
The Effect of Argument-Driven Inquiry Using the Science, Environment, Technology, and Society Approach on Students' Critical Thinking Skills in Thermochemistry Instruction

Muzainah¹, Muntholib^{2*}, Munzil², Yessi Afriyenni³

¹Students of Master's Program in Chemistry Education, Department of Chemistry, State University of Malang, Indonesia

²Lecturers in the Chemistry Education Program, Department of Chemistry, State University of Malang, Indonesia

³School of Physics, The University of New South Wales (UNSW), Sydney, Australia

*Corresponding author's email: muntholib.fmipa@um.ac.id

Article History:

Received date: December 28 2023

Received in revised from: January 13 2024

Accepted date: March 2 2024

Available online: April 19 2024

Citation:

Muzainah, Muntholib, Munzil, & Afriyenni, Y. 2024. The effect of argument-driven inquiry using the science, environment, technology, and society approach on students' critical thinking skills in thermochemistry instruction. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 12(2):354-363.

Abstract. Thermochemistry is a challenging topic in chemistry learning due to students' difficulty in grasping its concepts, often stemming from a lack of critical thinking skills (CTS). This study investigates the impact of using argument-driven inquiry (ADI) learning with a science, environment, technology, and society (SETS) approach on the critical thinking skills of high school students studying thermochemistry. This research, employing a quasi-experimental design with a pretest and posttest control group, involved 46 students divided into a control and experimental group. The control group received ADI learning, while the experimental group received ADI learning with the SETS approach. The instrument used in this research is a CTS test on thermochemistry. It contains five valid questions and has a reliability score of 0.708. The analysis was performed using the Independent t-Test. The CTS test results revealed a significant difference between the groups with the experimental group (15.91) scoring higher than the control group (12.78). This suggests that incorporating the SETS approach into ADI learning can enhance students' CTS.

Keywords: Argument driven-inquiry, SETS, critical thinking

Introduction

The 21st century is marked by rapid advancements in science and technology. This progress drives the need for individuals to possess strong skills in analyzing and evaluating deeply, one of which is critical thinking skills (CTS). As mentioned by Sawitri et al., (2023), the importance of CTS in the 21st century lies in providing individuals with the ability to analyze, evaluate, and interpret logically and rationally.

Critical thinking is important in the educational environment because it can help students gain a more complex understanding of the information presented to them (Dwyer et al., 2014). Furthermore, Lu et al., (2020) found that critical thinkers can make wise decisions and reasonable judgments when faced with situations that require solving complex problems. Jiang & McComas' (2015) also suggests that the ability to think critically and ask questions is the foundation of Learning and independent research. This is why the ability to think critically is crucial for students to possess.

One way to enhance students' critical thinking skills is by implementing an appropriate learning model, such as argument-driven inquiry (ADI). This model

integrates argumentation and inquiry methods to stimulate critical thinking and problem-solving. ADI is a well-integrated learning model with effective argumentation and inquiry methods (Kaçar & Balim, 2021). Ginanjar et al., (2015) indicates that the methods developed in the ADI model can train students' scientific argumentation skills, thereby improving their critical thinking abilities. Additionally, ADI is developed with the goal of transforming conventional teaching approaches, providing students with the opportunity to learn through reflective processes in scientific investigations, ultimately enhancing their abilities in argumentation and critical thinking (Kadayifci & Yalcin-Celik, 2016). Therefore, the ADI learning model requires students to engage in argumentation throughout the learning process.

Students' CTS can be optimized by combining them with the science, environment, technology, and society (SETS) approach. SETS allows students to recognize real-life problems, gather data for problem solutions, and consider alternative solutions (Seyhan & Okur, 2021). This approach has great potential to improve students' CTS by focusing on the interconnection between science, environment, technology, and society. Research conducted by Ozer et al., (2021) shows that the SETS approach can examine technology in terms of science, environment, technology, and society elements simultaneously. SETS as an approach also shapes individuals with scientific and technological literacy, fostering concern for societal and environmental issues (Imaduddin & Hidayah, 2019).

The ADI-based SETS learning model is particularly suitable for application in one of the chemistry topics, namely thermochemistry. According to experts, this subject requires conceptual understanding and training that involves considerable thinking. Thermochemistry is a branch of chemistry that studies the relationship between energy changes and the state of matter during a chemical reaction (Obaya-Valdivia et al., 2022; Rusci & Bross (2019). Thermochemistry is closely related to everyday life, and its phenomena can be directly observed, such as dew on a glass containing ice as an exothermic reaction.

