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THE INFLUENCE OF INQUIRY-BASED CHEMISTRY LEARNING WITH THE CONTEXT OF SOCIO-SCIENTIFIC ISSUES ON HIGH SCHOOL STUDENTS' SCIENTIFIC EXPLANATION SKILLS

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ABSTRACT

Students' must be able to reasons scientifically in understanding our rapidly changing world, in which scientific explanation skill can be defined as an ability to make a reasonable explanation of a phenomenon based on scientific facts as well as forming a relationship based on evidence and logical reasoning. In this study, we examine the development of students' scientific explanation skill through the implementation of POGIL inquiry model with Socio-scientific Issues (SSI) context. A difference in scientific explanation skill after learning was found and implications to chemistry learning are discussed.

Keywords: inquiry learning; socio-scientific issues; scientific explanation

ABSTRAK

Mahasiswa harus mampu untuk menalar secara saintifik untuk memahami dunia yang berubah dengan cepat dimana keterampilan eksplanasi saintifik dapat didefinisikan sebagai kemampuan untuk membuat eksplanasi beralasan tentang suatu fenomena berdasarkan fakta-fakta saintifik serta membuat hubungan berdasarkan bukti dan penalaran logis. Dalam penelitian ini, kami menyelidiki pengembangan keterampilan mahasiswa dalam membuat eksplanasi saintifik melalui implementasi model inkuiri POGIL berkonteks isu-isu sosial-saintifik (SSI). Terdapat perbedaan keterampilan eksplanasi saintifik setelah pembelajaran dan implikasi bagi pembelajaran kimia kemudian didiskusikan.

Kata kunci: pembelajaran inkuiri; isu socio-scientific; penjelasan ilmiah

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INTRODUCTION

The rapid development of science has improved the quality of human life, but science is often seen as a paradox: a solution to improve various aspects of human life while also can be the cause of new problems resulted from those efforts for improvement. One of the examples of this paradox is a Genetically Modified Organism (GMO). GMO is a product of advances in agricultural technology to improve crop yield and minimizing food shortage in which studies found that it could pose as possible health risk (Pryme and Lembcke, 2003; Dona and Arvanitoyannis, 2009; Zhang, Wohlhueter, and Zhang, 2016). In deciding our stance or personal decisions in matters the society as a whole (such as the use of GMO or other complex science-related issues), competencies to consider benefits and risks of applying science is an ability that each individual must possess (Organization for Economic Cooperation and Development, OECD, 2016). The competency to link science-related issues with science concepts as a reflective human being is defined as scientific literacy (OECD, 2016). Scientific literacy enables people to use scientific principles and processes in making personal decisions and to participate in discussions of scientific issues that affect society (Gräber et al., 2001, pp. 61). The importance of scientific literacy hence becomes the target of science education (see Holbrook and Rannikmae, 2009) and the main objective of science education in schools (Roberts and Bybee, 2014).

Programme for International Students Assessment (PISA) evaluate scientific literacy competencies of the children around the world and PISA assessment in 2015 showed that about 20% students across OECD countries performed below the baseline level of proficiency in science, in which Indonesia ranked 62nd out of 70 countries (OECD, 2018). Firman (2016) identified Indonesian students' scientific weaknesses based on the

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2012 PISA and found that Indonesian students faced difficulties in explaining phenomena scientifically: they were unable to state scientific explanation clearly. Therefore, educators must explicitly integrate aspects needed to develop scientific literacy in science learning, especially by focusing on activities that stimulate students to integrate knowledge in explaining scientific phenomena and solving complex related problems (Firman, 2016; Rahayu, 2017).

A scientific explanation is defined as a reasonable explanation of a phenomenon based on scientific facts (see Berland and Reiser, 2008; Osborne and Patterson, 2011) and forming a relationship based on evidence and logical arguments (National Research Council, 1996). Osborne and Patterson (2011) stated that Scientific Explanation (SE) comprises two components: explanandum (an undisputed fact serves as the phenomenon that will be explained) and explanans (elements that make these facts understandable). Developing skill in constructing SE is a complex process and requires cognitive abilities in which students must master the material content and understand the key features that underlie explanation (Wang, 2014). If it is associated with science learning practices and to engage the students in constructing knowledge, students must understand how to compose scientific explanation and the context that makes it meaningful (Berland and Reiser, 2008; Faria, Freire, Baptista, and Galvão, 2014).

