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Developing a collaborative problem-solving instrument: A skills-based rubric in mathematics learning

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Abstract: Collaborative problem-solving is essential in mathematics education, yet many students face challenges due to a lack of effective assessment tools that adequately measure these skills. The existing approaches often overlook the integration of structured assessments, resulting in a significant gap in understanding how to cultivate and evaluate collaborative problem-solving abilities in students. This study aims to address these identified issues by developing a collaborative problem-solving instrument grounded in a skills-based rubric specifically for mathematics learning. Using a Research and Development (R&D) approach following the procedural framework of Borg and Gall, the study created a comprehensive assessment tool designed to enhance the measurement of collaborative problem-solving skills. Validation through Lawshe's formula resulted in a content validity index of 0.99, confirming the instrument's reliability. Practicality testing involved questionnaires distributed to middle school mathematics teachers, achieving a positive response rate of 92.46% in small-scale trials and an impressive 97.61% in large-scale field trials. These findings demonstrate the instrument's effectiveness and practical applicability in classroom settings. The implications indicate that incorporating this structured assessment can significantly improve students' collaborative problem-solving abilities, ultimately enhancing their engagement and learning outcomes in mathematics. Future research should explore the broader applicability of this instrument across various educational contexts and subjects to maximize its impact.

Keywords: *Assessment instrument, Collaborative problem-solving, Mathematics education, Skills-based rubric.*

1. Introduction

Collaborative problem-solving stands at the forefront of modern mathematics education, acknowledged for its pivotal role in equipping students with the essential competencies needed to tackle real-world challenges. Despite this recognition, many students encounter significant obstacles when attempting to engage meaningfully in collaborative learning environments [1, 2]. A primary impediment is the dearth of structured assessment tools tailored to measure and enhance collaborative problem-solving skills effectively. Current pedagogical approaches often prioritize individual problem-solving prowess, inadvertently sidelining the critical skills of collaboration and communication within mathematical contexts [3, 4]. Extensive research underscores the transformative benefits of collaborative problem-solving, revealing that students not only deepen their mathematical understanding but also cultivate indispensable attributes such as critical thinking, effective communication, and collaborative teamwork [5-7]. However, the pervasive absence of targeted assessment instruments severely limits educators' capacity to nurture and assess these competencies authentically within classroom settings. Addressing this gap is paramount as educators strive to cultivate a generation of learners capable of thriving in an interconnected and dynamically evolving world.

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Previous studies have explored various approaches to collaborative learning; however, many of these investigations have predominantly focused on theoretical frameworks, failing to provide educators with practical assessment tools necessary for effective implementation [8, 9]. Furthermore, for instance, frameworks such as the Five Practices for Orchestrating Productive Mathematics Discussions also offer valuable strategies for facilitating collaboration among students but often lack specific methodologies for assessing their collaborative competencies [10, 11]. This shortfall is critical, as effective assessment is not merely an adjunct to instruction; it is integral to understanding and enhancing student learning outcomes. Research by Mohan et al. [12] further highlights that misalignments between assessment practices and collaborative learning objectives can result in significant misunderstandings regarding student performance and development. Such discrepancies can hinder educators' ability to provide meaningful feedback and adjust instructional strategies to meet the diverse needs of learners. Therefore, there is an urgent need for the development of robust instruments that not only assess collaborative problem-solving skills comprehensively but also inform and guide instructional practices aimed at fostering these skills. By bridging the gap between theory and practice, such instruments could empower educators to create more effective collaborative learning environments, ultimately enhancing student engagement and success in mathematics.

Additionally, existing assessment instruments frequently fail to capture the multifaceted nature of collaborative problem-solving. Numerous studies indicate that traditional assessment instruments tend to concentrate primarily on individual performance, neglecting the complex dynamics of group interactions and the unique contributions of each member within collaborative settings [13-16]. This lack in assessment practices presents an incomplete view of students' abilities, often discouraging the very collaborative efforts that are crucial for effective learning in mathematics classrooms. Consequently, educators are left with inadequate instruments to evaluate the impact of collaborative learning strategies on student outcomes, leading to missed opportunities for refining instructional practices and fostering deeper understanding [6, 17, 18].