The thermochemistry topic, as part of the chemistry curriculum, presents its own challenges in students' conceptual understanding. Several studies indicate that students often struggle to comprehend thermochemistry concepts and lack the ability to apply CTS to related problems (Rahmayani, 2017; Rahmi & Azra, 2023; Sihaloho et al., 2021). In addition to the challenging thermochemistry concepts, students' difficulties are also attributed to inappropriate teaching methods employed by teachers (Sokrat et al., 2014). Therefore, the ADI learning model combined with the SETS approach holds great potential for enhancing students' critical thinking skills in thermochemistry.

Previous researchers have focused on studies related to improving critical thinking skills through the application of various learning models, such as problem-based learning (Seibert, 2021), guided discovery-based modules (Sawitri et al., 2023), inquiry-based learning (Safitri & Mediatati, 2021), and inquiry-based learning models (Maryam et al., 2020). While efforts have been made to enhance CTS through these models, previous studies have not detailed their influence on students' CTS specifically in the context of thermochemistry. Particularly, the application of ADI based on the SETS approach to students' CTS in thermochemistry has not been fully explored. Therefore, there is a gap that needs to be addressed to enrich insights into the potential combination of ADI and SETS in improving students' CTS. This research will provide a significant contribution to the literature by offering a deep understanding of the effectiveness of this learning approach in the context of chemistry and may open opportunities for developing more efficient and contextual learning strategies.

Methods

This research was conducted at Nasional High School Malang in the academic year 2023/2024, focusing on the subject of thermochemistry. The study employed a quasi-experimental design with a pre-test and post-test control group design, involving a total of 46 students. The research design can be seen in Table 1.

Table 1. Quasi-experimental design with pre-test and post-test control group design

Score	Treatment	Score
Pretest	Learning with the ADI model based on SETS.	Posttest
Pretest	Learning using the ADI learning model.	Posttest

This research was conducted in the following stages: (1) preparation, (2) implementation, and (3) evaluation. The planning stage involved preparing the design and learning strategies, instructional materials, and assessment instruments. The implementation stage included a series of data collection activities in the field according to the established plan. The evaluation stage comprised preparing reports, correcting post-test answers, processing data, analyzing data, composing discussions, and drawing conclusions. The research design implemented can be seen in Table 2.

Table 2. Learning experiences of the control class (ADI) and the experimental class (ADI-SETS)

Learning Steps	Learning Experience	
	ADI learning model	ADI model based on SETS
Task identification	Students identify research topics based on the presented context	Students identify research topics related to issues, phenomena, and scientific problems in everyday life.
Data Collection	Students conduct investigations through laboratory activities.	Students conduct investigations through laboratory activities.
Data Analysis and Tentative Argument Production	Students analyze data, construct arguments to answer investigative questions based on claims, data, and warrants	Students analyze data, construct arguments to answer investigative questions based on claims, data, and warrants. Students analyze the connections between Science, Environment, Technology, and Society related to the material being studied.
Argumentation Session	Students share arguments related to the decisions made in groups.	Students share arguments related to the decisions made in groups.
Conducting reflective and explicit discussions	Further discussion on the material topic and its application in the presented context at the beginning.	Further discussion on the material topic and its application in the context presented at the beginning.

In this research, the population consists of all students in the eleventh grade at Nasional High School Malang, totaling 5 classes. The sample is drawn from classes XI-A and XI-B in the science program, each with 23 students. Class XI-B serves as the control group, while Class XI-A serves as the experimental group. Convenience Sampling is used

as the sampling method since the researcher collects data from readily available samples, namely students from classes XI-A and XI-B.

The study employs five essay test questions designed with consideration for different critical thinking indicators. These indicators refer to interpretation, analysis, inference, evaluation, and explanation, developed by Facione. Students' responses are assessed based on a critical thinking scoring guide. Each question is scored on a scale of 0-4 (Attached), allowing a maximum score of 20 for each student. This test is conducted before and after the learning process, both in the experimental and control groups, to evaluate students' CTS related to thermochemistry.

Before the test is administered, the questions are tested on 18 students who have studied thermochemistry to determine their validity and reliability. The validity is assessed using the Pearson correlation product moment test with the assistance of SPSS 26, indicating significant values for each question, with values greater than 0.05, demonstrating the validity of the test questions. Furthermore, the reliability of the questions is tested using Cronbach's Alpha, yielding a value of 0.708, which is greater than 0.60, indicating that the questions are reliable for measuring students' critical thinking abilities.

