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# Science Process Skills as Learning Outcomes in Inquiry-Based Learning: A Literature Review

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**Abstract:** This literature review aims to determine 1) forms of Inquiry-Based Learning (IBL) are applied to teach Science Process Skill (SPS), 2) forms of IBL implemented to teach specific SPS, and 3) the level of inquiry used in IBL. Based on these objectives, a literature review was carried out consisting of seven stages starting from determining the study questions, determining data sources, searching for articles from the database, selecting based on keywords, and determining which articles will be reviewed according to the criteria and whether there are answers to the study questions in the articles. There are 54 articles were obtained from this process which were then reviewed with the aid of the Atlasti.9 application. Several strategies can be used to carry out IBL, including POGIL, ADI, PCOI, and DOEI. These Various learning strategies are needed to support the attainment of SPS. IBL is implemented at various levels. Based on the review, it can be concluded that it prefers to use guided rather than free IBL, especially for students with new experience on inquiry.

**Keywords:** Guided Inquiry; Inquiry Based Learning; Level of Inquiry; Science Process Skills; Teaching Strategy

## Introduction

Scientific inquiry has long been considered as a main feature of science teaching and learning. Scientific inquiry is not a new thing in learning science. The use of it in learning can be drawn in to the mid-19th century. Scientific inquiry emerged in learning when it was realized that science was different from other sciences. Science comes from observable things that can be generalized into concepts, principles, laws, and theories (DeBoer, 2006)). Therefore, science learning in the classroom should also show how students can induce, with scientific inquiry, to build their own understanding based on the observations they make in the laboratory. Inquiry skills can be interpreted as skills to carry out each stage of the inquiry, which can be increased through learning with an inquiry based learning (IBL) approach. (Minner et al., 2009). In the newest Indonesian curriculum, the skills demanded are science process skills (SPS). In some literature, inquiry skills are also equivalent to the term SPS which is an important component for conducting scientific inquiry (Lin et al., 2018). SPS does overlap with scientific practice (Reynders et al., 2019)

SPS are skills used by professional scientists in actual scientific inquiry (Lewthwaite, 2014) and can be taught (Yager & Akcay, 2010), whereas in experiments the skills used are often isolated and limited (Lewthwaite, 2014). SPS plays an important role in developing understanding of science as part of scientific inquiry. The absence of science process skills will make students understand the nature of scientific inquiry naïvely and the concepts they understand will not make them understand their world (Durmaz & Mutlu, 2017). The inquiry process provides a way for students to practice and improve their science process skills (Lin et al., 2018). Therefore, the development of SPS can be conducted with guided-IBL (Orosz et al., 2023). Process oriented guided inquiry learning (POGIL ) is one of the IBL methods that can improve SPS (Idul & Caro, 2022).

IBL has been widely adopted in various educational environments, including primary, secondary and higher

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education and also in various countries, including Indonesia which firmly emphasizes SPS as an element of learning outcomes. Despite its popularity and increasing emphasis in implementing the latest curriculum in Indonesia, it is still necessary to realize that implementing IBL is not an easy thing. This happens mainly because there is not much information regarding types of IBL can be applied effectively in general learning and specifically for each skill in SPS. Further in-depth exploration of effective forms of IBL strategies in the SPS context as learning outcomes is still needed. So far, SPS is still a side learning objective. Teachers focus more on elements of understanding knowledge. Therefore, to get a clearer picture of implementing IBL in the curriculum in Indonesia, it is necessary to explore appropriate IBL strategies according to the results of research that has been carried out by many people.

Another interesting thing is the impact of IBL on student learning outcomes. IBL is often associated with improving student learning outcomes, more precisely mastery of knowledge. Teachers are not yet aware of other important learning outcomes. Therefore, further research is still needed to explore the impact of IBL on various types of learning outcomes, one of which is SPS specifically.

Moreover, the appropriate level of inquiry for the learning process in accordance with current conditions in Indonesia is an interesting factor to be explored. In IBL there are confirmatory, guided and free levels. Although all have been reported to provide improvements in learning outcomes, it is still necessary to explore the characteristics of the three levels that are suitable for science learning today.

