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Developing Chemistry Lesson Plan Design: Integrating Scientific Explanation by CER Framework in STEM Learning

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ABSTRACT

The main supporting component of a comprehensive learning implementation, scientifically prepared according to the chemical context, is developing a chemistry lesson plan. Scientific explanations in chemistry learning often involve causal mechanistic explanations of chemical phenomena, which provide a paradigm for understanding chemical concepts. This research aims to describe how prospective chemistry teachers use scientific explanations to develop CER framework in chemistry lesson plans that align with STEM learning. A descriptive qualitative research design was used. The authors conducted this research on 20 prospective chemistry teachers. This research used the document review, observation, CER framework assessment, and interviews. Prospective chemistry teachers can theoretically and practically prepare chemistry learning plans. The study reveals that prospective chemistry teachers struggle to offer scientific explanations for the concepts they explain through CER framework. Their responses to the CER framework assessment reveal numerous unconnected scientific explanations. One cannot combine evidence and reasoning claims into a systematic unity to explain a chemical phenomenon.

INTRODUCTION

An effective chemistry learning plan considers various aspects such as reform-based curricular materials, scientific explanation dimensions, sustainable social dimensions of chemistry, and integration of scientific engineering in chemistry. Teachers' knowledge and beliefs are critical in implementing a restoration-based chemistry curriculum(Roehrig & Kruse, 2005). Learning plans can integrate scientific and societal dimensions of explanation to create a framework for addressing real-world problems, making chemistry learning more interesting (Feierabend & Eilks, 2011). Lesson plans that focus on increasing students' motivation and providing chemistry's relevance to society can significantly impact students' engagement and learning outcomes (Stuckey & Eilks, 2014). A good lesson plan should lead students to active, joyful, and meaningful learning (Idawati et al., 2022). Additionally, the effectiveness of students' learning during experimental work is an important aspect to consider when designing chemistry learning plans, as it can significantly contribute to developing students' experimental competence (Logar et al., 2017). Teachers should design chemistry lesson plans that integrate various scientific fields, optimizing aspects of scientific explanation to connect concepts and context in chemical science.

Scientific explanations in chemistry learning often involve causal mechanistic explanations for chemical phenomena that provide paradigms for understanding chemical concepts. Explaining scientific ideas is challenging for audiences with disabilities, so clear and effective communication regarding complex scientific concepts is required (Becker et al., 2016; Kapon, 2014). Scientific practice in a teaching context can construct explanations that have the potential to provide high-impact learning activities in chemistry courses, especially through a discovery-based learning approach (Atkinson et al., 2020). In addition, for teachers to provide adequate scientific explanations of chemistry, they must have a solid scientific basis, allowing students to learn concepts comprehensively following everyday life (Karaaslan, 2022). Skills in mechanistic explanations in chemistry lessons attract significant interest due to the focus on exploring, developing, and assessing students' capacity to construct mechanistic explanations in chemistry (Alameh et al., 2023; Macrie-Shuck & Talanquer, 2020). Constructing scientific explanations in chemistry education is a multiphase and challenging endeavor that requires a strong scientific foundation, effective communication, and a deep understanding of chemical mechanisms.

In particular, preparing learning plans and scientific explanations in the chemistry education environment encounters various challenges. Preparation of learning materials by learning indicators and outcomes, especially in mathematics and science subjects (Fitriani, 2021). Another finding was a lack of understanding of higher-order thinking Skills (HOTS), contributing to the challenges faced in preparing learning plans (Kartika et al., 2019). Planning elements that suit the specific needs of diverse learning groups are the core challenges faced when learning plans are drawn up (Antallan et al., 2022)). Prospective chemistry teachers, in the context of preparing learning plans, try to comply with competency achievement indicators and arrange them systematically. However, basic chemistry skills are a problem that is encountered during lectures. The obstacles encountered are due to a lack of basic knowledge and understanding of concepts, which hinders the ability to construct comprehensive scientific explanations (Laksmi et al., 2021). Difficulties are also experienced in modifying scientific explanations based on evidence, resulting in inappropriate reasoning and a disconnect between evidence, reasons, and claims (Lim, 2015). Additionally, a lack of appropriate scaffolding in science teaching has been identified as contributing to students' difficulties in constructing scientific explanations (Yao et al., 2016).