To assess whether students have met each CTS indicator in solving problems presented in the test questions, the evaluation can be conducted based on the percentage score which was calculated by achieved score divided maximum score on the percentage scale. The percentage results of the evaluation of CTS are then categorized according to the information provided in Table 3.

Table 3. Categories of Critical Thinking Skill Percentages

Interval Values (%)	Kategori
$81.25 < X \leq 100$	Extremely High
$71.50 < X \leq 81.25$	High
$62.50 < X \leq 71.50$	Medium
$43.75 < X \leq 62.50$	Low
$0 < X \leq 43.75$	Extremely Low

The research data was analyzed through an Independent t-test to examine whether there is a difference in CTS between the experimental class, which received treatment in the form of the ADI learning model based on SETS, and the control class, which was taught using only the ADI model.

Results and Discussion

Data was collected through pretest and posttest questions given to students learning using the ADI learning model based on SETS and students learning using the ADI model. The pretest data were collected after the pilot test and before any treatment was given, both in the experimental and control classes. Pretest data collection aimed to determine the equivalence of initial abilities in CTS between the two classes selected as samples in this study. Pretest data on critical thinking skills in thermochemistry for students in class XI-A (experimental) and XI-B (control) at Nasional High School Malang are presented in Figur 1.

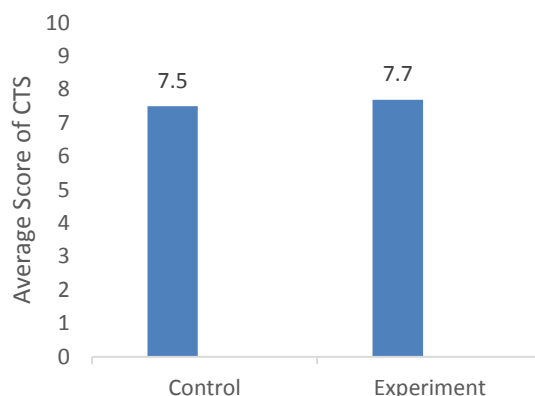


Figure 1. Average Pretest Scores for the Experimental Class and Control Class

The data in Figure 1 shows that the average scores of students in CTS for the experimental class are 7.5, and for the control class, it is 7.7. Based on this data, the initial abilities of students in both classes are not significantly different. Therefore, it can be concluded that both classes have the same or equivalent initial abilities. To verify this equivalence, a test of equality of two means was conducted using an independent t-test. Before conducting this test, normality and homogeneity tests were first performed using SPSS 26 for Windows. The normality test results for the pretest indicate that the data are normally distributed with a Sig. value of $0.157 > 0.05$ for the experimental class and a Sig. value of $0.057 > 0.05$ for the control class. Then, the homogeneity analysis of the pretest results shows a significance value greater than 0.05, namely 0.188, indicating that the pretest data are homogeneous. Furthermore, the test of equality of two means obtained a significant value of 0.726, proving that there is no difference in the initial abilities of students in the experimental and control classes regarding CTS.

After the pretest, both classes were taught thermochemistry material for six sessions. In Class XI-A (experimental), the ADI learning model based on SETS was applied, while in Class XI-B (control), the ADI learning model was applied. Then, after completing the instruction, a posttest was administered to assess the improvement in students' CTS after studying thermochemistry. The posttest results for the experimental and control classes can be seen in Figure 2.

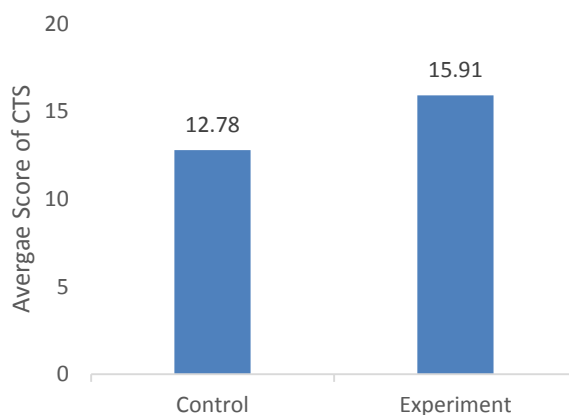


Figure 2. Average Scores for the Experimental Class and Control Class

Figure 2 shows a difference in the average scores between the experimental and control classes. The average score for students' CTS in the experimental class is 15.91, while in the control class, it is 12.78. To examine the difference in the results of ADI-SETS learning in the experimental class, an Independent t-Test was conducted. Prior to this, prerequisite tests were performed to assess the normality and homogeneity of posttest data. The normality test results for the posttest indicate that the data are normally distributed, with Sig. values of 0.141 for the experimental class and 0.192 for the control class. Furthermore, the homogeneity test indicates homogeneous data with a Sig. value of 0.384.

