Socio-scientific issues in physics learning to improve students' critical thinking skills

Febriani[a,*], Jumadi[b], and Wipsar Sunu Brams Dwandaru[b]

[a]*Physics Education Master Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Jl. Colombo No.1, Karangmalang, Sleman, Yogyakarta, 55281, Indonesia.*
[*]*e-mail: febriani.2021@student.uny.ac.id*
[b]*Physics Education Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Jl. Colombo No. 1., Karangmalang, Sleman, Yogyakarta, 55281, Indonesia.*

Received 07 January 2022; accepted 19 May 2022

Socio-Scientific Issues (SSI) are social issues that cause controversy and can be studied based on scientific facts. Applying SSI to the subject of physics helps students relate physics to real things in everyday life. The purpose of this study was to determine the teacher's view of the success of students' critical thinking processes that can be obtained from studying physics through SSI. This research used qualitative methodology with a phenomenological approach. This study involved two senior and two junior physics teachers. The results of this study indicate that SSI in physics learning can help students practice critical thinking skills. This is based on the various processes experienced by students during the physics learning process with SSI.

Keywords: SSI; critical thinking; physics learning; teacher's view.

DOI: https://doi.org/10.31349/RevMexFisE.20.010202

1. Introduction

Physics is a part of science that studies various natural phenomena. The objects studied include macro and micro objects. Physical sciences have contributed to various conveniences and advances that we experience in life nowadays, *e.g.*: electromagnetic waves are useful for cancer therapy [1] and the creation of vehicle engines are based on thermodynamics [2]. This makes physics one of the subjects that need to be taught at the junior and senior high school levels in Indonesia, especially for students majoring in Natural Sciences.

Learning physics at the school level cannot be separated from the challenges that must be faced. This challenge comes from the perception of students who regard physics as a difficult and boring subject to learn [3,4]. This is because physics is less descriptive and more likely to dwell on mathematical calculations and formulas [5,6]. In addition, students' self-motivation in studying physics is also low because they consider physics as something abstract, which is not directly related to everyday life [7,8]. In other words, students cannot appreciate the benefits of studying physics.

Stigma against physics learning is often used as a joke that spreads among students and even the public, such as "What is the point in calculating the speed of the ball falling?", "Before cooking, let's first count the amount of heat", and so on. This makes people think that learning physics does not produce significant benefits in life. But in fact, it is through physics learning that students are not only able to calculate the value of physical quantities on paper, but also to think critically and analytically through scientific process [9]. Of course, calculating the value of physical quantities is also an important part of daily life activities, *e.g.* calculating the total mass of groceries bought from a supermarket, calculating the total energy of electronics appliances utilized in a household for a certain time, and determining the temperature and humidity in a factory. According to Serway and Beichner [10], the main goal of physics is to discover physical laws relating to natural events and develop theories to predict experimental results. This is the goal of physics as a field of science in its fundamental level. Of course physics as a field of science must be brought to the level that can be understood by students. In other words, physics has to be appropriately conveyed to students, one of which is through the daily applications of its concepts. This is certainly very useful to train students in making decisions so that they are able to solve various problems in life.

Various stigmas that prevent students from interacting with physics must be eliminated. This is in order to make students appreciate the benefits of learning physics to everyday life. Associating physics with everyday life can help change students' perceptions that physics is abstract and useless subject [11]. One way to change students' perceptions is by providing interesting and challenging daily issues and phenomena that are connected to physics. This can be realized by applying Socio-Scientific Issues (SSI) in the physics learning process.

SSI are social issues related to science that cause controversies and highlight the application of moral and scientific reasoning to real world situations [12]. SSI present multiple points of view to allow students to make their own conclusions, sets expectations, and helps students to use evidence [13,14]. Applying SSI in physics learning can help students in associating physics learning with the phenomena of everyday life.

The potential application of SSI to encourage students in carrying out scientific processes in physics learning motivates the authors to examine the views of physics teachers on SSI in physics learning. These scientific processes include making an observation that describes a problem, creating a hypothesis, testing the hypothesis, drawing conclusions, and refining the hypothesis. The applications of SSI in other science learning, *e.g.* in biology and chemistry subjects, raise issues around biodiversity [15] and using sodium benzoate as a food preservative [16], respectively. Thus, this study presents facts regarding teachers' view of the scientific process that runs in physics learning through SSI so that it can improve critical thinking skills of students. In fact, through these things, students can be trained to think critically through the scientific process [17].