The Claim-Evidence-Reasoning (CER) framework has been applied to enhance students' scientific inquiry abilities, emphasizing using evidence to form explanations in response to scientific problems. This framework is a helpful way to assist students in building scientific explanations that are coherent and evidence-based.(McNeill & Krajcik, 2008). This framework emphasizes the formulation of a claim supported by evidence and justified through reasoning that supports an explanation of a scientific concept (McNeill & Krajcik, 2009; McNeill & Martin, 2011). CER framework can be used to adapt to conditions that exist in everyday life and accordance with scientific explanations of scientific concepts (Novak & Treagust, 2018). This framework directs and facilitates the methods students choose in discovering and trying to explain the scientific phenomena they find out (Novak et al., 2009). Integrating STEM education with scientific explanations is crucial to fostering students' understanding of complex scientific concepts. CER provides a structured approach to developing scientific explanations, essential in STEM education.

Several studies have highlighted the importance of CER framework in improving students' scientific reasoning and understanding of STEM concepts. For example, Nasir et al., (2022) show the positive impact of STEM-based guided inquiry on students' understanding of scientific concepts and problem-solving explanations. Walker et al., (2019) discuss the challenges of facilitating argumentation in the laboratory and the importance of distinguishing claims from hypotheses, data from evidence, and implicit reasoning from explicit reasoning. Beaty et al., (2023) emphasize the role of a scientific mindset in supporting scientific creative thinking, indicating the importance of cultivating scientific creativity in STEM education. This aligns with CER framework, encouraging students to generate original hypotheses and develop innovative scientific explanations. Additionally, in translating expertise into effective teaching, Feldon et al., (2010) underscores the relevance of structured approaches, such as the CER framework, in improving students' scientific explanation skills and overall retention in STEM disciplines. In addition, CER framework has played an important role in overcoming challenges related to managing learning and learning outcomes (Gunawan, 2017).

This research aims to describe the scientific work of prospective chemistry teachers in developing CER framework in planning chemistry lessons. Identification needs to be done to obtain information on the scientific thinking of prospective chemistry teachers in providing scientific explanations based on scientific evidence. This is a significant issue because apart from being able to prepare learning plans well and correctly, prospective chemistry teachers are also expected to explain chemical science phenomena more precisely and in-depth. Integrating the CER framework with STEM education is critical to improving students' scientific reasoning, understanding complex STEM concepts, and fostering scientific creativity. The structured approach provided by the CER framework supports students in building evidence-based scientific explanations, which is fundamental in STEM disciplines.

METHODS

Research Design

This article provides insight into the exploration of processes and procedures in exploring scientific explanations with CER framework in the context of STEM learning. The qualitative research design involves case studies so that details about the application of CER framework in chemistry learning plan design can be explored more optimally. This includes an in-depth exploration of learning plan planning, implementation and results. Qualitative data from interviews, observations, and document analysis will be analyzed thematically to identify patterns and themes related to integrating CER framework in chemistry learning planning.

Research Target

This research was conducted at an Islamic University in Indonesia with a chemistry education study program. This research was conducted in the even semester in February-April 2024. This research was used as a subject for 20 prospective chemistry teachers. The data source used in this research is prospective chemistry teachers who have taken lesson planning and STEM learning courses in chemistry. The specific selection of these two courses was because they were relevant to the problems and themes taken. This is because prospective chemistry teachers must be able to create learning plans that can explain scientific phenomena with appropriate scientific explanations.

Research Data

Research data was obtained through the lesson plan document that had been created, and then a review of the document was carried out regarding the scientific explanation that was created. Lesson plans can be used as initial data for tracing scientific explanations designed by prospective chemistry teachers. Observations were also carried out to see how to make lesson plans and the scientific mindset of prospective chemistry teachers. The data from CER framework that prospective chemistry teachers have filled in is also used as a reference. This data contains CER for chemical cases.

