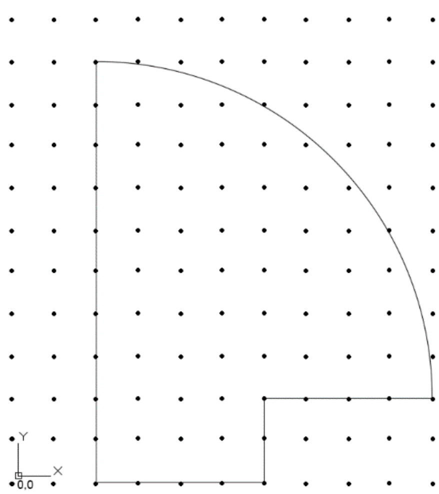
2. Write a program to drill 2 holes on the left and cut along the path on the right. The beginning and end of the program are given.

Operation	Profile mill contour
Tool	1
Depth	0.52 inch
Speed(rpm)	1200
Feed(ipm)0	8

N0010 G40 G80 (cancel cutter diameter compensation and fixed cycles)
N0020 G28 X0 Y0 Z0 (return to reference point)
(Write your code in this space)

N0210 G91 G28 Z0 Y0 (rapid move to XYZ reference point)
N0220 M30 (program end, memory reset)

Each : : = 0.5 inch



SAMPLE OPINION SURVEY QUESTION

I would like to have more courseware like this available to help me learn.

Strongly disagree **1 2 3 4 5 6 7** Strongly agree

Figure 3. Sample questions from tests and opinion Survey.

Procedure. Because the instructional effectiveness of CNC Tutor was unknown and because we did not want the evaluation activities to interfere with students' learning, the evaluation activities were treated as additional lab activities. To avoid confounding learning progress obtained because of the lecture with that resulting from use of the prototype, we evaluated students' knowledge immediately before and after using the prototype. Figure 4 shows the sequence of the evaluation activities

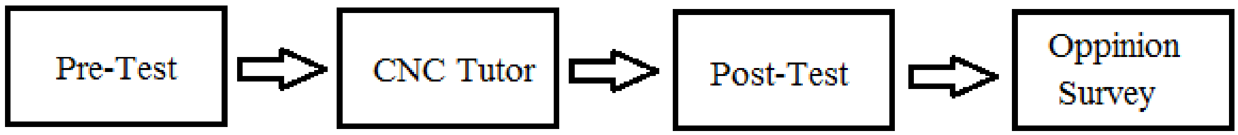


Figure 4. Evaluation event sequence.

Data Analysis and Results. This section summarizes the data gathered using the methodology described in the previous section. Results are presented in terms of instructional effectiveness (as measured by the two tests), student attitudes (as measured by the opinion survey), and student comments.

Test Data. We analyzed the test data to see if there was statistically significant score improvement between tests. The null hypothesis H_o was that there would be no change. Wilcoxon signed-rank two-tailed tests were performed to compare student performance on Test 1 (before prototype) with Test 2 (after prototype). The analysis was performed for two different groups of students. The analysis results revealed that the null hypothesis was rejected for all two groups of students. This suggests that CNC Tutor use caused significant improvement in learning.

Table 1 summarizes the test statistics, critical value and conclusions for each test, where the null hypothesis is $\mu_d = 0$, sample size was 51, 42, and the α value is 0.05.

Table 1. Instructional effectiveness analysis results.

Before and After CNC Tutor	Test statistic*	Critical value	Conclusion
Group #1	-10.2568	2.0086	Reject Null Hypothesis
Group #2	-6.9896	2.0195	Reject Null Hypothesis

The pre- and post-test average values were 30.0784 and 62.4510 respectively for group #1 with sample size of 51 (the maximum test score was 100). Pre-test and post-test average values were 37.4524 and 62.6429 respectively for group #2 with sample size of 42. Group #2 (senior level students) out-performed group #1 (junior level students) on the pretest, 37.4524 to 30.0784, perhaps because they took the course before. The post-test scores for both groups—62.4510 (Group #1) and 62.6429 (Group #2) were almost identical. This may imply that CNC Tutor is efficient in teaching students the subject matter regardless of prior background. The learning gain was 32.4 for group #1 and 25.2 for group #2 (that is, a 25% to 32% improvement). The post-test scores for both groups were about 63 out of 100 possible points. This suggests that the pre and post-tests may have been too difficult; perhaps topics such as how to write a CNC program and programming concepts should be emphasized more in the CNC tutor.