The hypothesis test using Independent t-Test was conducted based on the posttest scores of students' CTS between the experimental and control classes. The results of this hypothesis test are presented in Table 4.

Table 4. Hypothesis Testing Results

Skill	Class	Std. Deviation	Significant	Interpretation
Critical Thinking	Experimental	2.968	0.003	There is a significant difference.
	Control	3.717		

Table 4 displays the results of the hypothesis test regarding students' CTS between the experimental and control classes. The test results show a Sig. value of 0.003, which is less than the significance level of 0.05. This means that there is a significant difference in the CTS of students who received instruction using the ADI learning model based on SETS compared to students who used the ADI model for thermochemistry.

Furthermore, the improvement in students' CTS regarding thermochemistry is categorized based on CTS indicators. The CTS indicators used in this study include interpretation, analysis, conclusion, evaluation, and explanation. Details of the improvement in CTS for each indicator can be seen in Table 5.

Table 5. Recapitulation of students' improvement in CTS for each indicator

Critical Thinking Skills Indicators	ADI Learning Model		Improvement t (%)	ADI learning model based on SETS		Improvement (%)
	Pretest Average (%)	Posttest Average (%)		Pretest Average (%)	Posttest Average (%)	
Interpretation	52.2	73.9	21.7	48.9	79.93	31.03
Analysis	42.4	70.7	28.5	40.9	78.3	37.4
Inference	40.2	70.7	30.5	35.9	84.4	48.5
Evaluation	35.9	63.0	27.1	32.6	80.4	47.8
Explanation	19.6	41.3	21.7	31.5	75.5	44.0
Average	38	63.9	25.9	37.8	79.6	41.74

Based on Table 5, students' CTS in both the control and experimental classes were initially categorized as low during the pretest, with percentages of 38 % and 37.8%, respectively. The final test results indicate that the control class achieved a percentage of 63.9%, categorized as moderate. Meanwhile, the experimental class obtained a post-test score of 79.6, falling into the high category. Considering the average increase, the rise in CTS for the experimental class (41.74%) was higher than that for the control class (25.9%). Thus, it can be concluded that the use of the SETS approach in the ADI model proves to be more effective in enhancing students' CTS compared to using the ADI teaching model alone.

The analysis of pretest, posttest, and the improvement in students' CTS for each indicator indicates that the ADI learning model based on SETS can enhance critical thinking

skills more effectively than the application of the ADI model alone. The integration of SETS requires students to use their reasoning abilities to establish connections between science, technology, the environment, and society (Mahlianurrahman et al., 2023). Consequently, students are challenged to analyze, research, seek information, and apply new concepts in science that have been constructed in real-life situations with the use of specific technology and its impact on the environment and society.

The relevance of concepts to everyday life is one of the key factors contributing to the success of this model in motivating students to delve deeper into thermochemistry material. The implementation of the ADI learning model based on SETS can associate scientific concepts with real-world situations known to students. Integrating social and environmental contexts into learning strengthens scientific concepts and provides meaningful significance for students (Budi & Sunarno, 2018; Perdana & Rosana, 2023).

Additional support for these findings is found in the ADI model's focus on scientific argumentation skills, which has empirically proven to enhance students' conceptual understanding and CTS (Alvionita & Supardi, 2020). The ADI-based SETS model, placing scientific argumentation at the core of the learning process, has a positive impact on shaping students' scientific thinking. By designing activities that encourage students to develop their own scientific arguments, teachers create a reflective and profound learning environment. Therefore, it is crucial for teachers to pay attention to and facilitate scientific argumentation practices in the context of thermochemistry learning, ensuring that students not only master concepts but can also articulate their opinions scientifically.

