

## **ESHOPPS: A COMPUTATIONAL TOOL TO AID THE TEACHING OF SHORTEST PATH ALGORITHMS**

S. J. de A. LIMA, W. L. da SILVA, S. A. de ARAÚJO\*

Industrial Engineering Post-Graduation Program, Universidade Nove de Julho,  
Av. Francisco Matarazzo, 612, Água Branca, 05001-100, São Paulo, SP, Brazil

\*Corresponding Author: saraujo@uninove.br

### **Abstract**

The development of a computational tool called EShoPPS – Environment for Shortest Path Problem Solving, which is used to assist students in understanding the working of Dijkstra, Greedy search and A\*(star) algorithms is presented in this paper. Such algorithms are commonly taught in graduate and undergraduate courses of Engineering and Informatics and are used for solving many optimization problems that can be characterized as Shortest Path Problem. The EShoPPS is an interactive tool that allows students to create a graph representing the problem and also helps in developing their knowledge of each specific algorithm. Experiments performed with 155 students of undergraduate and graduate courses such as Industrial Engineering, Computer Science and Information Systems have shown that by using the EShoPPS tool students were able to improve their interpretation of investigated algorithms.

Keywords: Shortest path, Computational tool, Virtual learning environment, Engineering education, Routing algorithms.

### **1. Introduction**

The Shortest Path Problem (SPP) consists in determining a path between a beginning (source) location and a target (final) location with the minimum distance travelled [1]. In general, SPP is represented by a graph with several paths to be evaluated, that represents a computational difficulty. Thus, many researches from computer science and engineering areas focus on developing efficient algorithms to solve the SPP.

Nevertheless, SPP is one of the base operations of the network problems and occurs in several areas such as computer networks, transportation and logistics,

<b>Nomenclatures</b>	
A*	A Star pathfinding algorithm
C#	Programming language developed by Microsoft
C++	General purpose programming language
$E$	Set of edges that connect the nodes of the graph $G$
$e_i$	$i$ -th edge of graph $G$ ( $e_i \in E$ )
$f$	Cost function that combines $g$ and $h$ functions
$G$	Graph
$g$	Cost function (sum of distances)
$h$	Heuristic function
$V$	Set of vertices (nodes) of a graph $G$
$v_i$	$i$ -th node of graph $G$ ( $v_i \in V$ )
<b>Abbreviations</b>	
CAD	Computer-aided design
EShoPPS	Environment for Shortest Path Problem Solving
ICT	Information and Communications Technologies
OpenCV	Open Source Computer Vision Library
SPP	Shortest Path Problem
TML	Technology-Mediated Learning

among others. In computer networks, for example, there is a task of routing in which the information is moved from a source to a destination following the shortest possible path available [2]. In logistics, a typical problem is to provide the distribution of products quickly and efficiently, at the lowest cost/benefit ratio, offering a path that reduces time and cost of delivery. It is an essential activity to reduce the cost of transport and improve a competitiveness of a company [3].

Based on this context, it is clear the importance of teaching shortest path algorithms to students of undergraduate and graduate courses such as Industrial Engineering, Computer Engineering, Computer Science, Information Systems, Logistics and Business Administration.

In general, this content, as well as many others, is taught just using traditional methodologies and technologies, which discourage the students, making them passive and mere receivers of information [4, 5]. Contrary to these traditional practices is the actual society, which besides being characterized by information, is also a learning society since the speed that new information and knowledge are produced demands of individuals skills related to information management [6].

According to Chavez [7], the model of education that will characterize the information society and the knowledge that we are building will not be trampled on teaching, classroom or remote: it will be trampled on learning; therefore, it will not be a distance learning model, but a model of Technology-Mediated Learning (TML). Nevertheless, schools and teachers who want to participate of this process need to incorporate different approaches using computers and other information and communications technologies (ICT) in learning and teaching [8].

With technological advances, especially regarding to hypermedia resources, the ICT has been contributed for understanding and assimilation of information in several knowledge areas [9]. However, to be effective, it must be used for the

interaction between the student, teacher and knowledge in context and educational objectives well-defined [5].

In addition, it is important to remember that TML cannot and should not dispense the reading of texts and other materials given by the teacher, considering that reading is extremely important for the development of the student's capacity for abstraction [10].