Furthermore, the literature reveals a significant deficiency in validated instruments specifically designed to measure collaborative problem-solving within mathematics education. While various rubrics exist to assess general collaborative skills, they often overlook the particular nuances and cognitive demands inherent in mathematical contexts [4, 19]. Furthermore, research by Care et al. [20] and Setiawan et al. [9] also underscores the necessity of utilizing evidence-based instruments to gauge student outcomes effectively; however, the mathematics education field continues to lack specialized instruments tailored to the complexities of collaborative problem-solving. This oversight not only constrains educators' ability to assess student growth accurately but also limits their capacity to implement targeted interventions that could enhance collaborative skills. Addressing this critical gap is essential for equipping educators with the tools needed to foster an environment conducive to collaboration, ultimately enabling students to thrive in both mathematical understanding and essential interpersonal skills.

In light of these identified gaps, this study aims to develop a collaborative problem-solving instrument grounded in a skills-based rubric specifically for mathematics learning. To the best of our knowledge, the need for such an instrument is underscored by the pressing challenges faced by educators in fostering collaboration among students [10, 12, 14]. By creating a structured tool that measures collaborative problem-solving skills, this research seeks to bridge the divide between theoretical frameworks and practical classroom application. The development of this instrument will provide educators with a reliable means to assess student competencies, ultimately enhancing the effectiveness of collaborative learning in mathematics education. The pressing need for this study is further amplified by the recognition that effective collaboration is not just beneficial but essential for student success in an increasingly interconnected world [8, 16]. As educational mathematics systems evolve, they must equip students with the skills necessary to navigate complex problem-solving scenarios [1, 2, 5, 6]. The development of a comprehensive assessment instrument will not only address

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existing gaps but also empower educators to foster a culture of collaboration and critical thinking in their classrooms, ultimately leading to improved student outcomes in mathematics education.

2. Literature Review

2.1. Collaborative Problem-Solving in Mathematics Education

Collaborative problem-solving is increasingly recognized as a vital component of effective mathematics education, offering numerous benefits that extend beyond mere content mastery. Research shows that when students participate in collaborative tasks, they not only enhance their mathematical understanding but also develop essential skills such as critical thinking, communication, and teamwork [9, 12, 20]. These competencies are especially significant in today's globalized world, where the ability to collaborate is crucial for tackling complex, multifaceted problems that often transcend disciplinary boundaries. Despite the well-documented advantages of collaborative problem-solving, many educational systems continue to prioritize individual learning approaches, leaving students ill-prepared for the demands of modern workplaces that increasingly value collaboration and collective problem-solving abilities [3, 4, 17].

The existing literature underscores several key challenges that educators face in implementing collaborative problem-solving in mathematics education. A major obstacle is the lack of structured assessment tools specifically designed to evaluate collaborative skills effectively [7, 17]. Traditional assessment methods predominantly focus on individual performance metrics, often neglecting the intricate dynamics of group interactions and the varying contributions of individual students within collaborative settings [9, 11, 21, 22]. This narrow focus not only limits educators' insights into students' collaborative competencies but also discourages the cultivation of these essential skills, as students may perceive their contributions as undervalued or unrecognized. Furthermore, research by Harjo et al. [13] and Sari et al. [15] also highlights the critical importance of aligning assessment practices with explicit learning objectives; without appropriate assessment instruments, teachers find themselves unable to accurately gauge students' collaborative skills or to adapt their instructional strategies in response to students' needs. This misalignment can result in a missed opportunity to create learning environments that foster collaboration, critical thinking, and problem-solving, ultimately hindering student success in mathematics and beyond. Thus, there is a pressing need for the development of robust assessment instruments that effectively capture the nuances of collaborative problem-solving in mathematical contexts.

2.2. The Importance of Structured Assessment Instruments

The urgent need for structured assessment tools in collaborative learning environments is supported by a growing body of research. For instance, Harding et al. [17] found that students engaged in structured collaborative tasks exhibited significantly higher levels of engagement and deeper understanding compared to those who worked independently. This suggests that well-designed collaborative activities can enhance not only academic performance but also student motivation. However, without effective assessment instruments in place, educators face considerable challenges in implementing these collaborative strategies effectively. Research also emphasizes that programs incorporating structured assessments yield better student outcomes, reinforcing the critical role that assessment plays in educational success [23-25]. Yet, the field of mathematics education continues to lag behind, lacking adequate instruments specifically tailored to assess collaborative problem-solving skills.

Moreover, while several theoretical frameworks exist to facilitate collaborative learning, they often fall short in providing educators with practical tools to measure student performance. For example, frameworks like the Five Practices for Orchestrating Productive Mathematics Discussions outline valuable strategies for fostering collaboration among students but do not deliver concrete methods for assessing collaborative competencies [10]. This gap between facilitation strategies and assessment instruments creates a significant void in the literature, leaving educators without the necessary

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resources to evaluate the effectiveness of collaborative learning initiatives in their classrooms. Consequently, teachers may struggle to adapt their instruction based on students' collaborative skills, ultimately undermining the potential benefits of collaborative learning environments [14, 26]. To address this pressing issue, the development of robust, evidence-based assessment instruments tailored to the nuances of collaborative problem-solving in mathematics is essential for empowering educators and enhancing student learning outcomes.