Socio-scientific Issues (SSI) is an appropriate learning context to support the process of developing SE constructing skills because SSI encourages the students to consider issues that affect the community (Sadler, 2009). As a learning context, SSI is interdisciplinary: not only having relevance to social science but also directly related to the scientific realm (Ratcliffe and Grace, 2003; Sadler and Zeidler, 2004; Zeidler, 2014). SSI is a social problem that is controversial, complex, still being debated, and based on concepts or procedures related to science (Sadler, 2004; Zeidler, 2014). To be able to criticize the causes of the emergence of several views in certain SSI, students must understand the cause and effect associated with scientific content in those SSI problems (see Puig and Jiménez-Aleixandre, 2011). Through the implementation of SSI contextual learning, students are expected to be able to construct SE on the issue by considering relevant science concepts.

Learning approaches also vital in developing students' ability in constructing SE in which inquiry learning helps students to gain an in-depth understanding of learning material (for example Bailey, Minderhout, and Loertscher, 2012; Zawadzki, 2010; Yuliati, Kusairi, dan Munfaridah, 2016) and developing their skills in constructing scientific explanations (Wu and Hsieh, 2006). Process Oriented Guided Inquiry Learning model (POGIL) is a learning model with an inquiry approach, and consists of five learning steps: 1) orientation, 2) exploration, 3) concept formation, 4) application and 5) closure (Hanson, 2005). POGIL requires students to report their understanding of concepts and processes both in writing and orally, in which they submit answers and explain their strategies for solving problems. They also must explain it using terms and concepts used in the learning process (Eaton, 2006). POGIL model has been used previously in improving a wide range of learning aspects (Daubenmire and Bunce, 2008; Schroeder and Greenbowe 2008; Hein, 2012; Subarkah and Winayah, 2015; Daubenmire, Bunce, Draus, Frazier, Gessell, and van Opstal, 2015; Gale and Boisselle, 2015) but the use of POGIL model with SSI context spesifically designed to develop students' scientific explanation is absent in the literature. Therefore, in this study we evaluated the development of students' scientific explanation skill through the implementation of POGIL inquiry model with Socio-scientific Issues or (SSI) context.

METHOD

We obtained an official permit from local Education Office before conducting our study. Our study was conducted in one of public high schools in Malang-East Java by using a convenience sampling technique ($n = 85$). Students were divided into three classes, experimental class I (POGIL learning with SSI context), experimental class II (POGIL learning), and control class (conventional learning without SSI context). Experimental class I (79.89 ± 3.87), experimental class II (79.83 ± 4.08), and control class (79.78 ± 3.31) had the same initial ability ($p = 0.994$; $p > 0.05$). Table 1 depicted learning activities of POGIL-SSI with salt hydrolysis and buffer solution as the main chemistry topic explored.

The socio-scientific issues presented to the students were 1) the impact of MSG on Health, 2) Benefits and Dangers of Chemical Fertilizers, 3) Benzoate Buffer Solutions as Food Preservatives, and 4) Impact of Acid Rain on Natural Buffer Systems. Students were subjected to open questions test (r = 0.748) to evaluate their learning results. The quality of the SE as a result of the learning process was analyzed using the SOLO or Structure of the Observed Learning Outcome Taxonomy (Minogue and Jones, 2009, Table 2). Two raters examined students' SE (Kappa coefficient = 0.899). A nonparametric statistical analysis was conducted to evaluate SE skills difference between classes because data were not normally distributed.