For example, for teaching shortest path algorithms, there is a large amount of excellent textbooks that offer very good coverage about teaching this subject. However, they only offer limited forms of interactivity and a limited scope for students to test their knowledge on these algorithms.

In the last decade, many tools to aid the teaching contents at the undergraduate courses of Engineering and Technology areas have been proposed. Among them, it can be cited: a tool for teaching ergonomics to engineering students [11]; a tool to teach page replacement algorithms of operating systems [12]; a virtual environment for encouraging the use of computer programming in thermal engineering problems [13]; an application of Inventor CAD software for learning kinematics of machine tools [14]; a virtual environment learning with multimedia didactic material to support classroom teaching the discipline of digital signal processing [15]; educational tool for teaching processing images based on the OpenCV library [16]; a remote laboratory for teaching automatic control concepts to engineering students [17] and tools for evaluating and understanding routing algorithms [2, 18-19].

The objective of this paper is to propose a computational tool, called EShoPPS to help teach Dijkstra, Greedy Search and A\* algorithms, which are commonly seen in graduate and undergraduate courses, such as Industrial Engineering, Computer Engineering, Computer Science, Information Systems and Logistics, for solving optimization problems that can be characterized as Shortest Path Problem.

It is worth emphasizing that, in the literature review, a tool with the same characteristics and which considers the same algorithms incorporated in EShoPPS was not found. Thus, the main goal of this paper is the development of this tool. In addition, the evaluation results of EShoPPS by students are presented and discussed to demonstrate the importance of its use in studying the stated algorithms.

## 2. Shortest Path Algorithms

Given a graph  $G=(V,E)$ , in which  $V$  is the set of vertices (nodes) and  $E$  is the set of edges that connect the nodes, the objective of a shortest path algorithm is to find the shortest path between two nodes of graph  $G$ . There are many algorithms in the literature and among the most used ones are Dijkstra, Greedy Search and A\*, which are implemented in EShoPPS and briefly described in subsections 2.1 to 2.3.

### 2.1. Dijkstra

Dijkstra is an optimal algorithm for SPP and is usually the principle of working behind link-state routing protocols. In each step, the algorithm picks the unvisited node  $v_i \in V$  with the lowest distance (cost), calculates the distance from it to each

unvisited neighbour and updates the neighbours' distance, if smaller, and label  $v_i$  as visited. To this end, a function  $g(v_i)$  that represents the cost from the source node to  $v_i$ , is used by the algorithm. To achieve the shortest path is imperative that all  $e_i \in E$  have positive costs [1, 19-20].

## **2.2. Greedy search**

Greedy search strategies employ a heuristic function for making locally optimal choices at each step, aiming to find the global optimal solution [21]. Usually, the heuristic function of Greedy Search algorithm to solve a SPP is an estimated distance between adjacent nodes and the final node, used to choose the successors of a node  $v_i \in V$ , represented by  $h(v_i)$ . The Greedy Search algorithm always chooses to do what seems best in each interaction. The decision is based only on information available at the time, without worrying about the future effects of such decisions [22]. In SPP, as well as in many other problems, greedy search strategies do not find optimal solutions, but the use a greedy heuristic may yield locally optimal solutions that approximate a global optimal solution within a reasonable computation time [1, 22].

## **2.3. A\***

The Dijkstra algorithm needs to examine a large number of nodes of the graph representing the problem to ensure a minimal cost solution. On the other hand, Greedy Search reduces the search space greatly, but cannot guarantee a minimal cost solution. The A\* algorithm combines the search strategies used in Dijkstra and Greedy Search algorithms in a single algorithm using a function  $f(v_i)=g(v_i)+h(v_i)$ , where  $g$  and  $h$  are, respectively, admissible cost and heuristic functions [22]. Thus, A\* algorithm finds optimal solutions exploring a search space lesser than that examined by Dijkstra.

## **3. Experimental Procedure**

The development of EShoPPS was based on three main steps: design, implementation and evaluation. In the design step, the content to be covered and the needs of the target public was taken into account. In the implementation step, the development of proposed tool was performed using the C# programming language in order to provide, in the future, a web-based tool.