Table 1. CER Framework Chemistry Case

Framework	1	2	3
Claim: answers to your questions. This is also the conclusion you draw from the data	Claims are not related to evidence and reasoning	The claims are related, but only one.	Claims relate to evidence and reasoning. Has good traceability
Evidence: This is the data you obtained from the experiment that supports (or supports) your claim. This may be observations, measurements, calculations, or other information from experiments	Evidence does not or does not explain the experimental results thoroughly and well	Evidence provides some good experimental evidence that supports the reasoning	All evidence is explained comprehensively and supports reasoning
Reasoning: this is what connects your claims and evidence. That's usually the reason. Often, scientific principles, laws, definitions or rules will explain the concepts that occur in an experiment	There is no comprehensive connection in the reasons section, so that scientific explanations in supporting STEM learning do not appear	There is a connection between reasons and others. However, the reasons used are not/not strong enough, so the scientific explanation for supporting STEM learning is not optimal	Reason's connection with others is good. The reasons and claims used are vital so that scientific explanations support STEM learning.

Interviews were conducted to deepen data traceability:

1. What lesson plan has been prepared according to the correct principles? What difficulties did you experience when preparing the lesson plan? What is the reason?
2. What are the difficulties in integrating and promoting lesson plans with scientific explanation CER framework? Please write down these difficulties!
3. What characteristics and skills are developed in learning according to the STEM Learning plan? Please explain!

Research Instruments

The instruments in this research are document review, observation, assessment of CER framework, and interviews. Document studies are used as initial data about the learning plans that have been made. The document used is a chemistry lesson plan created by prospective chemistry teachers. The RPP created is based on the availability of the scientific explanation designed. Scientific explanation focuses on CER framework in chemistry learning plans. Observations were made by looking at how to convey CER framework in the preparation and implementation of CER framework. The aspects observed at the core of learning include a scientific explanation in CER framework. The claim aspect is a statement to understanding a phenomenon, result, or investigation. The evidence aspect is scientific data used to support the claim. The reasoning aspect ties together the claim and the evidence. Apart from that, the learning model used is also compatible with scientific explanation methods. The CER framework assessment provides a score for each chemistry case assessment given to prospective chemistry teachers. CER framework in this research was validated using the Gregory formula by getting a validation score 1, so it meets the content validation criteria. Interviews are conducted to deepen and confirm the data that has been obtained and then conclude. Interviews were conducted after the CER framework assessment. The interview is intended to be more convincing about the correct connection between lesson plans, scientific explanations with CER, and STEM learning.

Data Analysis

Data analysis is carried out by discussing the process of examining and interpreting data to obtain meaning and develop empirical knowledge, which may be relevant to qualitative data analysis in research (Bowen, 2009). Triangulating data is conducted in this research, which increases the reliability of the results and can be referred to as a qualitative analysis (Lauri, 2011). Data triangulation was carried out on learning plan documents, CER framework assessments, and interviews. The entire data is reduced, and several important "codings" are selected, which then become research results and are discussed. Numerical data is described and explained in the results obtained. The findings and discussion stages will use these two mutually supporting data.

RESULT AND DISCUSSION

Chemistry learning designs are created by prospective chemistry teachers to be used as preparation for practical work in the field. Learning plans are made in two main types: the "curriculum 2013" and "curriculum merdeka". This research focuses on the "curriculum merdeka". This is because the implementation of this curriculum will be massive in the next few years, so it is necessary to prepare a documented plan to make it more optimal. Lesson plans that focus on a broader understanding of the role of chemistry in students' daily lives and society, rather than overloading them with pure chemistry content knowledge, have been found to enhance students' perceptions of the relevance of chemistry learning (Zowada et al., 2020). Furthermore, developing culturally relevant chemistry pedagogy and computer-based lesson plans tailored to specific educational environments are essential for effective chemistry teaching and learning (Rodenbough & Manyilizu, 2019).