Table 1. POGIL Learning Model With SSI Context

Steps	Learning Activity(s)
Orientation	• Teacher presents familiar phenomena related to salt hydrolysis and buffer solutions to generate interest, motivation and curiosity. Students connect this phenomenon with their previous learning experience.
Exploration	• Students discuss the pictures or tables presented by the teacher to obtain information related to learning objectives. • Teacher guides the students to explore information, conduct experiments, completing worksheets and ask critical questions that can guide the students in developing and deepen their conceptual understanding. These questions encourages the students to conduct analysis and think critically (Hanson, 2006). Teacher subsequently gives confirmation regarding the concepts that will be constructed by the students.
Concept Formation	• Teacher gives critical questions that can guide students in constructing the concept of salt hydrolysis and buffer solutions. Students try to discover, recognize, and build concepts based on their findings at the exploration stage.
Aplication	• Teacher presents a contextual problem directly related to salt hydrolysis and buffer solution so that students' understanding of the concept is up to date to be transferred from the learning context to abstract contexts (Sadler, Romine, and Topçu, 2016). Teacher guides students to apply the knowledge in a new different situations so that they can proposed SE based on the SSI phenomenon. • Students apply the concept of salt hydrolysis and buffer solutions to solve problems presented by the teacher and submit SE related to SSI given by the teacher.
Closing	• Teacher assisted the students to draw conclusions on the topic that have been studied and also reflected on them.

Table 2. Scientific Explanation Category According to SOLO Taxonomy

Level	Indicator(s)
Prestructural	Students use incorrect data so the conclusions obtained are not relevant.
Unistructural	Students only use at least one information and one concept.
Multistructural	Students use some data/information but the data are not interconnected so they can't draw relevant conclusions.
Relational	Students use some data/information, apply the concept and then give temporary results. Students connect the data so that they can draw relevant conclusions.
Extended Abstract	Students use some data / information then apply the concepts and link between data so that they can draw relevant conclusions. Students think conceptually and can generalize it to another domain of knowledge and experience.

RESULTS AND DISCUSSION

Average Scientific Explanation (SE) skills in experimental classes were higher than control class. In POGIL learning, inquiry-based activities provide concrete learning experiences for students (Schroeder and Greenbowe 2008; Gale and Boisselle, 2015) so that they can develop skills of compiling and delivering scientific explanations (Wu and Hsieh, 2006) as well as improve their understanding of chemistry content (Bailey et al., 2012; Hein, 2012). Discussion activities in POGIL learning enable students to practice in expressing, communicating, and exchanging ideas with their peers (Daubenmire and Bunce, 2008) which in turn develop their skills in making and arranging scientific explanations. This is consistent with Amaral, Garrison, and Klentschy (2002) that inquiry learning activities improve students' ability in communicate and conveying ideas.