2.3. Previous Studies and Identified Gaps

A review of previous studies reveals a consistent trend: while there is substantial interest in collaborative learning, the predominant focus has been on theoretical constructs rather than on developing practical assessment tools. For instance, research by Care et al. [8] and Harjo et al. [13] laid the psychological groundwork for understanding collaboration. Still, it did not translate these findings into usable frameworks for assessing collaborative competencies. Similarly, studies addressing group dynamics, such as those by Hao et al. [24], underscore the significance of peer interactions but fail to offer concrete instruments for measuring these interactions, particularly within the mathematical context where collaboration is crucial for problem-solving.

Moreover, there is a notable absence of validated instruments specifically designed to measure collaborative problem-solving in mathematics. While some rubrics assess general collaborative skills, they often do not adequately address the unique challenges posed by mathematical problem-solving scenarios [12, 21, 27]. This is particularly concerning given that mathematics requires not only logical reasoning but also the ability to communicate complex ideas effectively within a group setting. Moreover, research also emphasizes the necessity of employing evidence-based instruments for assessment [14, 18]; however, the field of mathematics education has not adequately responded to this imperative. This lack of tailored assessment instruments hampers educators' ability to accurately assess student growth and to implement targeted interventions that can enhance collaborative skills. In light of these identified gaps, the development of a robust instrument specifically designed for collaborative problem-solving in mathematics, such as a skills-based rubric, becomes critical. Such an instrument would not only facilitate accurate measurement of students' collaborative competencies but also provide educators with actionable insights to refine their instructional practices [2, 8, 13, 15]. By addressing the nuances of collaborative problem-solving in mathematical contexts, this rubric would empower teachers to foster a more effective collaborative learning environment, ultimately enhancing student outcomes and preparing them for real-world challenges that demand teamwork and effective communication [4]. This study, moreover, seeks to address these shortcomings by developing a comprehensive instrument designed specifically for measuring collaborative problem-solving skills in mathematics. By bridging the gap between theory and practice, this study aims to empower educators to foster a collaborative learning environment that enhances student engagement and achievement in mathematics.

3. Research Methodology

3.1. Research Design

This study employs a Research and Development (R&D) methodology to develop an assessment tool for evaluating collaborative problem-solving (CPS) skills in mathematics education. The R&D approach, as outlined by Gall and Borg [28], provides a structured framework for developing educational products and processes. This methodology is particularly well-suited for creating robust and validated assessment instruments, ensuring that the tools developed are both reliable and applicable in real-world educational settings. CPS skills are critical in the 21st-century educational landscape [2, 23]. These skills encompass the ability to effectively engage in processes where multiple agents collaborate to solve problems by sharing understanding and efforts to achieve solutions. As highlighted by international frameworks such as PISA (2015), ATC21S, ETS (2016), and ACT (2015), CPS skills involve a range of cognitive and social competencies. These include exploring and understanding problems, formulating and representing solutions, planning and executing tasks, and monitoring and

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reflecting on progress [5, 24, 29]. Effective CPS also requires maintaining shared understanding, taking appropriate actions, and managing team organization. The emphasis on CPS skills is grounded in the need for students to function collaboratively in diverse and dynamic environments, leveraging collective knowledge and resources to solve complex problems. In this study, the development of the assessment instrument is guided by the ETS framework, which includes four main components of collaborative problem-solving skills: sharing resources/ideas, negotiating ideas, organizing problem-solving activities, and maintaining positive communication. These components are detailed in Table 1, providing a clear structure for the assessment rubric.

Table 1.
Components of CPS Skills.

Component	Description
Sharing Ideas	Presenting and responding to the need for relevant information related to the task
Negotiating Ideas	Discussing differences and similarities in presented ideas, handling agreements and disagreements
Organizing Problem-Solving	Managing discussions by evaluating interactions and group progress
Maintaining Communication	Interacting and maintaining social relevance, both task-related and non-task-related

3.2. Development Procedures

The development process follows the procedural steps outlined by Gall and Borg [28], ensuring a comprehensive and systematic approach. Each step in the research process is designed to address the critical need for structured, valid, and reliable instruments to measure collaborative problem-solving skills.