Critical thinking skills are the ability to ask questions correctly, combine and reduce relevant information, think logically upon the information obtained, and make reliable conclusions [18]. The mastery of critical thinking skills is associated with successful decision-making related to real-life problems [19]. Moreover, the process of science in physics learning can be optimized to improve students' critical thinking skills.

2. Research method

This study used qualitative research method via a phenomenological approach. The choice of using qualitative method in terms of the purpose of this study was to understand how physics teachers accept certain issues, *i.e.* SSI in physics learning, and its relation to students' critical thinking skills [20]. The phenomenological approach was chosen to look deeper into the point of view of the respondents regarding the personal meaning of the actions and choices that have been made. The steps of the study referred to the procedure for carrying out phenomenological research by Creswell [21] shown in Fig. 1.

2.1. Selection of the topic or phenomenon

The choice of the topic was adjusted to the problems faced in the physics learning process that has been described in the Introduction section. The topic chosen in this study was SSI, which were limited to high school physics. This topic was chosen because the use of SSI in physics learning was still relatively limited and can be explored more deeply [22]. The topic was then investigated in relation to critical thinking skills.

The topic of SSI with critical thinking was chosen in this study because it had strategic benefits in physics learning and the phenomenon had not been investigated previously. It was based on the understanding of the same or shared experiences of several individuals concerning the same phenomenon. The same experience was obtained from the support of the physics teacher's perspective as a driving force for the scenario of the physics learning process in the classroom.

FIGURE 1. The procedure of the study.

2.2. Data collection

The data used in this study were obtained from primary and secondary data. The primary data were collected from four physics teachers who were asked to be respondents. The secondary data were obtained from literature review activity. The selection of the respondents was done by purposive sampling because in this study specific criteria were determined in selecting respondents, *i.e.*: we have chosen individuals who were experienced and knowledgeable about the topic investigated in the study, *i.e.* the relationship between SSI and students' critical thinking skills [23]. Hence, the respondents chosen were 2 senior physics teachers with a minimum of 10 years of teaching experience and 2 junior physics teachers with a minimum of 6 months teaching experience (1 semester) in formal high school. All of the respondents selected in this study have experience teaching physics at all grade levels at the high school level, *i.e.* grades 10-12 high school.

The data collection technique was carried out by in-depth interviews through a video conference platform. The interview guide was made based on the main questions in phenomenological research, namely "What have they experienced?" and "How did they experience it?" , in the context of the learning process using SSI.

2.3. Data analysis

The Data analysis was carried out by analyzing interview transcripts obtained through the data collection process and referring to the technique by Moustakas [24]. This analysis was carried out by reducing the data to information that were considered relevant to the research objectives and compiling a list of statements so as not to repeat and overlap. For the data that was considered relevant to the research objectives, a manual coding process was carried out.

Codification began to be carried out on the name of the respondent. Two senior teachers were given codes of A and F, whereas two junior teachers received codes of E and L. After that, various important statements were coded to be grouped into various themes. The themes were i) the teacher's knowledge about SSI, ii) the process of learning physics, iii) motivating students in the physics learning process, iv) physics topic that can be linked to SSI, v) the process of training students' critical thinking skills, and vi) the teacher's view of

SSI concerning students' critical thinking skills. Codification was also given to various keywords such as "very supportive", "a lot", "very difficult", and "very likely". The next stage was to do a textural description by writing a description of "what" was experienced by the respondents and followed by a structural description by writing "how" the experience occurred. The final stage was to produce the essence of collaboration between textural and structural descriptions. These results were then presented to describe the context to be conveyed in detail.

3. Results and discussion

3.1. SSI in physics learning

SSI are social issues that have a scientific basis and are of concern in the community [25]. In this case, these social issues should be based on the knowledge of physics. Based on the interviews that have been conducted with the respondents, it is found that all respodents state that they have never heard of SSI and state that they have never applied SSI in the physics learning process.