In the evaluation step, experiments were performed aiming to investigate the contribution of the EShoPPS tool in learning the covered content. To this end, first an experiment was conducted in the second semester of 2013 for evaluating the use of the tool in classes of fourth-year undergraduate courses of Computer Science (with 66 students) and Information Systems (27 students) and a class of Post-Graduation in Industrial Engineering containing six students, from a private university located in the city of São Paulo, Brazil.

These 99 students were asked to solve a proposed exercise (described in section 4.2) using the tool and answer a survey, which was designed to collect the following data about the tool: level of contribution for learning shortest path

algorithms, potential to be used as a teaching tool, usability, interface and reliability of results. From 99 students of the mentioned classes, 77 did the exercise and responded the survey (49 from Computer Science, 22 from Information Systems and 6 from the Industrial Engineering Post Graduation course). Afterwards, in the first semester of 2014, the same exercise was solved by 78 students from two fourth-year classes of Computer Science course, without the use of the EShoPPS tool and therefore they did not answer the survey. The conclusions obtained from the collected answers are detailed in next section.

With respect to the samples, they can be classified as “volunteer sampling”, considering that the exercise was applied to all students from the mentioned classes, but only those who were interested in participating did it. Furthermore, although students are of the same university, one cannot say that their social conditions are similar. Actually, this fact was not taken into account for determining the results.

Finally, it is important to keep in mind that the theoretical concepts about shortest path, as well as breadth-first and depth-first search algorithms had been already taught to all experimented students, in regular classes.

#### **4. Results and Discussion**

This section presents the EShoPPS, a discussion on the suggested exercise for students to solve using the tool and, finally, a discussion about students' answers on the survey regarding the use of the tool.

##### **4.1. EShoPPS – environment for shortest path problem solving**

The proposed tool as shown in Fig. 1 seeks to provide an instructive interface, resources and properties that enable to draw and manipulate the graph representing the SPP to be solved by means of Dijkstra, Greedy Search and A\* algorithms. The tool interprets interactions, reactions and behaviours of selected algorithm, depending on the designed graph.

The C# programming language was used to build the tool. It is supported by the platform .NET Framework, which covers the power and versatility of Visual Basic, the strength and creativity of C++ and the intelligence of JavaScript for validations. The choice for this language use was based on the existing support for conversion of the tool in a web-based application.

EShoPPS consists basically in a tool menu, a panel of simulation and a panel of results. The tool menu provides controls for inclusion and manipulation of graph elements (nodes and edges) and definition of the initial and final nodes. It also provides controls to run algorithms step by step and create/display the matrices of distance, results and heuristic.

The simulation panel allows the student to interact directly with the designed graph, moving any element of choice using the mouse. It also presents the calculated path based on the selected algorithm.

Finally, the result panel displays a table containing the iterations of the selected algorithm or one of the matrices mentioned above. Note that no information about the student is stored in any database. The tool allows storing

only the created graphs in text files. The students' answers were passed onto an answer sheet for data collection purposes.

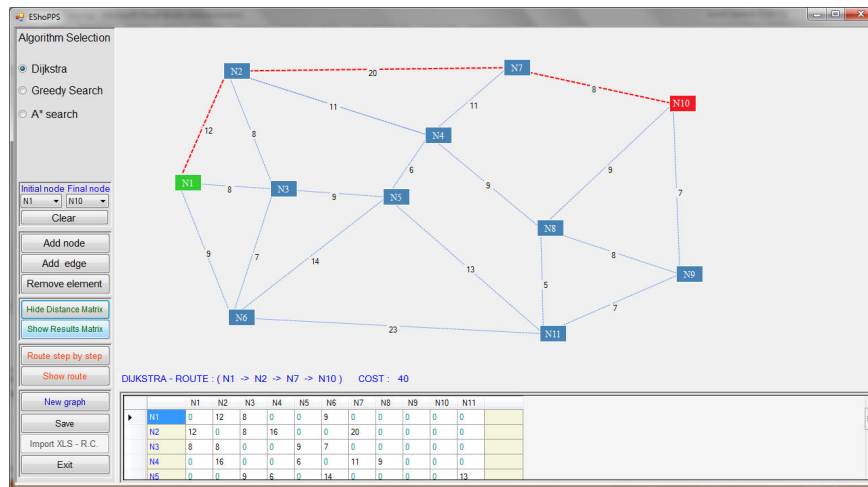


Fig. 1. Interface of EShoPPS.