Opinion Survey. We also computed means for the opinion survey. Figures 5 and 6 summarize these results. Student ratings were positive for all items. In general, students felt that the prototype was interactive, relevant, and easy to use and understand. Figure 5 shows the overall ratings of the first group and Figure 6 shows the overall ratings of the second group. The numbers from Group #1 (juniors) and Group #2 (seniors) were very similar, which suggests that CNC Tutor is appealing to students regardless of when they took the class. However, on question number #5, the average rating for seniors was 2% higher than for juniors. On question #4, the average rating for seniors was 4% higher than for juniors. On the other hand, on question #6, the average rating for seniors was 1% lower than for juniors. These data suggest that seniors appreciated CNC Tutor more, perhaps because they had already taken the class. Both the junior and senior ratings suggest that the practice questions need improvement. Overall, the CNC Tutor survey shows a positive impact of CNC Tutor on students' learning experience.

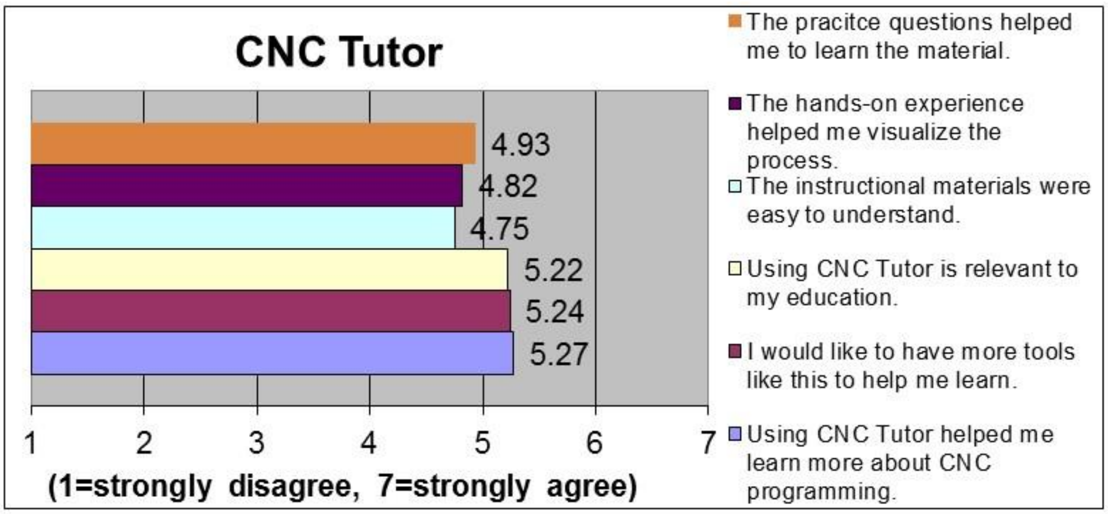


Figure 5. Survey summary for group 1 (Junior Level Students).

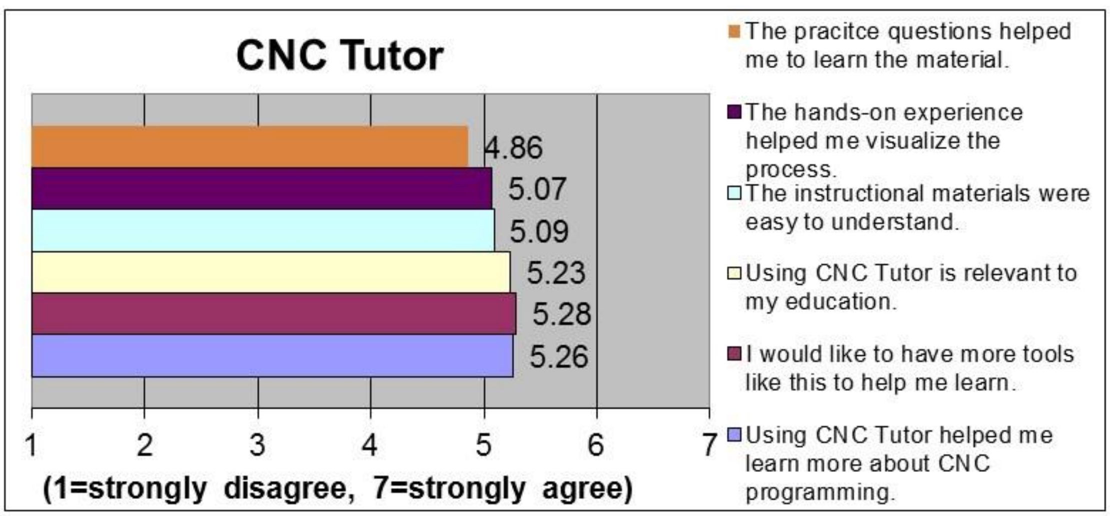


Figure 6. Survey summary for Group 2 (Senior Level Students).