All respondents in this study have been asked by their students about the reasons for studying physics, *i.e.*:

"*Why should we study physics?*" **- Students**.

This question can be interpreted in two ways by teachers, namely 1) students are really curious because they want to study physics more deeply and are interested in continuing it in college or 2) students feel they do not have the motivation to study physics so they seek encouragement by knowing the importance of studying physics. Various answers given by junior teachers always relate to the benefits of physics in everyday life, *e.g.*:

"*By studying physics, we know why we can make warm water that was originally hot, so that it can be used for a comfortable bath. We can also understand the meaning of a mathematical result so that it can help make everyday life easier*" **- teacher E**.

"*We can better understand life, because physics is related to various phenomena in everyday life*" **- teacher L**.

Meanwhile, senior teachers explain the relation of physics to everyday life. Moreover, they also added motivation regarding students' success in life, *i.e.*:

"*Successful people do not have to be good at physics, but the basis of thinking and building logic can be obtained from studying physics, so it is necessary to follow the flow of the physics learning process well.*" **- teacher A**.

"*When you don't like physics, then you can't be successful. This is because physics is needed to help solve various problems so that it is not only for physics itself, but also for many other things.*" **- teacher F**.

These answers show that all physics teachers attribute the importance of physics to everyday life. The urgency of studying physics is related to basic thinking skills and its relation to other things even outside of physics itself.

All teachers relate the material they teach in class to various phenomena in everyday life. Some teachers have unconsciously implemented SSI as part of their teaching, by presenting everyday scenarios. These scenarios are then discussed by situating them in the physics topics being explored with the students, for example:

"*I relate physics to the many accidents that have happened recently on toll roads (freeways). I asked students to study this using the Momentum and Impulse material.*" **- teacher A**.

When linking the learning process with problems that are controversial, the teachers also feel that students become more enthusiastic and actively involved in the process of collecting information. This also shows that the teachers have unconsciously applied SSI occasionally to the physics learning process.

Several studies that have investigated physics learning using SSI include Saefullah [26], who explored teaching material on the energy topic; Hariapsari [27], who explored validity of teaching material on the topics of vibration, waves, and sound; and Levinson [28], who explored teacher and student experiences concerning the topic of global warming. The existence of these studies has encouraged researchers to explore teacher's perspectives concerning the topics that can be used in the context of SSI. All respondents state that all physics topics can be used for learning using SSI because all physics topics explain various phenomena in life. The relationship between physics topics and SSI in everyday life can be seen in Fig. 2. Although there are many physics topics that can be related to SSI, the use of SSI in the physics learning process is still lacking [22]. So it is necessary to develop SSI based on various physics topics.

Besides the potential of developing SSI in physics learning, there are several factors that must be considered, such as the readiness of the teacher in preparing materials and issues that are in accordance with the thinking level of students at the high school level when applying SSI in the learning process. The following must be prepared in applying SSI, *i.e.*: 1) choosing an issue, which is being debated or disputed in the society and must contain science literacy, 2) restructuring the dynamics and culture of the class, 3) structuring student's involvement in the learning process, and 4) preparing ped-

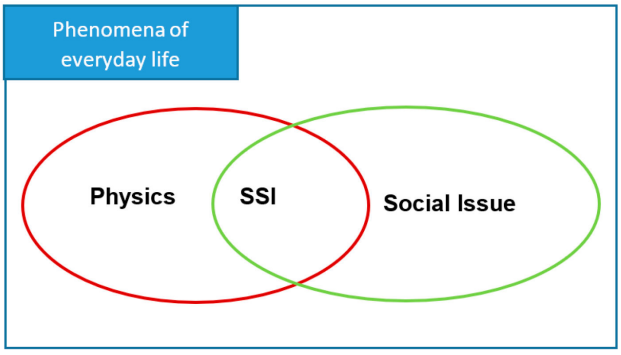

FIGURE 2. A relation between physics, SSI, and social issue.

agogical content knowledge (PCK) abilities [29-31]. This causes teachers to be deeply prepared in the learning process using SSI. Even so, all respondents support the use of SSI in physics learning because it could help create a more contextual learning process.