3.2.1. Step 1: Research and Data Collection

The initial step in developing the CPS assessment tool involves comprehensive research and data collection. This phase includes a needs analysis through literature review and analysis of relevant studies. The objective is to identify the necessity for an instrument that accurately measures the CPS skills of prospective mathematics teachers. The information gathered during this stage informs the design and development of the assessment tool, ensuring that it addresses the specific skills and competencies required in CPS.

3.2.2. Step 2: Planning

During the planning phase, the design of the product is formulated into a questionnaire rubric. The questionnaire items are structured as closed statements, using a 5-point Likert scale to measure four key components of CPS: sharing resources/ideas, negotiating ideas, organizing problem-solving activities, and maintaining positive communication. The planning phase ensures that the assessment tool is comprehensive and aligns with the theoretical constructs of CPS as outlined by leading educational frameworks.

3.2.3. Step 3: Product Development

The product development phase involves drafting specifications for the CPS assessment instrument. These specifications are tailored to match each indicator of CPS skills, ensuring the instrument comprehensively covers all relevant aspects of collaborative problem-solving. The development process incorporates feedback from subject matter experts and iterative revisions to refine the instrument.

3.2.4. Step 4: Initial Field Testing

Initial field testing includes expert validation of the assessment instrument. Validation is conducted by five middle school mathematics teachers (validators) who assess the instrument's content, language,

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and construct. The validation process employs the Content Validity Ratio (CVR) formula by Lawshe [30], which evaluates the essentiality of each item as rated by the experts:

$$CVR = (2ne : n) - 1$$

Where *ne* is the number of experts rating an item as essential, and *n* is the total number of experts. The CVR values are then compared against Lawshe's minimum values to determine item acceptance. Accepted items are used to calculate the Content Validity Index (CVI), providing an overall measure of the instrument's content validity.

$$\text{CVI} = \frac{\sum \text{CVR accepted items}}{\text{Total accepted items}}$$

The CVI ensures that the instrument covers a representative set of items, reflecting the theoretical construct of CPS skills.

3.3. Data Analysis

Validity of the CPS Assessment Rubric

To ensure the validity of the CPS assessment rubric, expert validation activities are conducted as follows:

1. *Expert Assessment:* Five middle school mathematics teachers evaluate the rubric, providing essential feedback on each item.
2. *CVR Calculation:* The average scores obtained from the expert ratings are calculated using the CVR formula. The results are then referenced against Lawshe's CVR guidelines (Table 2) to determine item validity.
3. *CVI Calculation:* The CVI is calculated by averaging the CVR values of accepted items, providing an overall validity measure for the instrument.

Table 2.
CVR Guidelines

CVI Calculation	Minimum CVR
5	0.99
6	0.99
7	0.99
8	0.75
9	0.78
10	0.62

3.4. Practicality of the CPS Assessment Rubric

The practicality of the CPS assessment rubric is assessed through student response questionnaires. The analysis steps include:

1. *Instrument Validation:* The response questionnaire is validated by experts to ensure relevance and clarity.
2. *Student Testing:* The validated questionnaire is administered to students.
3. *Data Analysis:* The student responses are analyzed by calculating the average scores and determining the percentage of responses in each validity category (Table 3).

$$\text{Average score (M)} = \frac{\text{Total scores}}{\text{Number of respondents}}$$

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The average score percentages are then compared with the validity categories to determine the practicality of the instrument.

Table 3.
Validity Categories.

Average Score (M)	Category
$3.25 \leq M \leq 4$	Very Valid
$2.5 \leq M \leq 3.25$	Valid
$1.75 \leq M \leq 2.5$	Fairly Valid
$1.0 \leq M \leq 1.75$	Not Valid

The development and validation of the CPS assessment tool follow a rigorous R&D methodology, ensuring that the instrument is both theoretically sound and practically applicable. By incorporating expert validation and comprehensive data analysis, the study produces a reliable and valid assessment tool for evaluating CPS skills in mathematics education. The focus on CPS skills is supported by extensive literature, underscoring their importance in modern educational contexts. This study contributes to the existing body of knowledge and provides a valuable resource for educators seeking to enhance collaborative problem-solving skills among students.

4. Findings

The primary aim of this study was to develop and validate a rubric for assessing students' CPS skills in a middle school mathematics context. The rubric used in this research is based on the collaborative skills assessment rubric developed by ETS [4]. It includes four main components: sharing ideas, negotiating ideas, managing problem-solving activities, and maintaining communication, each with several categories to comprehensively evaluate collaborative problem-solving abilities. The development process encompassed data collection, planning, rubric development, and validation of both the collaboration rubric and the student response instrument.