A Literature review aims to synthesize existing knowledge (in this case sourced from the literature) related to a particular topic, identify important biases and knowledge gaps in the literature, and propose further research directions. (Rowe, 2014). Based on this meaning, this literature review is aimed to find the main things related to how to teach inquiry skills or SPS . In line with these objectives, **the questions** that will be answered in this literature review are 1) what forms of inquiry-based learning are applied in the studies, 2) what forms of IBL are implemented to teach specific SPS, and 3) how the level of inquiry used in IBL is implemented in the studies

## Method

This literature review follows the steps used by (Fink, 2014) which consist of seven main steps. These steps include i) select research questions, ii) select bibliographical databases or articles, iii) select key terms, words or phrases for search, iv) apply practical or initial screening criteria, v) apply methodological screening criteria, vi) conduct a study or review, and vii) synthesize results. In line with these steps and also followed the practical steps taken by Ronnebeck et al. (2016), the literature review was carried out in some steps as presented in **figure 1.**

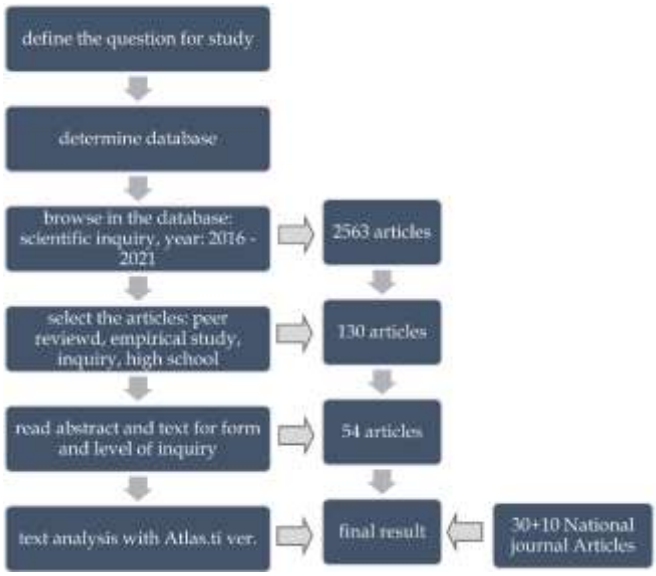


**Figure 1**. Steps in this literature review

The first step in this literature review is determining questions for the literature review. As explained above, the aim of this literature is to focus on the forms and levels of scientific inquiry. The team then determined literature sources in the form of research articles from several publishers. Taylor and Francis, John Wiley, Springerlink, and Chemical Education Research and Practice (CERP) were determined as sources for the articles to be analyzed. The team then searched the database of journal articles using the keyword "scientific inquiry" or "specific inquiry skills in the field of education and science education" published from 2016 to 2021. Based on these predetermined criteria, from all the data bases used, There are 2653 articles related to these keywords.

Not all articles that appeared were used, therefore the next stage was carried out, namely selecting articles based on appropriate titles by paying attention to the criteria: 1) research based on empirical data, 2) using keywords inquiry, scientific inquiry, and/or terms related to practice inquiry, 3) conducted at a high school level, preparing prospective teachers, or initial university or with basic chemistry material, 4) published in a peer-reviewed journal. Based on these criteria, 130 articles were obtained.

The next step is to filter the articles obtained by reading the abstract (and full text if necessary) to

determine which articles will be analyzed further based on the answers to the literature review question, namely "what is the appropriate form of application of an inquiry-based learning approach to develop SPS?" according to the curriculum in Indonesia", and "how is the level of inquiry used in accordance with the SPS level? By using this filter, 54 articles were obtained which were then carried out by text analysis using Atlas.ti software version 9. The codes used were Level: confirmatory, guided, free; SPS: observing, asking (for questioning and estimating skills), planning (for planning and inquiry skills), data processing (for processing, analyzing data and information skills), evaluating (for evaluating and reflecting skills), and communication ( to communicate data skills). The final step in this literature review is analyzing the research results, namely discussing the research results and comparing them with existing theories and conditions encountered in the context of the research to be carried out.

## Result and Discussion

Most of the articles found for further study report how inquiry-based learning is implemented. There are 54 articles reviewed in this section on scientific inquiry-based learning strategies for students.

*Form of Inquiry Based Learning*

In this review, most of study is focused on how IBL affects the expected learning outcomes. IBL is placed as a whole in the learning process (Bachhawat et al., 2020; Cairns, 2019; Goeltz & Cuevas, 2021; Schmid & Bogner, 2017), or placed as a basis or learning context (Anstey, 2017). Bielik and Yarden (2016) using the term inquiry-oriented learning. Science process skills are also seen to be a focus on the application of IBL, for example designing (Kodani & Koga, 2021; Szalay & Tóth, 2016) modeling experiments, argumentation, explanation or reasoning, as well as SPS in general. IBL is implemented with a focus on modeling, applied in a guided manner to improve students' model development abilities (Vilardo et al., 2016) or applied by modifying it with learning steps focused on modeling (Jimenez-Liso et al., 2022) and synthesizing it into a form of IBL innovation such as Modeling in the Primary Grades (MPG) (Samarapungavan et al., 2017)and Model-based Inquiry, MBI ) (Gray & Rogan-Klyve, 2018).