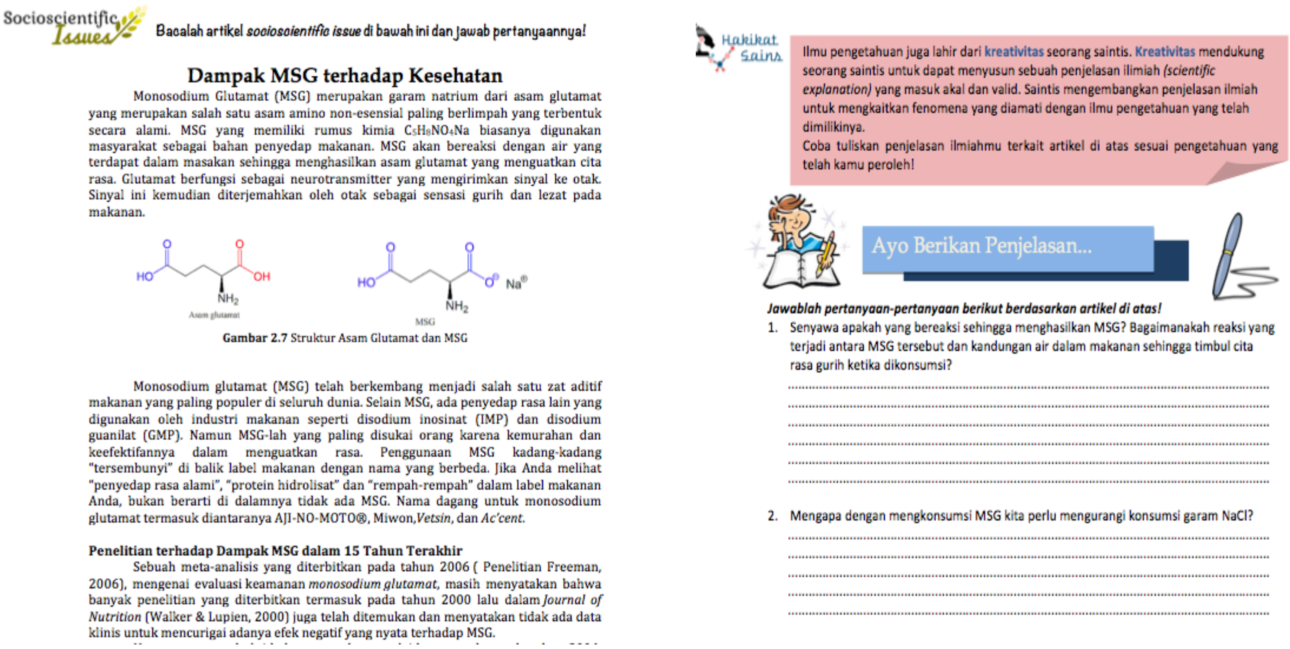
Students' scientific explanations (SE) complexity showed that 21.43% of students in the experimental class I (POGIL with SSI context) could reach the extended abstract level whereas experimental class II (POGIL) and control class were only able to reach the relational level (Table 3). SE skills difference between classes was statistically significant (p = 0,000, p <0.005). To determine the effect of SSI context on the development of SE, we conducted Mann-Whitney Test in which the test showed that difference between two classes was significant (Table 4). A statistically significant difference between experimental class I and experimental class II indicated that the use of SSI resulted in better SE skills. The presence of socio-scientific issues presented during learning process not only triggered discussion among students, but also trained the students to be able to link material concepts with phenomena in these issues. Learning with social issues can provide opportunities for students to understand the relevance of science to problems in everyday life thereby increasing students' decision-making abilities (Lee, 2007) and supports the students to be able to deliver valid scientific explanations. In the experimental class I, the teacher explicitly trained the students in building SE by providing information about SE construction based on SOLO's taxonomy. Students' worksheets also facilitate the students in practicing the construction of adequate scientific explanation of a certain phenomenon. These explicit students' involvement can increase their success in practicing it in everyday life (Osborne, Erduran, and Simon, 2004). Results in our study are in line with the previous study which found that the use of the SSI context improved students' scientific explanation skills (Puig and Jiménez-Aleixandre, 2011; Tsai, 2018).

Table 3. Students' Scientific Explanation Complexity

		Class I	**Class II**	**Control Class**
	Mean	**12.79**	**7.83**	**6.71**
Level	*Prestructural*	19.64 %	31.90 %	45.54 %
	Unistructural	15.18 %	47.41 %	42.86 %
	Multistructural	12.5 %	13.79 %	9.82 %
	Relational	31.25 %	6.90 %	1.79 %
	Extended Abstract	21.43 %	0 %	0 %

Table 4. Mann-Whitney U-Test for Students' Scientific Explanation Results

	Mean Rank	**Sum of Rank**	***U* Value**	**Asymp. Sig. (2-tailed)**
Class I	37.93	1062.00	156.00	0.00
Class II	20.38	591.00		
Class I	39.20	1097.50	92.50	0.00
Control	17.80	498.50		
Class II	33.40	968.50	278.00	0.04



Socioscientific Issues

Bacalah artikel *socioscientific issue* di bawah ini dan jawab pertanyaannya!

Dampak MSG terhadap Kesehatan

Monosodium Glutamat (MSG) merupakan garam natrium dari asam glutamat yang merupakan salah satu asam amino non-esensial paling berlimpah yang terbentuk secara alami. MSG yang memiliki rumus kimia $C_5H_8NO_4Na$ biasanya digunakan masyarakat sebagai bahan penyedap makanan. MSG akan bereaksi dengan air yang terdapat dalam masakan sehingga menghasilkan asam glutamat yang menguatkan cita rasa. Glutamat berfungsi sebagai neurotransmitter yang mengirimkan sinyal ke otak. Sinyal ini kemudian diterjemahkan oleh otak sebagai sensasi gurih dan lezat pada makanan.

