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Enhancing Problem-Solving Reliability with Expert Systems and Krulik-Rudnick Indicators

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Abstract

Problem-solving is one of the skills needed in the 21st century, but there is a significant gap between the ideal conditions and the reality of students' problem-solving skills. One method that can improve students' problem-solving skills is Krulik and Rudnick, but implementing this method with an expert system to improve problem-solving skills is still limited. This research aims to build an expert system to determine the level of problem-solving using Krulik and Rudnick's problem-solving indicators processed using the forward chaining and certainty factor algorithms. The study had five stages: data analysis, rule generation, certainty measurement, prediction, and testing. The data was processed by developing 5 Krulik and Rudnick problem-solving indicators into 35 statements. Each statement was categorized using Forward Chaining by producing three rules: low, medium, and high. The problem-solving level obtained is calculated using the Certainty Factor for a confidence value. The system's prediction results were evaluated using a confusion matrix, resulting in an accuracy of 80%, a precision of 92%, and a recall of 85%, indicating the system's reliable performance in measuring the level of problem-solving. This research can be used as a reference to support problem-solving in various more advanced educational and professional environments.

Keywords: *problem-solving; krulik and rudnick method; forward chaining; certainty factor; confusion matrix*

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1. Introduction

The education sector has experienced significant development in influencing aspects of life [1],[2]. This sector requires students as learners to innovate by using technology and information media [3],[4] and have relevant life skills in facing future challenges [5]. Students must be assisted in adjusting and transforming positively in several aspects of life to achieve educational goals [6]-[8]. Educational goals will be achieved with educational activities that can improve students' Communication, critical thinking, creative thinking, and collaboration skills, in enhancing problem-solving abilities [9]-[11]. There is a significant gap between the ideal and the real conditions of students' problem-solving skills [12]-[14].

In mathematical literacy, the 2022 Program for International Student Assessment (PISA) report shows that students in Indonesia have low problem-solving skills, which are at Level 2, or only 18% have basic level proficiency [15]. Students' problem-solving skills can be improved using the Krulik and Rudnick method [16]-[18], which consists of 5 stages, namely: read and think; explore and plan; select a strategy; find an answer; and reflect and extend more flexibly and systematically [19],[20]. The application of this method can be supported by expert systems or intelligence technology. Expert systems have a knowledge base that serves to solve problems and support decision-making effectively [21], with the ability to detect and produce the best judgment based on identified characteristics or symptoms [22]-[24].

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In the field of education, the application of expert systems in problem-solving has been widely researched. Saadyah and Winiarti developed an expert system that can help counsel teachers in making decisions to handle student problem-solving at school [25]. Esteban et al. developed a web-based simulator that allows students to flexibly access problems and solutions in a distance education environment [26]. Eshbayev and Nasiba demonstrated the effectiveness of expert systems as a support tool in the academic problem-solving process in a more structured way, providing immediate feedback that helps students improve their shortcomings [27]. Nonetheless, implementations of expert systems that specifically evaluate students' problem-solving levels based on the Krulik and Rudnick model are still limited [28], [29]. In addition, the combination of Forward Chaining and Certainty Factor algorithms to handle uncertainty and organize systematic steps in evaluating students' problem-solving ability is rarely applied [30]. This research is important to address these shortcomings and contribute to developing a more effective and structured evaluation of students' problem-solving skills.

This research addresses the gap by developing an expert system based on forward chaining and certainty factor algorithms. The combination of these algorithms is used to handle uncertainty in assessing student abilities and provide systematic evaluation steps. The advantage of this approach is its ability to provide objective problem-solving evaluation using Krulik and Rudnick's problem-solving indicators. The system also allows students' abilities to be grouped into three levels (low, medium, and high) so that teachers can use it as an evaluation tool and a guide to improve students' skills. Students' problem-solving ability becomes a benchmark for training and developing their thinking [31]. This solution can contribute to improving the quality of education, especially in helping to develop problem-solving skills that are very important to face the challenges of the 21st century.