In detailing the indicators of CTS, the analysis results also demonstrate that the ADI model based on SETS provides a greater improvement in each aspect, including interpretation, analysis, inference, evaluation, and explanation. These findings align with the research by Handayani et al., (2020), which showed a significant increase in students' attitudes and skills in arguing, designing, researching, analyzing, interpreting data, and writing scientific papers. These results strengthen the argument that the SETS approach is not only effective overall but also capable of creating a positive impact on various dimensions of CTS. Students are actively involved in sorting information, prioritizing various details, identifying connections between information, and seeking the foundations that support argument formation. Thus, this approach can serve as an exercise for students to enhance their critical thinking abilities.

In ADI-based learning, students are less prepared to solve problems related to the learned concepts. They are not introduced to new knowledge to invest in real-life issues. Consequently, students do not have the opportunity to apply their knowledge to a broader real-world context. Students taught with an argumentation-based learning model are trained to discover concepts only in their own experiences (Riyanti et al., 2023). In their activities, they investigate to gather data to form strong arguments to enhance their thinking skills.

Conclusion

From the research results and analysis, it can be concluded that the ADI approach, combined with the SETS approach, proves effective in enhancing students' CTS. This is evident from the results of the independent t-test, showing a significance value of 0.003, which is smaller than the significance level of 0.05. The average score of the experimental group (15.21) is also proven to be higher than that of the control group (12.78). The implications of this research indicate that the use of ADI learning combined with the SETS approach has a positive impact on improving students' CTS. The ADI model using the SETS approach provides an opportunity for students to think holistically about the relationship between chemistry and technology, as well as its application in the context of the environment and society. Additionally, this research also indicates that this approach can help students understand how chemistry interacts with technology around them. It enables

students to connect their learning to real-world applications in daily life, reinforcing their understanding of concepts and the relevance of chemistry in practical contexts.

References

- Alvionita, D. & Supardi, Z.A.I. 2020. Problem based learning with the SETS method to improve the student's critical thinking skill of senior high school. *IJORER: International Journal of Recent Educational Research*, 1(3):246–260. <https://doi.org/10.46245/ijorer.v1i3.46>
- Budi, A.P.S. & Sunarno, W. 2018. Natural science modules with SETS approach to improve students' critical thinking ability. *Journal of Physics: Conference Series*, 1022(1): 12015. <https://doi.org/10.1088/1742-6596/1022/1/012015>
- Dwyer, C.P., Hogan, M.J., & Stewart, I. 2014. An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, 12:43–52. <https://doi.org/10.1016/j.tsc.2013.12.004>
- Ginanjari, W.S., Utari, S., & Muslim, M. 2015. Penerapan model argument-driven inquiry dalam pembelajaran IPA untuk meningkatkan kemampuan argumentasi ilmiah siswa SMP. *Jurnal Pengajaran MIPA*, 20(1):32–37. <https://doi.org/10.18269/jpmipa.v20i1.559>
- Handayani, D., Sutoyo, S., & Sanjaya, I.G.M. 2020. Effectiveness of the teaching materials based on argument driven inquiry learning model for practicing students critical thinking skills. *International Journal of Scientific and Research Publications*, 10(3): 477–481. <https://doi.org/10.03.2020.p9957>
- Imaduddin, M. & Hidayah, F.F. 2019. Redesigning laboratories for pre-service chemistry teachers: From cookbook experiments to inquiry-based science, environment, technology, and society approach. *Journal of Turkish Science Education*, 16(4):489–507. <https://doi.org/10.36681/tused.2020.3>
- Jiang, F. & McComas, W.F. 2015. The effects of inquiry teaching on student science achievement and attitudes: Evidence from propensity score analysis of PISA data. *International Journal of Science Education*, 37(3):554–576. <https://doi.org/10.1080/09500693.2014.100042>
- Kaçar, S. & Balim, A.G. 2021. Investigating the effects of argument-driven inquiry method in science course on secondary school students' levels of conceptual understanding. *Journal of Turkish Science Education*, 18(4):816–845. <https://doi.org/10.36681/tused.2021.105>
- Kadayifci, H. & Yalcin-Celik, A. 2016. Implementation of argument-driven inquiry as an instructional model in a general chemistry laboratory course. *Science Education International*, 27(3):369–390. <https://eric.ed.gov/?id=EJ1118430>
- Lu, Y.-Y., Lin, H., Smith, T.J., Hong, Z.-R., & Hsu, W.-Y. 2020. The effects of critique-driven inquiry intervention on students' critical thinking and scientific inquiry competency. *Journal of Baltic Science Education*, 19(6):954–971. <https://doi.org/10.33225/jbse/20.19.954>