3.2. Critical thinking skill

One of the skills needed by students to face life in the 21st century is critical thinking skills [32,33]. Critical thinking is a critical assessment of the truth of phenomena or facts. Everyone has the potential to master critical thinking that can be developed optimally in achieving a better life [34].

Based on the data from the interview, it is known that there are several ways that physics teachers do to train students' thinking skills as well as assess the critical thinking skills of students in the physics learning process. These activities include:

"*I train and assess the skills of students by giving various physics questions that must be done by students during learning, the process of students completing each question with certain steps will be used as material for assessing critical thinking skills.*" **- teacher E**.

Practicing physics questions especially high order thinking levels is something that can be done to provide an assessment of students' critical thinking skills. This is because the thinking process can be seen from the activity of solving problems. Problems that contain mathematical calculations also help students to practice critical thinking skills because mathematics is a tool used to help understand various phenomena interpreted through physics.

Another method used by the respondents is the direct question and answer (Q and A) process with students. This is intended to create direct interaction between teachers and students and explore more deeply about students' critical thinking skills. Moreover, through Q and A the teacher can understand the character of the student directly starting from the low to the high level of critical thinking.

Besides focusing on critical thinking skills, the methods used by the teachers can also help to find out the students' understanding of physics concepts. This is necessary to know because when evaluating problems, all concepts become tools to parse appropriate and relevant information with logical reasons to practice critical thinking skills [35,36].

3.3. The relation of SSI and critical thinking skills

The results of this study show support and positive feedbacks from teachers regarding the use of SSI to train students' critical thinking skills. These statements include:

"*-This collaboration is something good and interesting. In many ways, physics can actually be used to help solve various problems in life, for example in the concept of econophysics, especially the stock market problem.*" **- teacher F**.

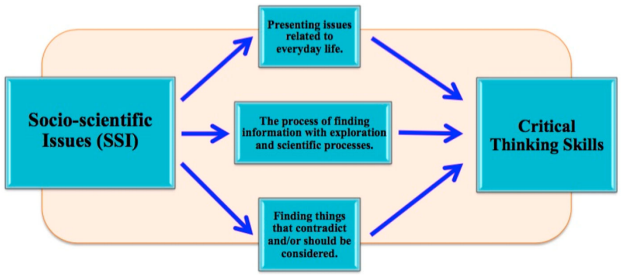

FIGURE 3. A relationship between SSI and critical thinking skills.

This positive affirmation is of course also supported by various theories regarding the use of SSI in the physics learning process [37,38]. This concept can be seen more clearly in Fig. 3. The initial process is started from the problems in the physics learning process, which has previously been described in the Introduction section. To overcome these problems the solution offered is in the form of SSI. SSI is accompanied by the latest social issues related to science so that it trains students to find solutions to real problems in life [39]. Real issues are presented to help students know more about the meaning of life. Critical thinking skills can be enabled by applying strategies based on real-life problems [40-42].

In the process of finding solutions to solve the problems presented, students find various sources of conflicting information, allowing for a process of argumentation and discussion between them. Students actively participate in the learning process by taking part in activities and answering questions that arise. The discussion increases the critical thinking of students, helps students improve the ability to make connections between the argument and evidence [43,44].

The inference factor enables students to distinguish between true and false inference based on the data. Students can then decide whether the conclusions are true or false, or there is still not enough evidence to reach a conclusion [45,33]. With students having to put forward arguments when overcoming problems, they must distinguish between weak and strong arguments, and find the best arguments to practice critical thinking skills. In the final process, students can make decisions to solve the problems presented through SSI learning [46,47].

4. Conclusion

The use of SSI in the physics learning process can help train students' critical thinking skills. This can be seen from the various processes that can occur when learning physics involves SSI. The use of SSI in physics learning needs to be developed in various physics topics. This is because all physics topics can be situated within a SSI context. However, the interviews show that the physics teachers (respondents) are not familiar with SSI and never applied SSI in the physics learning process. On the other hand, physics teachers attribute the importance of physics to everyday life, which is an aspect of SSI. Hence, it seems that physics teachers are uncon-

sciously aware of the importance of SSI. Moreover, physics teachers also relate the urgency of physics learning through SSI with critical thinking skills and the success of students outside physics itself.