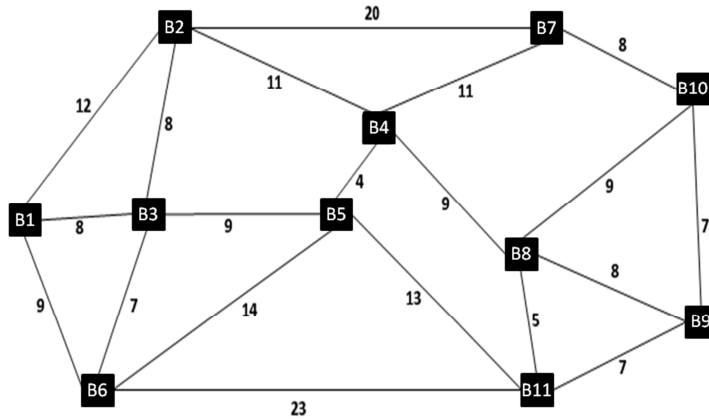
#### 4.2. Results of applied exercise

In order to evaluate the students' perceptions about the theoretical concepts discussed in the classroom, a simple exercise was proposed (adapted from [21]), and they were asked to present a solution to the problem and discuss their choice of algorithm.

Exercise: The network shown in Fig. 2 is a representation of a set of 11 residential buildings built in a remote area of town. The lines connecting the buildings are the pipes for the passage of all electrical wiring, telephone, etc., and the numbers next to the lines indicate the length (in meters) of pipe. A data communication scheme to be adopted by the condominium complex involves the placement of two electronic devices in buildings 1 and 10, which need to be connected by a cable. So with that in mind, the questions were: Which path of pipes would we have to use in order to connect the cable to the two electronic devices so that the size of the cable is minimized? How many meters of cable would be needed?

Only five out of the 77 students who did the exercise using EShoPPS, i.e., 6.5%, presented solutions using Greedy Search algorithm, which led to a non-optimal solution. This shows that the theoretical concepts about the algorithms were reinforced by the use of the tool. In addition, it allowed the students to quickly test the algorithms and choose the one who presents the optimal solution.

From the 78 students who did the exercise without the use of EShoPPS, 21 (i.e. 26.9%) indicated the Greedy Search algorithm to solve the problem and from the 57 students who chose the correct algorithm, 23 (i.e. 40.3%) failed to provide the optimal solution. These percentages corroborate the improvement of students' learning with the use of EShoPPS.



**Fig. 2. Graph Representing the Residential Condominium Described in Section 4.2.**

### 4.3. Results of applied survey

The following items introduce and discuss the student’s answers on the survey about the use of EShoPPS, showed in Fig. 3. As mentioned before, it was designed to collect the following data: level of contribution for learning investigated shortest path algorithms, potential to be used as a teaching tool, usability, interface and reliability of results. For each data, a table summarizing the results is presented.

**Answer Sheet**

1. What was the chosen algorithm to solve the problem? Justify your choice.

\_\_\_\_\_

\_\_\_\_\_

2. What is the solution of the problem (path and cost)?

\_\_\_\_\_

\_\_\_\_\_

3. In the following questions we want to know your opinion regarding the EShoPPS. Please, assign a note to each of them.

	(1) Very Weak	(2) Weak	(3) Average	(4) Good	(5) Very Good
3.1 Contribution for learning investigated shortest path algorithms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.2 Usability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.3 Potential to be used as a teaching tool	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.4 Reliability of results	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.5 Interface	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

4. Please, cite three things you would change in the EShoPPS to improve it:

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Fig. 3. Instrument used for Collection of Students' Answers.**

### 4.3.1. Contribution for learning algorithms

In general, students who used EShoPPS indicated that it contributed substantially to their learning. As shown in Table 1, 76.6% of students rated the contribution of the tool in their learning as good or very good. If the amount of students that rated the tool as average is considered, then the percentage of acceptance of the tool rises to 97.4%. In addition, no students classified the tool as very poor for learning.