2. Research Methods

This research uses the Krulik and Rudnick Method to assess students' problem-solving abilities systematically. It is focused on testing the accuracy and effectiveness of the system in predicting the level of students' problem-solving ability based on data collected through instruments prepared by the Krulik and Rudnick stages. The research employs forward chaining and certainty factor algorithms to handle uncertainty and enhance prediction accuracy. The research stages focus on testing the accuracy and effectiveness of the system in predicting the level of students' problem-solving ability. Figure 1 illustrates the research stages.

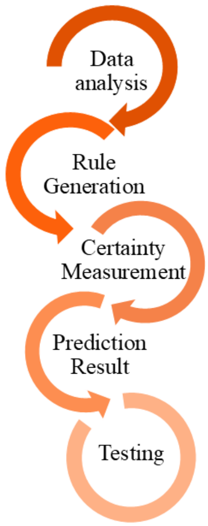

Figure 1. Stage of Research

Each stage in Figure 1 must be processed in sequence, namely Data Analysis, Rule Generation, Certainty Measurement, Prediction Result, and Testing. Each stage produces output that is processed by the next stage, so that the system provides a more objective assessment of students' real problem-solving abilities.

2.1 Data Analysis

The data processed in this study come from students' answers to several statements. This data is the basic foundation of expert system reasoning at the Krulik and Rudnick problem-solving stage. This data was developed from 5 stages of Krulik and Rudnick's method indicators: read and think, explore, select a strategy, find an answer, and reflect and extend into 35 statement instruments in describing aspects of problem-solving ability. This instrument is used as a reference for determining forward-chaining rules. Each instrument is given the code G as the initial of the instrument and followed by a sequential number according to the Krulik and Rudnick method stage group. The problem-solving instruments are presented in Table 1. The problem-solving instrument in Table 1 is categorized into three problem-solving levels: high, low, and medium.

Table 1. Problem-Solving Instrument

Stage	Code	Instrumen
1	G01	I can convey problems related to learning difficulties that I experience directly to the teacher.
	G02	I immediately ask the teacher when I get a low grade in a particular subject.
	G03	I am able to concentrate on learning even when the classroom atmosphere is not conducive (e.g., noisy atmosphere and hot weather).
	G04	I ask the teacher to repeat the material that I do not understand.
	G05	I find it challenging to understand the material if the teacher explains only by telling stories.
	G06	I can easily understand the material presented if the teacher uses PowerPoint/images in learning.
	G07	I cannot if a friend talks to me while I'm studying.
2	G08	I will find out the cause of my learning difficulties

Stage	Code	Instrumen
	G09	I look at the problem from different perspectives
	G10	I try to compare possible solutions to solving learning difficulties
	G11	I see the possibility of the same problem requiring different solutions
	G12	I will try to elaborate on a problem to make it easier to understand and find a solution.
	G13	I solve problems on the spot without thinking about the cause.
	G14	I can find the sources of the causes of my negligence in learning.
	G15	I will see a counselling teacher to get help when facing problems
	G16	I make a list of solutions to the issues I experience
	G17	I feel stuck when I get into trouble
3	G18	I keep my issues to myself rather than sharing them with others.
	G19	I remember God and pray to be given guidance in experiencing difficulties
	G20	I create *stories* on social media when experiencing problems to reduce the burden
	G21	I lock myself in my room for days to contemplate when experiencing problems.
	G22	I make drawings, scribbles or diagrams to make it easier to solve the problem that arises
	G23	I solve the problem based on previous experience
	G24	I dare ask the teacher about a subject I do not understand.
4	G25	I ask a more thoughtful friend to help re-explain material I do not understand.
	G26	I double-check the steps I take in solving learning problems
	G27	I can do my assignments optimally, even though they are challenging.
	G28	I can try to complete the tasks the teacher gives, little by little, consistently.
	G29	I can complete the subject assignments before the deadline.
	G30	I can exert my willpower to overcome laziness when doing schoolwork.
	G31	I can think positively to maintain motivation to achieve my learning success target
5	G32	I work out possible solutions to a problem
	G33	I consistently make a customized schedule for studying at home to make it easier to understand lessons.
	G34	I make small notes to make it easier for me to memorize lessons
	G35	I train myself to be brave enough to speak in public to make asking questions easier.