Acknowledgements

We would like to thank all the respondents who have been involved in this study. We also would like to appreciate the Physics Education Department, Universitas Negeri Yogyakarta for supporting this study.

1. L. A. Koehler, H. N. Mayrovitz, Tissue dielectric constant measures in women with and without clinical trunk lymphedema following breast cancer surgery: A 78-week longitudinal study, *Phys. Ther.* **100** (2020) 1384, https://doi.org/10.1093/ptj/pzaa080.
2. R. León, C. Montaleza, J. L. Maldonado, M. Tostado-Véliz, F. Jurado, Hybrid Electric Vehicles: A review of existing configurations and thermodynamic cycles, *Thermo.* **1** (2021) 134, https://doi.org/10.3390/thermo1020010
3. R. Mualem, and B. S. Eylon, Physics with a smile Explaining phenomena with a qualitative problem solving strategy. *Phys. Teach*. **45** (2007) 158, https://doi.org/10.1119/1.2709674
4. P. Mulhall, R. Gunstone, Views about physics held by physics teachers with differing approaches to teaching physics. *Res. Sci. Educ*. **38** (2008) 435, https://doi.org/10.1007/s11165-007-9057-6
5. 5. S. Owen, D. Dickson, M. Stanisstreet, E. Boyes, Teaching physics: Students' attitudes towards different learning activities, *Res. Sci. Tech. Educ.* **26** (2008) 113, https://doi.org/10.1080/02635140802036734
6. E. Ekici, Why do I slog trough the physics? Understanding high school students' difficulties in learning physics, *J. Educ. Pract.* **7** (2016) 95, https://eric.ed.gov/?id=EJ1095264
7. E. Suzuk, M. A. Corlu, C. Gurel, Student's perceptions of learning effiency of introductory physics course, *Int. J. Phys. Chem. Educ.* **3** (2011) 65, https://www.ijpce.org/index.php/IJPCE/article/view/124.
8. R. M. D. Guido., Attitude and motivation towards learning physics, *Int. J. Eng. Res. Tech.* **2** (2013) 1, https://arxiv.org/abs/1805.02293.
9. B. Mitrevski, Teaching critical thinking and problem solving in physics, *AIP Conf. Proc.* **2075** (2019) 180001, https://doi.org/10.1063/1.5091398.
10. R. A. Serway, R. J. Beichner, *Physics for Science and Engineering* 1. (Ankara: Palme Publications, 2012).
11. R. Trumper, Factors affecting junior high scholl students interest in physics, *J. Sci. Educ. Tech.* **34** (2006) 47, https://eric.ed.gov/?id=EJ748824
12. T. D. Sadler, S. A. Barab, B. Scott, What do students gain by engaging in socioscientific inquiry?. *Res. in Sci. Educ*. **37** (2007) 371, https://doi.org/10.1007/s11165-006-9030-9.
13. A. Borgerding, M. Dagistan, Preservice science teachers' concerns and approaches for teaching socioscientific and controversial issues, *J. Sci. Teacher Educ.* **29** (2018) 283, https://doi.org/10.1080/1046560X.2018.1440860.
14. V. Albe, E. Padretti, Introduction to the special issue on courting controversy: socioscientific issues and school science and technology, *Can. J. Sci. Math. Tech. Educ.* **13** (2013) 303, https://doi.org/10.1080/14926156.2013.847219.
15. A. R. Santika, W. Purwianingsih, E. Nuraeni, Analysis of students critical thinking skills in socio-scientific issues of biodiversity subject, *J. Phys. Conf. Ser.* **1013** (2018) 012004, http://dx.doi.org/10.1088/1742-6596/1013/1/012004.
16. S. Rahayu, Socio-scientific issues (SSI) in chemistry education: Enhancing both students' chemical literacy & transferable skills, *J. Phys. Conf Ser.* **1227** (2019), http://dx.doi.org/10.1088/1742-6596/1227/1/012008
17. B. Mitrevski, Teaching critical thinking and problem solving in physics, *AIP Conf. Proc.* **2075** (2019) 1, https://doi.org/10.1063/1.5091398.
18. L. D. Puspitasari, E. Suhardi, A. P. Putra, I. Rachman, Enhancement of student's critical thinking skill through science context-based inquiry learning. *J. Penelit. Pendidik. IPA.* **9** (2020) 97, https://doi.org/10.15294/jpii.v9i1.21884
19. D. F. Halpern, *Thought and Knowledge: An Introduction to Critical Thinking*, 5th ed. (psychology press, New York, 2014). pp 33.
20. K. McCusker, S. Gunaydin, Research using qualitative, quantitative or mixed methods and choice based on the research, *Perfusion* **30** (2014) 537, http://doi.org/10.1177/0267659114559116
21. J. W. Creswell, Qualitative Inquiry & Research Design: *Choosing Among Five Approaches*, 1st ed. (Sage Publishing, 2013), pp. 107-109.
22. U. A. Deta *et al*., Research trend of socio-scientific issues (SSI) in physics learning through bibliometic analysis in 2011-2020 using scopus database and the contribution of Indonesia, *J. Penelit. Pendidik. IPA* **7** (2021) 682, https://doi.org/10.29303/jppipa.v7i4.862
23. I. Etikan, S. A. Musa, R. S. Alkassim, Comparison of convenience sampling and purpsive sampling, *Am. J. Theor. Appl. Stat.* **5** (2016) 1, https://doi.org/10.11648/j.ajtas.20160501.11.
24. T. Groenewald, A phenomenological research design illustrated, *Int. J. Qual. Meth.* **3** (2004) 42, https://doi.org/10.1177%2F160940690400300104
25. V. Dawson, K. Carson, Introducing argumentation about climate change socioscientific issue (Ssis) in disadvantaged school, *Res. Scie. Educ*. **50** (2018) 863, https://doi.org/10.1007/s11165-018-9715-x