The design of chemistry lesson plans for prospective chemistry teachers is based on recommended learning models and is suitable for scientific thinking. The models and reasons for selecting each learning model are presented below.

Table 2. Learning Models in Chemistry Learning Plans

Learning Model	Reasons for Election
Problem-Based Learning	1. PBL encourages students to learn based on the problems they encounter 2. Improve understanding of chemistry content 3. Learning syntax can be applied by teachers and students
Project Based Learning	1. Involve students in learning collaboratively and have a timeline for completing a project 2. Build creativity in solving a problem 3. Real learning by placing knowledge in the context of real projects
Discovery Learning	1. Provide opportunities to find solutions to problems that fit the chemical context 2. Foster independent learning and collaboration between students 3. Increase student learning motivation
Inquiry Learning	1. Develop critical and creative thinking skills 2. It can be used on various chemical materials
Cooperative Learning	1. Learning is fun and can be played with games 2. Learning invites group collaboration and rewards

The learning model above is most commonly found in learning plans prepared by prospective chemistry teachers. Problem-based learning can deliver a deep understanding of environmental chemistry and an efficient learning methodology (Jansson et al., 2015). The Blended-Problem Learning method can be effectively used to understand the concept of oxidation reactions (Musyarofah et al., 2020). Project-based research is recommended in teaching and learning situations because it provides opportunities for students' active participation and development of their creativity (Mahasneh & Alwan, 2018). Discovery learning influences students' learning abilities in buffer material and can integrate students' self-regulation. (Permatasari & Laksono, 2019). The STEM-integrated inquiry learning model effectively develops the ability to think critically and dynamically on thermochemical topics. (Sutoyo et al., 2019). Activities and learning outcomes in redox reaction material increase with guided inquiry equipped with chemistry mind map media (Hidayah et al., 2021). Cooperative learning encourages students to be active and participatory so that it provides better learning results compared to conventional methods (Simesso et al., 2024)

In learning during lectures, scientific explanations are carried out to explain scientific phenomena where there are gaps and problems in the learning plan. Even though prospective chemistry teachers can create exciting lesson plans according to the expected learning model, they cannot fully explain how science works in chemistry. Focus on learning plans that discuss the theme of redox reactions. Redox is a phenomenon commonly encountered in everyday life. It is necessary to see how redox works in chemical reactions in the laboratory. Explanations of redox reactions will be easier to understand and accept if a suitable model is used. Interactive and compensatory learning models can improve chemistry teaching(Crippen et al., 2005). According to them, appropriate learning models will help explain science. The difficulties in implementing this model include limited time, abstract chemical concepts, and the inability to develop a more integrative learning model that supports STEM learning.

Learning planning that includes STEM in learning is currently a trend for secondary schools. STEM learning is one of the reasons why the explanation must be systematic, measurable and conceptual in chemistry (Fitriyana et al., 2021). According to prospective chemistry teachers, STEM characteristics can develop problem-solving, critical thinking, collaboration and creativity skills. STEM provides an understanding of science, technology, engineering, and mathematics through practical approaches and problem-based projects (Moore & Smith, 2014). These many benefits are why STEM should be an option in the learning process, which can later become the first step in scientific thinking. In the context of its learners, STEM requires a scientific method, one of which is scientific explanation.