- Mahlianurrahman, I., Candiasa, I.M., & Suastra, I.W. 2023. The effect of nyerayo based sets learning on student's scientific literacy. *Pegem Journal of Education and Instruction*, 13(2):79–84. <https://doi.org/10.47750/pegegog.13.02.10>
- Maryam, M., Kusmiyati, K., Merta, I.W., & Artayasa, I.P. 2020. Pengaruh model pembelajaran inkuiri terhadap keterampilan berpikir kritis siswa. *Jurnal Pijar Mipa*, 15(3):206–213. <https://doi.org/10.29303/jpm.v15i3.1355>
- Obaya-Valdivia, A.E., Montaña-Osorio, C., & Vargas-Rodríguez, Y.M. 2022. Exploratory Study to determine the effectiveness of discussion sessions as a teaching strategy on the concepts of spontaneity. *Science Education International*, 33(4):422–426. <https://doi.org/10.33828/sei.v33.i4.9>
- Ozer, S., Kiray, S.A., & Cardak, O. 2021. Science teacher candidates' views about science-technology-society-environment relations. *Eurasian Journal of Educational Research*, 91:83–104. <https://doi.org/10.14689/ejer.2021.91.5>
- Perdana, P.A. & Rosana, D. 2023. Pengembangan eksperimen virtual model science, environment, technology and society berbasis augmented reality materi ekosistem untuk meningkatkan keterampilan pemecahan masalah dan sikap peduli lingkungan. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 11(1): 152–164. <https://doi.org/10.24815/jpsi.v11i1.27655>
- Rahmayani, R.F.I. 2017. Identifikasi kesulitan siswa dalam memahami materi termokimia dengan menggunakan three-tier multiple choice diagnostic instrument di kelas XI MIA 5 MAN Model Banda Aceh. *Jurnal Ilmiah Mahasiswa Pendidikan Kimia*, 2(1). <https://jim.usk.ac.id/pendidikan-kimia/article/view/3402/1703>
- Rahmi, S. & Azra, F. 2023. Description of student learning difficulties in the thermochemistry. *Jurnal Pijar Mipa*, 18(5):736–742. <https://doi.org/10.29303/jpm.v18i5.5581>
- Riyanti, V., Hamdiyati, Y., & Purwianingsih, W. 2023. The effect of argument-driven inquiry (adi) on argumentation skills and students' concept mastering of human excretory system materials. *Journal of Science Learning*, 6(2):125–135. <https://doi.org/10.17509/jsl.v6i2.54634>
- Rusci, B. & Bross, D.H. 2019. Thermochemistry. *In Computer Aided Chemical Engineering*, 45:103–114. <https://doi.org/10.1016/B978-0-444-64087-1.00001-2>
- Safitri, W.C.D. & Mediatati, N. 2021. Penerapan model discovery learning dalam pembelajaran ipa untuk meningkatkan kemampuan berpikir kritis dan hasil belajar siswa sekolah dasar. *Jurnal Basicedu*, 5(3):1321–1328. <https://doi.org/10.31004/basicedu.v5i3.925>
- Sawitri, R., Mulyani, S., & Ariani, S.R.D. 2023. The effect guided discovery-based thermochemistry module on critical thinking skills of high school and vocational students. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 11(3):625–638. <https://doi.org/10.24815/jpsi.v11i3.30569>
- Seibert, S.A. 2021. Problem-based learning: A strategy to foster generation Z's critical thinking and perseverance. *Teaching and Learning in Nursing*, 16(1):85–88. <https://doi.org/10.1016/j.teln.2020.09.002>

- Seyhan, H.G. & Okur, M. 2021. Examining the changes in pre-service science teachers' views on science, technology and society: The impact of socio-scientific issues*. In *International Journal of Curriculum and Instruction*, 13(3):57-63 <https://eric.ed.gov/?id=EJ1312940>
- Sihaloho, M., Hadis, S.S., Kilo, A.K., & La Kilo, A. 2021. Diagnosa miskonsepsi siswa SMA Negeri 1 Telaga Gorontalo pada materi termokimia. *Jambura Journal of Educational Chemistry*, 3(1):7-13. <https://doi.org/10.34312/jjec.v3i1.7133>
- Sokrat, H., Tamani, S., Moutaabbid, M., & Radid, M. 2014. Difficulties of students from the faculty of science with regard to understanding the concepts of chemical thermodynamics. *Procedia-Social and Behavioral Sciences*, 116,:368-372. <https://doi.org/10.1016/j.sbspro.2014.01.223>