Gambar 2.7 Struktur Asam Glutamat dan MSG

Monosodium glutamat (MSG) telah berkembang menjadi salah satu zat aditif makanan yang paling populer di seluruh dunia. Selain MSG, ada penyedap rasa lain yang digunakan oleh industri makanan seperti disodium inosinat (IMP) dan disodium guanilat (GMP). Namun MSG-lah yang paling disukai orang karena kemurahan dan keefektifannya dalam menguatkan rasa. Penggunaan MSG kadang-kadang "tersembunyi" di balik label makanan dengan nama yang berbeda. Jika Anda melihat "penyedap rasa alami", "protein hidrolisat" dan "rempah-rempah" dalam label makanan Anda, bukan berarti di dalamnya tidak ada MSG. Nama dagang untuk monosodium glutamat termasuk diantaranya AJI-NO-MOTO®, Miwon,*Vetsin*, dan *Ac'cent*.

Penelitian terhadap Dampak MSG dalam 15 Tahun Terakhir

Sebuah meta-analisis yang diterbitkan pada tahun 2006 (Penelitian Freeman, 2006), mengenai evaluasi keamanan *monosodium glutamat*, masih menyatakan bahwa banyak penelitian yang diterbitkan termasuk pada tahun 2000 lalu dalam *Journal of Nutrition* (Walker & Lupien, 2000) juga telah ditemukan dan menyatakan tidak ada data klinis untuk mencurigai adanya efek negatif yang nyata terhadap MSG.

Hakikat Sains

Ilmu pengetahuan juga lahir dari **kreativitas** seorang saintis. **Kreativitas** mendukung seorang saintis untuk dapat menyusun sebuah penjelasan ilimiah *(scientific explanation)* yang masuk akal dan valid. Saintis mengembangkan penjelasan ilmiah untuk mengkaitkan fenomena yang diamati dengan ilmu pengetahuan yang telah dimilikinya.
Coba tuliskan penjelasan ilmiahmu terkait artikel di atas sesuai pengetahuan yang telah kamu peroleh!

Ayo Berikan Penjelasan...

Jawablah pertanyaan-pertanyaan berikut berdasarkan artikel di atas!

1. Senyawa apakah yang bereaksi sehingga menghasilkan MSG? Bagaimanakah reaksi yang terjadi antara MSG tersebut dan kandungan air dalam makanan sehingga timbul cita rasa gurih ketika dikonsumsi?
   ....
   ....
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   ....
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   ....
2. Mengapa dengan mengkonsumsi MSG kita perlu mengurangi konsumsi garam NaCl?
   ....
   ....
   ....
   ....
   ....

Figure 1. Students' Worksheet Example

Aside from POGIL with SSI context overall promise in developing students' scientific explanation skills, students' process in reaching certain SOLO Taxonomy levels should also be addressed. During learning activity in experimental class I, students could not directly compose extended abstract level-scientific explanation. Students tend to submit answers according to the articles presented without explaining the phenomena that occurred: they are not accustomed to explaining the causes and the process of the phenomenon. For example, SSI about the Impact of MSG on Health (SSI 1 in students' worksheet, Figure 1). For these problems, students on average only reached uni structural level and only a few reached the multistructural level.

"Monosodium Glutamate (MSG) is a salt that is formed from the reaction of NaOH with $C_5H_9NO_4$ (glutamic acid). MSG or $C_5H_8NO_4Na$ (aq.) can react with water to produce glutamic acid which is the cause of the resulted savory taste." (Unistructural level).

"Monosodium Glutamate (MSG) is a salt derived from NaOH which is a strong base and $C_5H_9NO_4$ (glutamic acid) which is a weak acid. MSG can react with water and produce glutamic acid which causes a savory taste in food. Therefore, MSG or $C_5H_8NO_4Na$ (weak). aq.) is used as a flavoring in food." (Multistructural level).