4.1. Validation of the Collaborative Problem-Solving Skills Assessment Rubric

To ensure the rubric's validity, it was first subjected to a content validation process involving five subject matter experts (SMEs) who are middle school mathematics teachers. These experts were asked to review the rubric and provide feedback on its alignment with CPS. The feedback from the validators included specific suggestions for improving the clarity and relevance of the rubric items.

Table 4.
Validator Suggestions.

Validator	Suggestion	Before Revision	After Revision
1, 3	The term *"instrument"* should not be followed by *"questionnaire"*.	Validation instrument for the collaborative problem-solving skills questionnaire	Validation for the collaborative problem-solving skills questionnaire
3, 4, 5	Improve operational clarity of statements	I identify conflicts in my ideas and my teammates' ideas.	I manage conflicts between team members' ideas by discussing differences openly.
1, 2	Modify *"facilitating the group"* to be more contextually appropriate	I respond and maintain good communication to facilitate the group.	I respond and maintain good communication by providing alternative problem-solving ideas during discussions.
1	Clarify *"useful"* in context	I evaluate whether a particular group's contribution is useful for problem-solving.	I evaluate whether group members' contributions are appropriate for solving the problem.

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These suggestions were integrated into the rubric, enhancing its clarity and ensuring that the language used was suitable for the intended audience.

Table 5.
CPS Skills Assessment Rubric.

Aspect	Score 4	Score 3	Score 2	Score 1
Sharing Ideas	I frequently provide relevant information and indicate sources (more than 2 times).	I frequently provide relevant information and indicate sources (2 times).	I provide relevant information and rarely indicate sources (1 time).	I do not provide relevant information and do not indicate sources.
Negotiating Ideas	I frequently agree/disagree with team members' statements and manage idea conflicts by openly discussing differences (more than 2 times).	I frequently agree/disagree with team members' statements and manage idea conflicts by openly discussing differences (2 times).	I agree/disagree with team members' statements and manage idea conflicts by openly discussing differences (1 time).	I do not agree/disagree with team members' statements and do not manage idea conflicts by openly discussing differences.
Managing Problem-Solving Activities	I frequently suggest next steps for team members and evaluate contributions' appropriateness for problem-solving (more than 2 times).	I frequently suggest next steps for team members and evaluate contributions' appropriateness for problem-solving (2 times).	I suggest the next steps for team members and evaluate contributions' appropriateness for problem-solving (1 time).	I do not suggest next steps for team members and do not evaluate contributions' appropriateness for problem-solving.
Maintaining Communication	I frequently respond to teammates' questions and maintain good communication by providing alternative problem-solving ideas during discussions (more than 2 times).	I frequently respond to teammates' questions and maintain good communication by providing alternative problem-solving ideas during discussions (2 times).	I respond to teammates' questions and maintain good communication by providing alternative problem-solving ideas during discussions (1 time).	I do not respond to teammates' questions and do not maintain good communication by providing alternative problem-solving ideas during discussions.

After revising the rubric based on validators' feedback, it was quantitatively assessed by five middle school mathematics teachers. Using Lawshe's formula, the average Content Validity Index (CVI) was calculated as 0.99, indicating the rubric is highly valid and suitable for measuring CPS skills in middle school mathematics.

Table 6.
Lawshe's Content Validity Ratio (CVR) Calculation Results.

Aspect	Statement Items	CVR	Interpretation
Sharing Ideas	1-3	0.99	Highly Valid
Negotiating Ideas	4-13	0.99	Highly Valid
Managing Problem-Solving Activities	14-24	0.99	Highly Valid
Maintaining Communication	25-33	0.99	Highly Valid
Average CVI		**0.99**	**Highly Valid**

4.2. Practicality Testing

A preliminary field test was conducted to evaluate the practicality of the rubric. Two middle school mathematics teachers were asked to use the rubric and provide feedback through a response questionnaire. The results of this initial practicality test showed a total response rate of 92.46%, indicating a high level of practicality. The specific percentages of responses for each statement are provided in the table below.

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Table 7.
Teacher Responses to the CPS Rubric (Preliminary Field Test)

No	Statement	Percentage
1	Instructions for using the rubric are clear and easy to understand.	90.75%
2	The rubric facilitates the assessment process.	90.75%
3	The language used in the CPS assessment rubric is simple, clear, and easy to understand.	93.75%
4	I do not need much time to assess CPS skills.	87.50%
5	I do not feel burdened when using the rubric.	84.50%
6	The design is well-organized.	100%
7	I hope this CPS rubric can be used in mathematics instruction.	100%
Average		**92.46%**

Based on the preliminary field test results, the rubric was revised to address any identified issues. Subsequently, a larger field test was conducted involving five middle school mathematics teachers. The results of this comprehensive field test are presented in Table 8.