26. A. Saefullah, Y. Guntara, L. Nulhakim, Reconstruction of teaching materials with socio scientific issues context on source of energy content, *J. Phys. Conf Ser*. **1467** (2020) 012022, http://dx.doi.org/10.1088/1742-6596/1467/1/012022

27. K. W. Hariapsari, Tukiran, E. Sudibyo, Validity of teaching materials based on socio-scientific issues approach on the topic ov vibration,waves, and sound, *J. Phys. Conf Ser.* **1108** (2018) 012034, http://dx.doi.org/10.1088/1742-6596/1108/1/012034

28. R. Levinson, A perspective on knowing about global warming and a critical comment about school and curriculum in relation to socio-scientific issues. *Cult. Stud. Sci. Educ.* **7** (2012) 693, http://dx.doi.org/10.1007/s11422-012-9418-y

29. H. Lee, J, Yang, Science teachers taking their first steps toward teaching socioscientific issues through collaborative action research, *Res. Scie. Educ.* **49** (2017) 51, https://link.springer.com/article/10.1007/s11165-017-9614-6

30. T. S. Hancock, P. J. Friedrichsen, A. T. Kinslow, T. D. Sadler, Selecting socio-scientific issues for teaching a grounded theory study of how science teachers collaboratively design SSI-based curricula, *Scie. Educ.* **28** (2019) 639, https://dx.doi.org/10.1007/s11191-019-00065-x

31. J. Chang, J. Park, Developing teacher professionalism for teaching socio scientific issues: What and how should teachers learn?, *Cult. Stud. Sci. Educ* **15** (2020) 423, https://doi.org/10.1007/s11422-019-09955-6

32. D. T. Tiruneh, M. D. Cock, J. Elen, Designing learning environments for critical thinking: Examining effective instructional approaches, *Int. J. Scie. Math. Educ.* **16** (2018) 1065, https://doi.org/10.1007/s10763-017-9829-z

33. S. Mahanal, S. Zubaidah, I. D. Sumiati, T. M. Sari, N. Ismirawati, A learning model to develop critical thinking skills for students with different academic abilities, *Int. J. Instr.* **12** (2019) 417, https://eric.ed.gov/?id=EJ1211048