**Table 1. Responses about Contribution for Learning.**

<b>Classification</b>	<b>Votes</b>	<b>Percentage</b>
Very Good	19	24.7%
Good	40	51.9%
Average	16	20.8%
Weak	2	2.6%
Very Weak	-	0.0%
<b>Total</b>	<b>77</b>	<b>100%</b>

### 4.3.2. Potential to be used as a teaching tool

In this sense, the survey indicated that EShoPPS has a promising potential to be used as teaching material. Overall, the tool pleased most students that handled it since 76.7% of students classified it as good or very good, as can be seen in Table 2.

**Table 2. Responses about the Potential to be used as a Teaching Tool.**

<b>Classification</b>	<b>Votes</b>	<b>Percentage</b>
Very Good	25	32.5%
Good	34	44.2%
Average	16	20.8%
Weak	1	1.3%
Very Weak	1	1.3%
<b>Total</b>	<b>77</b>	<b>100%</b>

### 4.3.3. Usability

According to the results presented in Table 3, one can infer that the architecture and layout of controls provided a reasonable understanding of the tool. The results also show that there is the need of improving the existing commands, aiming to leave EShoPPS more intuitive. It was also suggested by students to include a help module.

**Table 3. Responses about usability.**

<b>Classification</b>	<b>Votes</b>	<b>Percentage</b>
Very Good	13	16.9%
Good	25	32.5%
Average	34	44.2%
Weak	4	5.2%
Very Weak	1	1.2%
<b>Total</b>	<b>77</b>	<b>100%</b>



#### 4.3.4. Interface

Based on the results described in Table 4, note that the interface had a good acceptance rate, possibly due to the simplicity of objects provided for graph manipulation. However, some adjustments were suggested aiming to facilitate its use.

**Table 4. Responses about Interface.**

Classification	Votes	Percentage
Very Good	17	22.1%
Good	26	33.8%
Average	24	31.2%
Weak	9	11.7%
Very Weak	1	1.2%
<b>Total</b>	<b>77</b>	<b>100%</b>

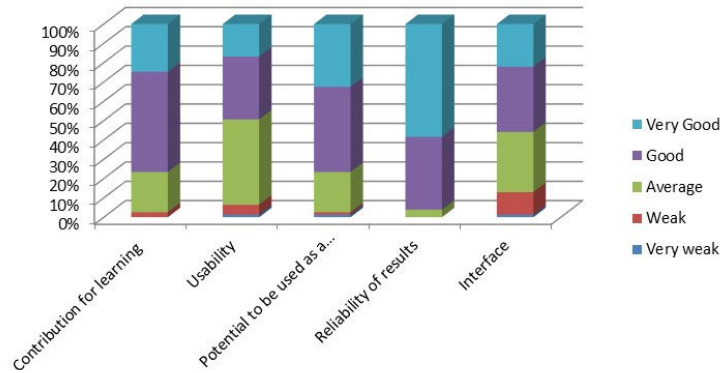
#### 4.3.5. Reliability of results

Students highlighted a high degree of reliability of the tool. As shown in Table 5, 96.1% of students classified the tool as reliable, ensuring that it worked properly in tests conducted beyond the requested exercise.

**Table 5. Response about Reliability.**

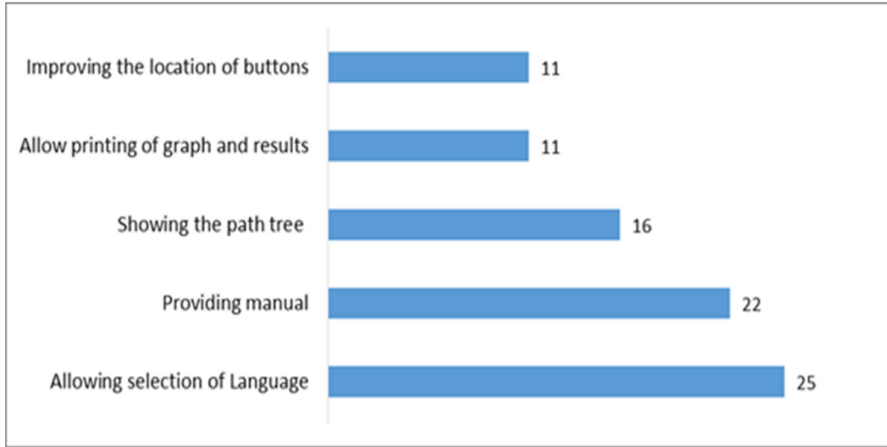
Classification	Votes	Percentage
Very Good	45	58.4%
Good	29	37.7%
Average	3	3.9%
Weak	-	0.0%
Very Weak	-	0.0%
<b>Total</b>	<b>77</b>	<b>100%</b>