Student Comments. Student comments can be summarized as follows: 1) Many students liked CNC Tutor; they felt concepts were well-explained; you can see the solution when you get a question wrong, and the materials were self-paced; 2) Some students suggested adding video and simulations to provide more visual learning; and 3) Overall, students thought the lessons were helpful and supplemented the lecture well.

Discussion and Lessons Learned

These results suggest that the CNC Tutor design is instructionally effective, and that students' subjective impressions of the system are positive; however the average post -test score is around 62 out of 100. Perhaps the test questions need to be modified to better align with CNC Tutor's test bank or a greater variety of practice questions are needed in the tutor test bank. It appears that we may safely continue to develop similar types of Intelligent Tutoring System for other engineering subjects. It also appears that CNC Tutor's explanations and feedback are a good fit for active, visual learners. Possible enhancements include the addition of more video and/or simulation tools to help visual learners in visualizing the abstract concepts.

Conclusion and Future Directions

This paper has described continuing steps in the process of developing an Intelligent Tutoring System, called CNC Tutor, to teach programming in G-code for CNC education. So far, evaluation results have been very encouraging. The average learning gain ranges from 25% to 32%. The post-test scores for both groups were about 63 out of 100 possible points. This suggests that the pre and post tests may have been too difficult; perhaps topics such as how to write a CNC program and programming concepts should be emphasized more in the CNC tutor.

In the student opinion survey, ratings by juniors and seniors were very similar, which suggests that CNC Tutor is appealing to students regardless when they took the class. However, on question number #5, the average rating for seniors was 2% higher than for juniors. On question #4, the average rating for seniors was 4% higher than for juniors. On the other hand, on question #6, the average rating for seniors was 1% lower than for juniors. These data suggest that seniors appreciated CNC Tutor more, perhaps because they had already taken the class. Both the junior and senior ratings suggest that the practice questions need improvement. Possible enhancements include the addition of more video and/or simulations to help learners to visualize abstract concepts.

Future plans include continuing to develop intelligent tutoring systems for engineering applications and embedding animations, simulations, and/or videos into future system designs to make abstract concepts easier to grasp.

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References

[1] Graesser, A.C., M. W. Conley, and A. Olney, Intelligent tutoring systems. Washington, DC: American Psychological Association, 2012.

[2] Koedinger , K. R., E. Brunskill, R. S. Baker, E. A. McLaughlin, and J. Stamper, “New potentials for data-driven intelligent tutoring system development and optimization,” AI Magazine, vol. 34, no. 3, pp. 27–41, 2013.

[3] Butz, C. J., S. Hua, and R. B. Maguire, “A web-based intelligent tutoring system for computer programming,” in Proceedings of International Conference on Web Intelligence, pp. 159–165, IEEE, 2004.

[4] Hsiao, I.-H., P. Brusilovsky, and S. Sosnovsky, “Web-based parameterized questions for object-oriented programming,” in Proceedings of World Conference on ELearning, E-Learn, pp. 17–21, 2008.

[5] Brusilovsky, P. and S. Sosnovsky, “Individualized exercises for self-assessment of programming knowledge: An evaluation of quizpack,” Journal on Educational Resources in Computing, vol. 5, no. 3, p. 6, 2005.

[6] Abu-Naser, S., A. Ahmed, N. Al-Masri, A. Deeb, E. Moshtaha, and M. AbuLamdy, “An intelligent tutoring system for learning java objects,” International Journal of Artificial Intelligence and Applications, vol. 2, no. 2, 2011.

[7] Hsieh, S., and P. Hsieh, “Intelligent tutoring system authoring tool for manufacturing engineering education,” International Journal Engineering Education, Vol. 17, No. 6, pp. 569 to 579, 2001.

[8] Hsieh, S. and Cheng, Y.T. “Algorithm and intelligent tutoring system design for programmable controller programming,” International Journal of Advanced Manufacturing Technology, 2014, Volume 71, Issue 5-8, pp 1099-1115.