In improving students' SE level, teachers guide the students during the class discussion by asking leading questions concerning MSG reactions mechanism in water so that students can be able to broaden their understanding and explain more comprehensively. After the teacher's guidance, students can compose a more comprehensive explanation as follows.

"Monosodium Glutamate (MSG) is a salt derived from NaOH which is a strong base and $C_5H_9NO_4$ (glutamic acid) which is a weak acid. When dissolved in water, monosodium glutamate undergoes dissociation reaction as follows.

$C_5H_8NO_4Na\ (aq) \rightleftharpoons Na + (aq) + C_5H_8NO_4{-}\ (aq)$

The Na + ion is a residual cation of a strong base which is a weak conjugate acid so that the ion cannot react with water. Meanwhile, the $C_5H_8NO_4$ ion - which is an anion of the remaining weak acid is a strong conjugate base so that it can react with water. The equation of reaction is as follows.

$C_5H_8NO_4{-}\ (aq) + H_2O\ (l)) \rightleftharpoons C_5H_9NO_4\ (aq) + OH{-}\ (aq)$

MSG undergoes partial hydrolysis when it dissolves in water. From the salt hydrolysis reaction, OH-ions are produced which cause the salt solution to be basic. Glutamic acid or $C_5H_9NO_4$ produced from the MSG hydrolysis reaction acts as a neurotransmitter that sends signals to the brain. These signals are then translated by the *brain as savory and delicious sensations in food. (Extended Level Abstract)*

The SE level improvement indicated that teacher plays an important role in POGIL with SSI in which similar results was found in Daubenmire et al., (2015) study about the implementation of POGIL in college students. Daubenmire et al., (2015) found that students' conceptual understanding is influenced by how their teachers interacted with them during a learning activity. The teacher's active role in guiding the students resulted in students' scientific explanation improvement. The duration in which students interacted and accustomed to SSI articles also affects the quality of their SE. At the third SSI (principle of benzoate preservatives as a buffer system) students' SE was dominated with multi structural to relational abstracts, which was an improvement from their uni structural level dominated-SE in SSI I.

"The presence of benzoic acid and sodium benzoate maintain a stable pH of food. Benzoic acid and sodium benzoate form a buffer system that is acidic so as to prevent bacterial growth. Microbial cell contents have a pH that tends to be neutral. If the atmosphere is acidic then microbial growth will be disrupted and eventually die." (Multistructural level)

"Benzoic acid and sodium benzoate play a role in maintaining the pH of packaged foods. Benzoic acid which is a weak acid and benzoic ions from sodium benzoate are its conjugate bases, both forming an acidic buffer solution. As a result microbes that tend to develop at neutral pH cannot survive. Benzoate buffer also prevents excess acid in food because the acid or H^+ ion will react with the conjugate base of the buffer solution with the following reaction $C_6H_5COO- + H + \rightleftharpoons C_6H_5COOH$" (Relational Level).

Results indicated that students' scientific explanation is not resistant to improvement, with the right approaches, improvement can meaningfully happen. It is also important to note that the conceptualization and specifications of scientific explanation shall be clearly stated in the learning syllabus so that students understand learning expectation. Our study offers a snapshot of the implementation of POGIL with a socioscientific context in learning salt hydrolysis and buffer solution, but considering the promising features of this learning approach, application for learning other chemistry or science subjects deserves a thoughtful consideration.

CONCLUSION

The POGIL learning model with Socio-scientific context (POGIL-SSI) proved to be more effective in developing students' scientific explanation (SE) skills compared to the POGIL model and conventional learning methods. POGIL-SSI learning model provides opportunities for students to gain an in-depth understanding of concepts and practicing their communication skills so that they can submit valid scientific explanations related to socio-scientific issues as part of inquiry activities. Results indicated the vital role of teacher's guidance in POGIL-SSI learning, therefore, educator should play their role as learning facilitator by asking leading questions in the discussion phase so that students' could deepen their understanding and can be able to explain it more comprehensively.

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