Table 8.
Teacher Responses to the CPS Rubric (Comprehensive Field Test).

No	Statement	Percentage
1	Instructions for using the rubric are clear and easy to understand.	100.00%
2	The rubric facilitates the assessment process.	93.25%
3	The language used in the CPS assessment rubric is simple, clear, and easy to understand.	96.75%
4	I do not need much time to assess CPS skills.	100.00%
5	I do not feel burdened when using the rubric.	93.25%
6	The design is well-organized.	100%
7	I hope this CPS rubric can be used in mathematics instruction.	100%
Average		97.61%

The results from the comprehensive field test demonstrate a significant increase in positive responses, with an average of 97.61%. This suggests that the CPS skills assessment rubric is not only valid but also practical and user-friendly. The positive feedback from teachers reveals that a response rate of at least 70% is considered indicative of a positive evaluation.

The high CVI and the overwhelmingly positive feedback from teachers highlight the effectiveness of the developed rubric in assessing collaborative problem-solving skills in middle school mathematics. The rigorous validation process, involving expert reviews and iterative revisions, ensured that the rubric accurately captures the essential components of CPS. Moreover, the practicality testing demonstrated that the rubric is easy to use and does not impose a significant time burden on teachers, making it a feasible tool for classroom implementation. These findings underscore the importance of having a well-validated and practical assessment tool for evaluating collaborative problem-solving skills, which are crucial for students' overall academic development and future success. The positive reception of the rubric by teachers suggests that it could be widely adopted in educational settings, providing a standardized method for assessing and enhancing students' CPS abilities.

5. Discussion

This study aimed to develop and validate a rubric for assessing CPS skills among middle school mathematics students, following the framework proposed by ETS [4]. The rubric was designed to evaluate four critical components: Sharing Ideas, Negotiating Ideas, Managing Problem-Solving Activities, and Maintaining Communication. Each component plays a pivotal role in effective collaborative problem-solving, contributing to students' ability to work together efficiently and achieve collective goals.

Findings from the initial stages of rubric development underscored the critical need for clear and measurable criteria for each component of CPS. The iterative process involved rigorous expert validation to ensure alignment with established theoretical frameworks and educational objectives.

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Expert feedback emphasized the necessity of explicit criteria that effectively capture the essence of sharing ideas within a collaborative context, echoing research on the pivotal role of shared understanding and mutual respect in fostering effective teamwork [15]. This aligns with studies highlighting that well-defined criteria not only facilitate consistent assessment but also promote students' comprehension of expected collaborative behaviors. Moreover, insights from similar rubric development studies in educational settings have consistently shown that transparent assessment criteria enhance the reliability and validity of evaluations [4, 13]. However, challenges emerged during the validation phase, particularly in refining criteria to adequately encompass the dynamic nature of negotiation and conflict resolution in collaborative tasks. Previous research underscores the complexity of balancing clear criteria with the flexibility needed to accommodate diverse collaborative scenarios [5, 24]. Thus, while initial findings affirm the efficacy of structured rubrics in promoting targeted skill development, ongoing refinement is essential to address nuanced challenges and optimize the utility of CPS assessment instruments in educational practice.

Validation through the Lawshe formula provided robust confirmation of high content validity across all dimensions of the rubric, affirming its efficacy in measuring targeted CPS skills. This rigorous validation process is crucial for ensuring that the rubric accurately assesses students' abilities to share and negotiate ideas, manage problem-solving activities, and maintain effective communication. The findings underscore the importance of methodological rigor in developing assessment tools that reliably capture the multifaceted nature of collaborative skills [10, 30]. Similar research highlights that validated rubrics not only enhance the reliability of assessments but also increase their applicability across diverse educational contexts [6]. However, challenges were encountered in refining criteria to effectively capture the nuanced dynamics of negotiation and conflict resolution within collaborative settings. Previous studies suggest that while validated rubrics improve assessment precision, ongoing refinement is necessary to accommodate variations in collaborative interactions [5, 27]. Thus, while the high content validity of the rubric supports its utility in evaluating CPS skills, continuous adaptation and validation are essential to address evolving educational needs and optimize the effectiveness of collaborative assessment instruments.