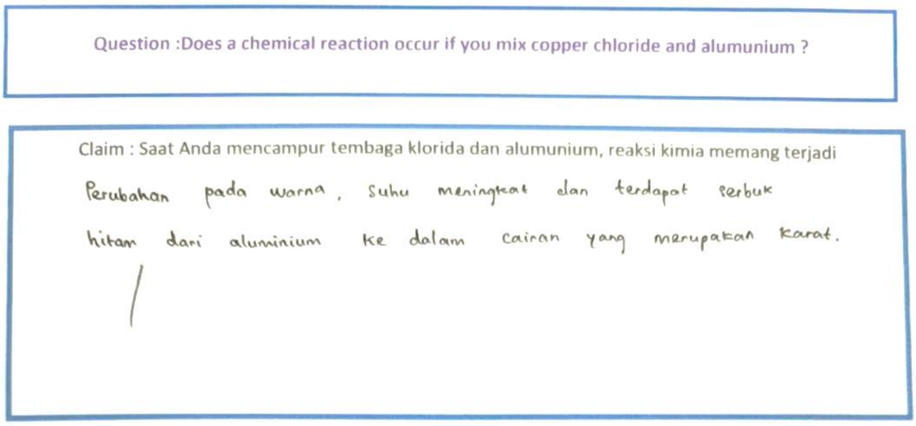
This research tries to explain a scientific explanation that attempts to explain a phenomenon's cause-and-effect relationship. Redox reactions are phenomena selected by mixing oxidized and reduced substances. This scientific explanation was tried using $CuCl_2$ and Aluminum practicum. The findings obtained by prospective teachers are that they still have difficulty finding the proper context for scientific and chemical explanations. Scientific explanations that are integrated into learning are CER framework, which is commonly used in STEM learning. The following are the results of scientific explanations by prospective chemistry teachers in answering scientific phenomena regarding the reaction of $CuCl_2$ and Aluminum.

Table 3. Results of CER Framework Chemical Reactions

	Answering		
Framework	**1**	**2**	**3**
Claim	50%	30%	20%
Evidence	15%	75%	10%
Reasoning	20%	55%	25%

The data above was obtained from 20 prospective chemistry teachers who answered about CER framework of $CuCl_2$ and Aluminum. The percentage is obtained from the answers they gave. The value shows the ability to answer scientific explanations. The CER results show that Claim gets the most dominant value of 1, Evidence gets the most dominant value of 2, and reasoning gets the most dominant value of 2. In the answers given by prospective chemistry teachers, Claims found difficulties in drawing complete conclusions regarding various phenomena that had been put into practice. In terms of evidence, the answers produced by prospective chemistry teachers can provide some good experimental evidence and support reasoning but cannot explain it thoroughly. Reasoning does not get maximum points because the reasons used to support scientific evidence cannot provide scientific explanations to support STEM learning. This causes the method of scientific explanation in STEM not to be optimal.

Claims, conclusions, or opinions from prospective chemistry teachers regarding scientific explanations were found to be complicated. Prospective chemistry teachers, in making claims, still write evidence, not their views, from the results of the observations they have provided.


Question :Does a chemical reaction occur if you mix copper chloride and alumunium ?

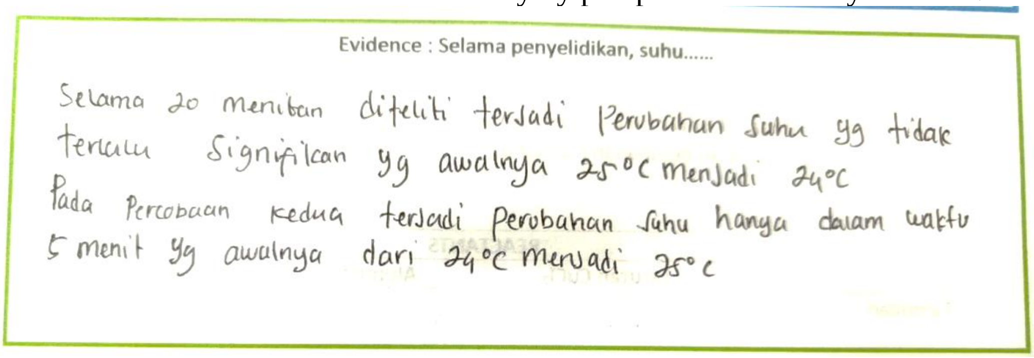
Claim : Saat Anda mencampur tembaga klorida dan alumunium, reaksi kimia memang terjadi

Perubahan pada warna, suhu meningkat dan terdapat serbuk hitam dari aluminium ke dalam cairan yang merupakan karat.