2.2 Rule

This stage determines the rules using the Forward Chaining algorithm expert system, based on the facts obtained [29], [32], [33]. The process starts from the initial data or facts by activating rules based on the data-driven reasoning inference that has been obtained. The approach is a bottom-up technique that moves from facts to conclusions through existing rules (IF-THEN). Relevant facts are placed in the IF part of the rule, and after the rule is executed, new facts in the THEN part are added to the database. This process continues until all conditions of the rule are met, which corresponds to the Krulik and Rudnick method instrument rules. Forward Chaining rules are grouped into three rules according to the level of problem-solving, namely high, medium, and low, presented in Table 2.

Table 2. Forward Chaining Rules

No.	Level	Rule
1	Low	IF [G07] AND [G13] AND [G17] AND [G18] AND [G21] THEN P001
2	Medium	IF [G01] AND [G02] AND [G04] AND [G05] AND [G08] AND [G15] AND [G20] AND [G24] AND [G25] AND [G28] AND [G30] AND [G34] THEN P002
3	High	IF [G03] AND [G06] AND [G09] AND [G10] AND [G11] AND [G12] AND [G14] AND [G16] AND [G19] AND [G22] AND [G23] AND [G26] AND [G27] AND [G29] AND [G31] AND [G32] AND [G33] AND [G35] THEN P003

2.3 Certainty Factor

Certainty Factor (CF) serves to avoid uncertainty in expert reasoning, such as "probably" or "most likely" [34], [35]. CF performs a probability function by analyzing the sensitivity of several factors that affect an event [36]. The CF value involves accumulating values from multiple "rules" relevant to the situation or problem being analysed. This CF value measures the magnitude of confidence or disbelief in a recommended conclusion against the results obtained [37]. The prediction of students' problem-solving level from the forward chaining process is then measured using the confidence level in CF based on the rule using Equation 1 [38].

$$CF(H,E) = MB[H,E] - MD[H,E] \quad (1)$$

H is the resulting hypothesis or conclusion with a value between 0 and 1, E is the evidence or event or fact, CH(H, E) is the certainty factor in the Hypothesis (H) influenced by the evidence (E), MB(H, E) is the confidence level which is a measure of the confidence of H influenced by E, and MD(H, E) is the level of uncertainty which is a measure of the disbelief of H influenced by the phenomenon E. Measure of Belief (MB) is a measure of confidence in hypothesis H based on evidence E, with a value between 0 and 1. A value of 0 indicates no belief, and 1 means full belief. Meanwhile, the Measure of Disbelief (MD) measures the amount of disbelief in hypothesis H based on evidence E with a value between 0 and 1, where 0 is no disbelief, and 1 is complete disbelief [33] [38]. An expert from the field of psychology gave the MB and MD values in this study. The CF value of each fact is processed from the combination of the CF values.

After obtaining the CF value of each fact, the combined CF value is calculated. At the problem-solving level, more than one fact supports a conclusion, so the CF values of these facts must be combined to produce a CF that reflects the confidence level in the final conclusion. The combination CF equation is found in Equations 2, 3, and 4 [39], [40] .

$$CF\ Kombi\ (CF_1, CF_2) = CF_1 + CF_2(1 - CF_1) \quad (2)$$

$$CF\ Kombi\ (CF_1, CF_2) = CF_1 + CF_2(1 + CF_1) \quad (3)$$

$$CF\ Kombi\ (CF_1, CF_2) = \frac{CF_1 + CF_2}{1 - MIN\ (|CF_1|, |CF_2|)} \quad (4)$$

These three combined CF equations are used under the following conditions [39]: Equation (2) is used when both CF values are positive; Equation (3) is used when both CF values are negative; Equation (4) is used when the CF value is positive and negative.

The combination value's result will be multiplied by 100% to determine the confidence level in the percentage scale range.