In Fig. 4, which summarizes results described in Tables 1 to 5, one can see that the percentage of students who classified the tool as weak or very weak is very low. On the other hand, the percentage of ratings as average indicates a need for improvements.

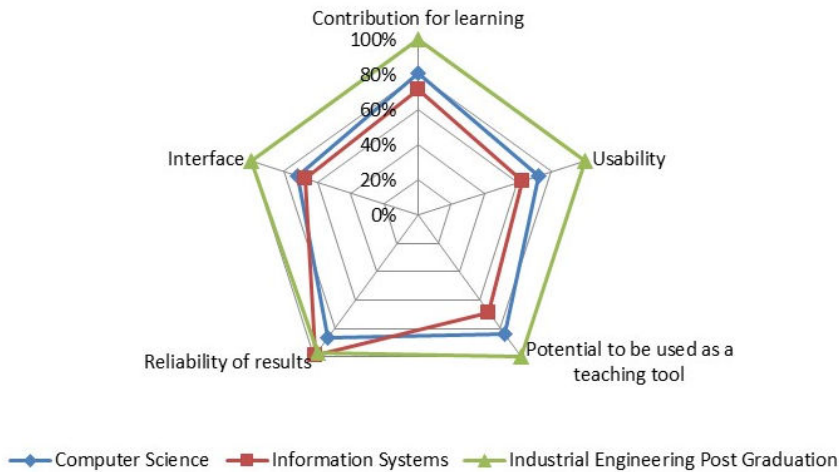


**Fig. 4. Summarization of the Results Described in Tables 1 to 5.**

One can also observe that the items with the lowest satisfaction were the interface and usability. It is in good agreement with the graph illustrated in Fig. 5 that shows the five suggestions given by students with the highest number of occurrence. However, it does not reflect the opinion of graduate students who answered the survey, as showed in Fig. 6. This may be related to the pre-acquired experience of these students, given they have less difficulty with the English language and have already used other tools like Matlab and Scilab for solving several optimization problems, including SPP.



**Fig. 5. Suggestions for Improving EShoPPS with the Highest Number of Occurrences.**



**Fig. 6. Percentage of Students' Satisfaction with Respect to the use of EShoPPS.**

Although some environments such as Matlab and Scilab make algorithms for solving SPP available, they do not have the same goal and characteristics of EShoPPS. Nevertheless, it was not found, in the literature review, a tool with the same goal and characteristics of EShoPPS, so it was not possible to compare the proposed tool with any other tool.

## 5. Conclusions

In this paper, a computational tool called EShoPPS was presented in order to help students understand how Dijkstra, Greedy Search and A\* algorithms work. Conducted experiments with EShoPPS have shown that it can bring benefits to graduate and undergraduate students by improving learning capabilities, especially if its use is based on a pedagogical context and with other means of teaching, considering that implemented algorithms require prior knowledge of theoretical concepts about the shortest path problem.

The contribution of the tool regarding the students' learning is corroborated by the fact that in other similar exercises, without the use of EShoPPS, the percentage of errors in selecting the appropriate algorithm for solving a problem was much higher. However, as indicated by the students, EShoPPS needs to be improved, especially with respect to interface and usability. It can be considered as a limitation of the presented tool.

Unfortunately, a comparison of EShoPPS with other tool was not possible, due to the problems described in previous section. It could be seen as a limitation of this study. In the future works, we intend to improve the EShoPPS implementing all students' suggestions, including other algorithms, making it able to solve other types of network optimization problems and, finally, conducting more experiments in order to make a more complete evaluation of the tool.

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