Figure 1. Answers to Claim of Chemical Reaction

At this claim stage, most prospective chemistry teachers still have opinions about what they see, which is not the result of scientific reasoning obtained when looking at various chemical phenomena that have occurred. Claims are the initial construction of scientific reasoning (McNeill & Krajcik, 2008). Based on the results of the CER framework pencil writing regarding the chemical reaction of $CuCl_2$, which reacts with Aluminum Foil, prospective chemistry teachers should provide an answer in the form of a conclusion. The claims that are filled in become like evidence because they discuss various indicators of changes in substances. They answered according to the phenomena they saw but did not correctly connect the claims they wrote. At this stage, they can write down what comes to their mind after seeing this chemical reaction. According to Osborne & Patterson (2011), A scientific explanation of a claim represents a conclusion about an issue, evidence supporting the claim, and reasons justifying why the evidence supports the claim. This is in line with the research of Atkinson et al., (2020), which defines an explanation as consisting of claims, evidence, and reasons, with claims as statements that answer research questions and evidence as data that supports claims, and reasons. explain evidence using relevant scientific concepts.

Evidence that appears from scientific explanation with several observations made and filling in the results of the observations. As a result of the observations, most prospective chemistry teachers could write them down well. The findings obtained at this evidence stage were not all evidence written down entirely by prospective chemistry teachers.


Evidence : Selama penyelidikan, suhu......

Selama 20 menitan diteliti terjadi Perubahan suhu yg tidak terlalu signifikan yg awalnya 25°C menjadi 24°C Pada Percobaan kedua terjadi perubahan suhu hanya dalam waktu 5 menit yg awalnya dari 24°C menjadi 25°C

Figure 2. Answers to Evidence of Chemical Reactions

Evidence provides several indicators of appearance, temperature, colour, state of matter and other changes. The answers obtained are still about temperature changes or colour changes. This evidence should be written from the beginning before the change occurs until the change occurs at the end of the chemical reaction. Not all of the evidence written is included in the evidence column. This causes prospective chemistry teachers to be less than optimal in responding to the reaction results, which are shown as evidence of the chemical reaction between $CuCl_2$ and Aluminum Foil. Evidence in scientific explanations is about presenting data, interpreting and presenting evaluations, formulating and revising explanations effectively (Ruiz-Primo et al., 2010). Incorporating evidence in scientific explanations is essential to developing a deep understanding of scientific concepts. Engaging in scientific practices, such as collecting, discussing, and interpreting data, better prepares to construct meaningful explanations supported by evidence (Islakhiyah et al., 2017). Evaluation of evidence and the ability to restructure beliefs based on new or anomalous evidence are fundamental aspects of scientific reasoning (Venkadasalam et al., 2024)

Reasoning provides answers that are connected to the evidence that has been provided. This relates to scientific principles, laws, definitions, or rules that will explain the concepts in an experiment.