2.4 Confusion Matrix (CM)

A Confusion Matrix (CM) is a method for analyzing and evaluating a Model's performance [41]. In this study, the matrix is used to test predictions and provide confidence in the expert system in determining the level of problem-solving. CM provides an overview of the State of comparison between the prediction results and the student's problem-solving level. CM shows the performance in classifying test data with actual known values [42]. The CM matrix is presented in Figure 2.

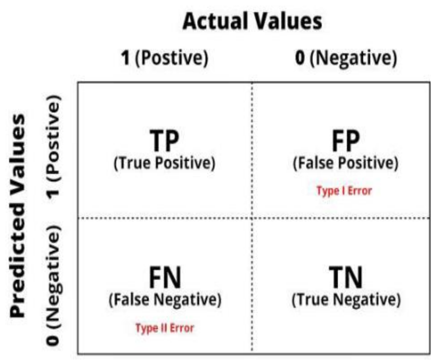

Figure 2. Matrix CM

Based on the matrix in Figure 2, where True Positive (TP) is data with positive actual values that are predicted positive, True Negative (TN) is data with negative actual values that are predicted negative, and False Positive (FP) is data with negative actual values but predicted positive. A False Negative (FN) is data with positive actual values that are predicted negatively. The combination of values from TP, TN, FP, and FN can determine the accuracy, precision, and recall values, which are calculated using Equations 5, 6, and 7 [41].

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (5)$$

$$Precision = \frac{TP}{TP+FP} \quad (6)$$

$$Recall = \frac{TP}{TP+FN} \quad (7)$$

3. Results and Discussions

This study conducted testing involving senior high school students as respondents. Students are given access to the expert system developed by filling in data through the choice of "agree" or "disagree" statements on the system online. The data that has been entered becomes input that is processed by the system using the Forward Chaining method to produce predetermined rule-based conclusions. Furthermore, the Certainty Factor measures the level of certainty the system generates. The test results include an evaluation of the system's ability to identify the level of student problem-solving based on the data provided and an analysis of the system's accuracy in providing conclusions.

The results of calculations using the Forward Chaining algorithm group students based on the level of problem-solving, namely P1 (low), P2 (medium), and P3 (high). In the calculation of one of the data, the identified characteristic codes are G01, G02, G04, G05, G07, G08, G09, G11, G15, G16, G19, G20, G21, G30, G31, G32, G33, G34, and G35. The results of grouping students' problem-solving levels in the three categories are presented in Table 3.

Table 3. Division of Forward Chaining Rule Characteristics

Criteria	Rules
P1	G07, G21,
P2	G01, G02, G04, G05, G08, G15, G20, G30, G34
P3	G09, G11, G16, G19, G31, G32, G33, G35

Each feature code at each level is summed and divided by the total number of feature codes at each rule level. The calculation results are presented in Table 4.

Table 4. Rule Value Result

Criteria	Number of Criteria in Rule	Total number of rules	Rule Value
P1	2	5	0.4
P2	9	13	0.69
P3	8	17	0.47

In Table 4, rule P2 (medium) value produces the highest value compared to other rules. This condition states that the student's problem-solving level is moderate. The rules obtained with students who have a problem-solving level of P2 (medium) were continued with the calculation of the Certainty Factor to measure the level of confidence of the Forward Chaining conclusion using the basic Certainty Factor formula in Equation (1), which is presented in Table 5.

Table 5. CF Value Results for Each Fact

Fact	MB	MD	CF
G01	1.0	0.0	1.0
G07	0.8	0.4	0.4
G13	0.2	0.8	-0.6
G17	0.0	1.0	-1.0
G18	0.0	1.0	-1.0
G21	0.0	1.0	-1.0
G22	1.0	0.2	0.8
G25	1.0	0.0	1.0
G28	1.0	0.0	1.0
G30	1.0	0.0	1.0
G33	1.0	0.0	1.0
G35	1.0	0.0	1.0

In the calculation results, more than one fact supports a conclusion, so the CF values of these facts are combined to produce a CF that reflects the confidence level in the final conclusion. The results of the combined CF calculation using Equations 2, 3, and 4 are presented in Table 6.