34. A. Ramdani, A. W. Jufri, G. Gunawan, M. Fahrurrozi, and M. Yustiqvar, Analysis of student critical thinking skills in terms of gender using science teaching materials based on The 5E learning cycle integrated with local wisdom, *J. Penelit. Pendidik. IPA* **10** (2021) 187, https://doi.org/10.15294/jpii.v10i2.2995

35. A. F. Musyarrof, S. E. Nugroho, M. Masturi, The analysis of students' critical thinking weakness in senior high school on physics learning, *Adv. Soc. Scie. Educ. Humanit. Res.* **247** (2018) 38, https://doi.org/10.2991/iset-18.2018.8

36. S. J. Husnaini, S. Chen, Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment. *Phys. Rev. Phys. Edu. Res.* **15** (2019) 1, https://doi.org/10.1103/PhysRevPhysEducRes.15.010119

37. Y. N. Pratiwi, S. Rahayu, F. Fajaroh. Socio-scientific issues (SSI) in reaction rates topics and its effect on the critical thinking skills of high school students. *J. Pendidik. IPA Indo.* **5** (2016) 164, https://doi.org/10.15294/jpii.v5i2.7676

38. A. P. Utomo, E. Narulita, R. N. I. Billah, Application of the problem based learning model based on socio-scientific issue (SSI) on the critical thinking skills of junior high school students. *J. Pendidik. IPA Veteran.* **4** (2020) 148, https://doi.org/10.31331/jipva.v4i2.1259

39. D. P. I. Suryani *et al*., Implementing group investigation (GI) learning model combined with socio scientific issues (SSI) to improve students' problem solving skills in XI grade IPA 4 SMAN 2 Malang. *AIP Conf. Proc.* **2215** (2020), https://doi.org/10.1063/5.0000570

40. C. Carvalho *et al*., Critical thinking, real life problems and feedback in science class. *J. Turk. Sci. Educ.* **12** (2015) 21, http://dx.doi.org/10.12973/tused.10138a

41. A. Ramdani, A. W. Jufri, Gunawan, M. Fahrurrozi, M. Yustiqvar, Analysis of Student critical thinking skills in terms of gender using science teaching materials based on the 5E learning cycle integrated with local wisdom, *J. Pendidik. IPA Indo.* **10** (2021), 187, https://doi.org/10.15294/jpii.v10i2.29956

42. G. Reynders, J. Lantz, S. M. Ruder, C. L. Stanford, R. S. Cole, Rubrics to assess critical thinking and information processing in undergraduate STEM courses, *Int. J. STEM Educ.* **7** (2020) 1, https://doi.org/10.1186/s40594-020-00208-5

43. Wartono, M. N. Hudha, J. R. Batlolona, How are the physics critical thinking skills of the students taught by using inquiry-discovery through empirical and theorethical overview?, *Eur. J. Math. Scie. Techno. Educ.* **14** (2017) 691, https://doi.org/10.12973/ejmste/80632

44. W. Wahyudi, N. N. S. P. Verawati, S. Ayub, S. Prayogui, Conceptual framework of inquiry-creative-process learning model to promote critical thinking skills of physics prospective teachers, *J. Pen. Fis. Indo.* **15** (2019) 5, https://doi.org/10.15294/jpfi.v15i1.10693

45. M. D. Saputra, S. Joyoatmojo, D. K. Wardani, K. B. Sangka, Developing critical-thinking skills through the collaboration of jigsaw model with problem-based learning model, *Int. J. Instr.* **12** (2019) 1077, https://eric.ed.gov/?id=EJ1201249

46. H. Jho, H. G. Yoon, M. Kim, The relationship of science knowledge, attitude and decision making on socio-scientific issues: The case study of students' debates on a nuclear power plant in Korea, *Scie. Ed.* **23** (2014) 1131, https://doi.org/10.1007/s11191-013-9652-z

47. A. R. Alred, J. M. Dauer, Understanding factors related to undergraduate student decision-making about a complex socio-scientific issue: Mountain Lion Management, *Eur. J. Math. Scie. Techno. Educ.* **16** (2020) 1, https://doi.org/10.29333/ejmste/113757