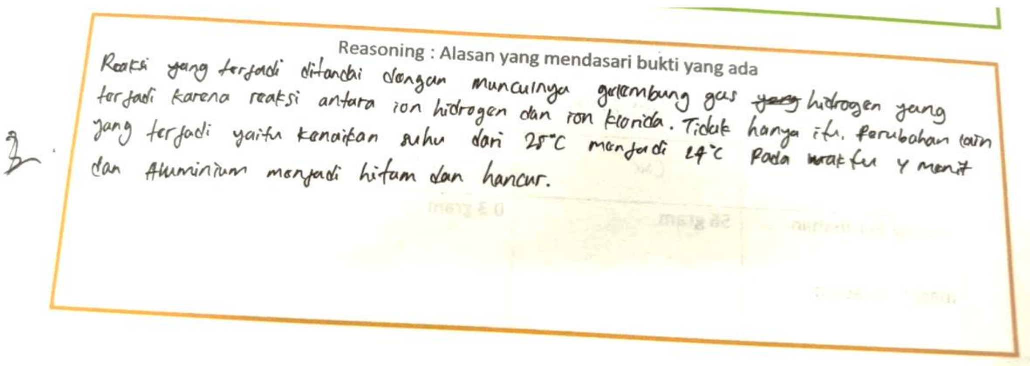


Figure 3. Answers to Reasoning Chemical Reactions

Unlike copper, aluminium foil is more reactive when placed in a copper salt solution. The aluminium atoms on the surface of the foil react with the solution and replace the copper(II) ions in the solution, which is now an aluminium chloride solution. In chemistry, aluminium "displaces" copper from salts, so a brown solid copper powder forms from copper(II) ions forced out of the solution. In the reasoning section, prospective chemistry teachers have not provided the underlying reasons for the evidence, so some previously presented evidence has not been concluded as a claim. Prospective chemistry teachers can still not summarize a claim, evidence and reasoning with a scientific explanation based on reasoning.

Reasoning shows the logical relationship between data and conclusions drawn in scientific explanations. Becker et al., (2016) highlight that scientific explanations can utilize various types of reasoning, such as legal reasoning, rules, statistics, and causal relationships. Every kind of reasoning contributes to the coherence and power of scientific explanations. Scientific reasoning provides a different perspective and approach to support claims with evidence effectively. McNeill & Krajcik, (2008) emphasize that reasoning in scientific explanations is very important for building valid arguments and explanations. Learners are encouraged to justify their claims using evidence and scientific principles, honing their reasoning skills and increasing their understanding of scientific concepts. Songer & Gotwals (2012) underline the importance of reasoning in scientific explanations by defining reasoning as one of the critical components alongside claims and evidence. This comprehensive view of the construction of scientific explanations emphasizes the role of reasoning in claims that are well-supported and logically connected to the evidence presented.

Scientific explanations are a form of support for STEM (Science, Technology, Engineering, and Mathematics) learning. The study from Freeman et al., (2014) showed that active learning significantly improves student performance in STEM fields. Scientific explanation, as highlighted by Pitaloka et al., (2021), using framework such as Claim-Evidence-Reasoning (CER), can improve skills aligned with the Next Generation Science Standards (NGSS) and deepen understanding of scientific concepts. As discussed by Laksmi et al., (2021), applying Problem-Based Learning can also improve students' scientific explanation abilities, especially in biology education. Songer & Gotwals (2012), emphasize the importance of supporting the reasoning component of explanations to develop scientific explanations that integrate core ideas with scientific practice. These strategies and framework can encourage scientific reasoning and improve STEM learning outcomes.

CONCLUSION AND RECOMMENDATIONS/IMPLICATIONS

The conclusion is that a suitable model is needed for chemistry lesson planning that incorporates STEM learning. Combining and including this suitable learning model into a scientific explanation must be possible. It facilitates STEM learning, which aspiring chemistry teachers can investigate or clarify. It is essential because CER can offer framework paths that aid scientific explanations. In theory and practice, prospective chemistry teachers can create lesson plans, but they are not qualified to provide scientific justifications for the ideas that have been presented. They are unable to develop thorough lesson plans. The assertion that logic and evidence cannot be combined to explain chemical phenomena systematically serves as proof for this discovery. In this instance, the chemical phenomenon is the chemical reaction of $CuCl_2$ and Aluminum Foil. An unrelated scientific explanation was evident from their answers in the framework assessment. The dominant answer shows no optimal point in the scientific explanation of the redox reactions of $CuCl_2$ and aluminium.

CER framework can be a way to support scientific explanations that are in line with STEM learning. This framework can be used for science-based students in chemistry, physics, mathematics, and biology, and it has a design that can be adapted to the scientific context. Suggestions for research in prospective chemistry teachers can include or integrate CER framework, especially in parts that require a scientific explanation project. CER framework can be improved by combining various approaches, reasoning and scientific methods. The limitation of this research is that the research is only limited to prospective chemistry teachers and is only carried out on small subjects. More significant subjects can be carried out on science candidates in other study programs. In addition, the focus of this research is limited to learning planning and CER framework.

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