Table 6. Combination CF Calculation Result

Fact	Value
CF1 & CF2	
CF2 & CF3	
CF3 & CF4	
CF4 & CF5	
CF5 & CF6	
CF6 & CF7	
CF7 & CF8	
CF8 & CF9	
CF9 & CF10	
CF10 & CF11	
CF11 & CF12	
CF12 & CF13	
CF13 & CF14	
CF14 & CF15	
CF15 & CF16	
CF16 & CF17	
CF18 & CF19	

The calculation results in Table 5 show that the combined CF value is 1. This result shows that 100% confidence is needed to predict the problem-solving level using forward chaining.

Furthermore, the results were tested using the Confusion Matrix equation. This test was conducted on senior high school students, and 60 respondents were selected based on specific criteria to ensure a representative sample. The sampling technique used was purposive sampling with student criteria: diverse academic levels, involvement in problem-based learning methods, and consistency of academic grades in Mathematics. These criteria were considered so the system could generalize its results more broadly to various student profiles. The testing scenario was structured so students could access the system and fill in the statements according to their condition. Then, the system analyzes their responses using Forward Chaining and certainty factor algorithms to determine each student's problem-solving ability level. The system's prediction results are compared with the students' original grades taken from the Math report card. This subject is used because it reflects students' ability to think logically, analyze, and solve problems systematically [43]. Mathematics teaches skills directly relevant to problem-solving, and grades in this subject often indicate students' ability to face challenges [44] at school and in everyday life.

The test results were then analyzed using the Confusion Matrix, where evaluation is done based on accuracy, precision, and recall to measure how well the system can accurately classify students' problem-solving levels. The Confusion Matrix results are presented in Table 7.

Table 7 shows that the Confusion Matrix has a 3x3 dimensional format, where the TP value is 48, TN is 0, FP is 4, and FN is 8.

Table 7. Confusion Matrix Testing

Report card grades	Prediction		
	Low	Medium	High
Low	0	0	0
Medium	4	28	4
High	0	4	20

Each element can be calculated at the level of Accuracy, Precision, and Recall using Equations 5, 6, and 7 as follows:

$$Accuracy = \frac{48+0}{48+0+4+8}\ x\ 100\ \% = 80\% \quad (5)$$

The system achieved an accuracy rate of 80%, which corresponds to the students' actual grades. This result shows that the system has an excellent accuracy rate in reducing errors in some cases.

$$Precision = \frac{48}{48+4}\ x\ 100\% = 92\% \quad (6)$$

The system achieved a precision level of 92%, so it is highly capable of ensuring that the positive predictions generated really reflect the students' Problem-Solving level, which is closer to reality and relevant. This result shows that the system is very low in giving false positive predictions.

$$Recall = \frac{12}{48+8}\ x\ 100\% = 85\% \quad (7)$$

This result shows that the system can recognize most students with a certain level of problem-solving ability, and only a few positive cases, 15%, are not detected by the system.

Based on the test results, the problem-solving expert system performed excellently. The combination of high precision and good recall shows that the system can provide accurate predictions in positive predictions.

4. Conclusions

The research results were intended to categorize students into three levels of problem-solving ability, namely low, medium, and high, by developing the Krulik and Rudnick Method into 35 indicators. These indicators were effective in building a problem-solving assessment instrument. By integrating an expert system based on forward chaining and the certainty factor calculation method, the processing results can provide a diagnosis closer to reality and relevant to user data. Based on the results of testing 60 students, the system shows good performance with an accuracy value of 80%, precision of 92%, and recall of 85%. Forward chaining and certainty factor algorithms combine to effectively handle uncertainties commonly encountered in decision-making. Therefore, the research can serve as a reference for its broad application, supporting the development of problem-solving skills in various educational and professional environments. Thus, the research can serve as a reference in its broad application to support the development of problem-solving skills in various educational and professional environments. Further development can be pursued by integrating additional algorithm combinations, enhancing the system's accuracy and flexibility in handling uncertainty.

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