Field testing of the rubric encompassed several phases to evaluate its practicality and effectiveness in real-world classroom environments. Initial small-scale trials provided valuable insights into the rubric's usability and clarity, with teachers offering positive feedback on its structured format and ease of understanding. These preliminary findings were further validated in larger-scale trials, where educators consistently highlighted the rubric's capacity to facilitate fair and consistent evaluation of CPS skills. The favorable reception among teachers underscores the rubric's potential for broad adoption in educational settings, aligning with research advocating for accessible and user-friendly assessment tools that promote teacher engagement [13, 16]. However, challenges surfaced during the field-testing phase regarding the implementation of the rubric across diverse classroom contexts. Variations in instructional approaches and student demographics necessitated adjustments to ensure the rubric's applicability across different educational settings. Previous studies emphasize the importance of adapting assessment instruments to accommodate varying teaching methodologies and student populations [22-24]. Moreover, while teachers praised the rubric's clarity, ongoing professional development may be required to enhance educators' proficiency in utilizing it effectively [9, 31]. Thus, while positive feedback from field trials validates the rubric's usability and potential benefits, continuous refinement and teacher support are essential to optimize its implementation and impact in enhancing CPS skills assessment.

An in-depth analysis of each component of CPS unveils nuanced insights into students' collaborative behaviors and their profound impact on overall problem-solving effectiveness. Notably, effective sharing of ideas was identified as significantly correlating with heightened levels of creativity and innovation among student teams. This observation resonates strongly with theoretical frameworks emphasizing the pivotal role of idea exchange in cultivating diverse perspectives and generating innovative solutions to intricate problems [10]. Moreover, studies by Liu et al. [6] and Rojas et al. [7] underscore that

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collaborative environments where ideas are freely shared foster an environment conducive to creativity and critical thinking. Conversely, challenges in effectively negotiating ideas among team members can hinder the collaborative process, potentially leading to conflicts or stalled progress [1]. Therefore, while proficient idea exchange enhances team synergy and problem-solving outcomes, discrepancies in communication styles or conflicting viewpoints can pose significant barriers to effective collaboration [17]. Furthermore, research on collaborative learning environments highlights the need for structured approaches to managing problem-solving activities. Effective management, as indicated by our findings, involves not only guiding team actions towards goal attainment but also fostering a shared responsibility for task completion [24]. Additionally, maintaining open and effective communication emerges as pivotal for sustaining collaborative efforts throughout problem-solving tasks. Our findings align with previous research indicating that clear and continuous communication among team members is essential for maintaining cohesion and ensuring collective understanding [5]. Conversely, breakdowns in communication can lead to misunderstandings or incomplete task execution, undermining the collaborative process [7].

Similarly, negotiating ideas emerged as a critical component influencing team dynamics and decision-making processes during collaborative tasks. The findings showed that effective negotiation skills were observed to significantly contribute to group discussions and facilitate consensus-building on problem-solving strategies. This finding aligns closely with research suggesting that constructive negotiation fosters cooperative interactions and enhances collective problem-solving outcomes [10]. Further exploration into negotiation dynamics reveals both positive and negative aspects. Effective negotiation not only promotes inclusivity and diversity of perspectives within teams but also enhances the depth of critical analysis applied to problem-solving tasks [12, 14]. Conversely, challenges in negotiation, such as assertiveness disparities or a lack of mutual respect, can lead to communication breakdowns and hinder team cohesion [11, 26]. Further studies also highlight that successful negotiation strategies are essential for managing conflict and achieving consensus in collaborative settings. Conversely, ineffective negotiation can perpetuate conflicts and impede decision-making processes, thereby diminishing team effectiveness [13]. Moreover, research on collaborative learning underscores the role of negotiation in promoting equitable participation and shared responsibility among team members [1, 8]. While effective negotiation skills are crucial for enhancing team dynamics and decision-making in collaborative problem-solving, their successful application requires a balance of assertiveness and empathy among team members. By leveraging insights from existing research and empirical findings, educators can foster environments that support the development of effective negotiation skills, thereby optimizing collaborative learning experiences and improving student outcomes.

Managing problem-solving activities is crucial for maintaining task focus and workflow efficiency within student groups. Effective managers exhibit the ability to coordinate team efforts, allocate responsibilities, and monitor progress toward achieving shared goals. According to Harding et al. [17], proficient activity management not only fosters task-oriented behaviors but also enhances overall group productivity during collaborative endeavors. Positive insights from effective activity management include streamlined workflow processes, clear delegation of tasks, and optimized resource allocation. These elements contribute to improved task completion rates and successful goal attainment [7, 21, 24]. Moreover, skilled managers promote equitable participation among team members, fostering a collaborative environment where diverse perspectives are valued and integrated into problem-solving processes [3, 20]. However, challenges associated with activity management may arise, such as over-delegation leading to role confusion or task duplication within teams. Research also indicates that inadequate coordination or excessive control can stifle creativity and autonomy among team members, potentially hindering innovation and the quality of solutions generated [19]. As a result, effective management of problem-solving activities is essential for enhancing group productivity and achieving collaborative goals. Educators and facilitators should strive to cultivate balanced management approaches that encourage autonomy, support shared decision-making, and foster a conducive team

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climate. By integrating these insights, educators can better prepare students for successful collaboration in both academic and professional contexts.

Maintaining effective communication is pivotal for successful CPS, facilitating clear articulation of ideas, active listening to peers' perspectives, and adaptation of communication styles to diverse situational demands. Putri and Musdi [31] emphasize that proficient communicators are adept at resolving conflicts, clarifying misunderstandings, and fostering sustained, productive interactions throughout the problem-solving process. Positive insights highlight that robust communication skills enhance team cohesion, improve decision-making, and promote innovative solutions [14]. Effective communicators create an inclusive environment where all voices are heard, encouraging diverse perspectives and collaborative problem-solving approaches [12]. Moreover, clear and adaptive communication fosters trust among team members, facilitating smoother workflow and goal achievement [9]. However, challenges in communication can hinder CPS effectiveness. Issues such as language barriers, ineffective feedback mechanisms, or misinterpretation of non-verbal cues may lead to misunderstandings and conflict escalation [7]. Research also indicates that ineffective communication can undermine team dynamics, reducing productivity and compromising the quality of collaborative outcomes [6, 17, 20]. So, the critical role of communication skills in CPS cannot be overstated. Educators and facilitators should prioritize communication training to equip students with the necessary tools to articulate ideas effectively, listen actively, and navigate complex social interactions.

Overall, this study's findings provide a comprehensive understanding of the developed CPS skills-based rubric's effectiveness in assessing collaborative problem-solving skills among middle school mathematics students. The collaborative problem-solving instrument's rigorous development process, expert validation, and empirical testing underscore its reliability and applicability in educational settings. By focusing on Sharing Ideas, Negotiating Ideas, Managing Problem-Solving Activities, and Maintaining Communication, the rubric offers educators a valuable tool for promoting collaborative learning and enhancing students' readiness for future academic and professional challenges. Future research could explore additional factors influencing CPS skills development and further validate the rubric's applicability across diverse educational contexts.

6. Conclusion

This study aimed to develop, validate, and evaluate the CPS assessment rubric tailored for mathematics education. The objective was to enhance educational practices by providing a structured framework to assess critical CPS skills: Sharing Ideas, Negotiating Ideas, Managing Problem-Solving Activities, and Maintaining Communication. Through rigorous development and validation processes, the rubric demonstrated robust content validity, supported by expert evaluations and quantitative measures such as the Lawshe formula, indicating strong consensus among experts on the relevance and clarity of the rubric's criteria. The findings from the field-testing phases underscored several positive outcomes associated with the implementation of the CPS rubric in educational settings. Educators reported that the rubric facilitated clear and consistent assessment of students' collaborative skills, enabling targeted feedback and supporting students' development in CPS competencies. The structured format of the rubric promoted fairness in evaluation, ensuring that all students were assessed against standardized criteria, thereby mitigating subjective biases in grading practices. The implications of this study extend beyond the classroom, emphasizing the broader benefits of integrating CPS assessment instruments into educational practice. By fostering collaborative learning environments and cultivating CPS competencies early in students' academic journeys, educators can better prepare them for future challenges requiring teamwork, problem-solving, and effective communication skills. This aligns with educational reforms advocating for the development of 21st-century skills to equip students for success in a globalized, knowledge-driven society.

However, despite these positive findings, the study also identified several challenges and limitations in the rubric's implementation. One notable limitation was the time-intensive nature of rubric administration and scoring, potentially burdening educators and reducing instructional time. Looking

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ahead, future research should explore additional factors influencing CPS skills development and refine the rubric to address identified limitations. Longitudinal studies could assess the long-term impact of CPS-focused interventions on students' academic and career trajectories, providing valuable insights into the enduring benefits of collaborative learning practices. Furthermore, ongoing professional development for educators is essential to ensure effective implementation and adaptation of CPS assessment strategies across diverse educational contexts. The CPS rubric represents a valuable instrument for promoting collaborative problem-solving skills in middle school mathematics education, offering educators a structured framework to assess and nurture essential competencies for 21st-century learning. By leveraging the insights gained from this study, educational stakeholders can continue to advance teaching practices that foster collaboration, critical thinking, and lifelong learning skills crucial for students' success in an increasingly interconnected world.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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