A synthesis of new terms for IBL was also carried out to highlight the focus of the intended learning. Starting from POGIL which emphasizes how to guide students to master the overall process skills. (Stanford et al., 2016)believes that the application of POGIL can improve students' argumentation skills due to two factors. Qureshi et al. (2016)found based on self-reports that their students better understood the concept by using POGIL. The application of POGIL can also improve students' argumentation skills (Moon et al., 2017), mastery of students ' knowledge (Özkanbaş & Taştan Kırık, 2020) and encourage students on positive affective experiences (Vishnumolakala et al., 2017).

IBL which focuses on argumentation skills is Argumentation Driven Inquiry (ADI) . The ADI model is described by Sengul et al. (2021) has eight stages, i.e. i) identifying tasks and guiding questions, ii) designing methods and data collection, iii) developing initial arguments, iv) argument sessions, v) explicit and reflective discussions, vi) writing investigative reports, vii) peer review, viii ) revise and submit reports. Sengul et al. (2021) insert a step before the fifth steps, if needed, collect additional data or perform new tests.

*The Argument Driven Inquiry (ADI)* model aims to help teachers prepare classes to implement explicit arguments (Sengul et al., 2021). A series of studies using ADI showed that ADI could improve scientific writing and presentation skills (Çetin & Eymur, 2017), students' perceptions of self-efficacy, inquiry skills, and laboratory skills, but did not improve students' attitudes towards chemistry (Eymur, 2018), students' understanding of the nature of science (Eymur, 2019), and students' views. to the nature of inquiry (Çetin, 2021).

Chen et al. (2019 ) used modified ADI (MADI) with the following steps: (a) identify tasks from demonstrations or presentations, (b) identify related research questions, (c) create hypotheses related to research questions, (d) design investigations and procedures, (e) collect data from direct activities, (f) providing evidence-based conclusions, and (g) forming and sharing group arguments and critiquing and refining their explanations and evaluations. The results of this study indicate that MADI can increase the involvement of female students in science and argumentation.

In contrast to the research above, Lu et al. (2018) examines the application of EDI. EDI is an explanation-oriented inquiry that focuses all student activities on the construction and evaluation of explanations. The EDI activity itself consists of three main steps centered on specific questions, namely proposing hypotheses, collecting data, and drawing conclusions. EDI can improve conceptual understanding and reduce students' misconceptions

Similar to POGIL and ADI, the articles in this study also apply learning strategies to support IBL implementation with a specific focus. Van Duzor (2016) apply the *Decision Explanation Observation Inference* (DEOI) method. In contrast to DEOI which leads to

several skills, planning and carrying out scientific investigations, (PCOI) is a form of guided inquiry that focuses on one skill, namely planning and carrying out scientific investigations (Crujeiras-Pérez & Jiménez-Aleixandre, 2017). Another form studied is conceptual learning and inquiry-based practices ( CLIP ) (Gao & Lloyd, 2020). Using the CLIP to prepare students for important skills, and guiding questions to measure knowledge, specific objectives and reinforce deep thinking and closer observation, students can acquire knowledge and use it in their own experimental error analysis (Gao & Lloyd, 2020). Meanwhile, Saleh et al. (2020)combining problem-based learning (*PBL*) with inquiry.

There are various forms of inquiry-based learning strategies used in the articles reviewed, including Socioscientific Inquiry Based Learning (SSIBL) (Putra et al., 2023), 5E (Ong et al., 2020, 2021), Argument Driven Inquiry (ADI) (Fitri et al., 2022; S. Rahayu et al., 2020; Salsabila Utami et al., 2022), and modifications of ADI such as Argumentative Inquiry Blended Learning (AIBL) (Fitri et al., 2022) and argument-driven inquiry with scaffolding (ADIS) (Hasnunidah et al., 2022)). Some researchers also combine inquiry with other strategies used to form a synthesis of learning strategies, such as the Inquiry learning model with multiple-coping modeling (Hakim et al., 2023), Lesson Study for Learning Community (LSLC) based Guided Inquiry Learning (GIL) learning model (Ramadani & Suriati, 2022), Peer Led Guided Inquiry (PLGI) (Lestari, 2021), Collaborative inquiry (Kusairi et al., 2021; Nisfah et al., 2022), the guided-inquiry learning model and the Socratic dialogue-integrated guided-inquiry (Pitorini et al., 2020), and Inquiry learning with Green Learning Method (GeLeM) (Savitri et al., 2017). IBL is also combined with media such as swing (the guided inquiry learning with the digital swing model, (Khoiri et al., 2020), real media (Doyan et al., 2020), Google Classroom (M. Rahayu et al., 2022), Experiment (A. Rahayu & Sardiana Sari, 2023; Sari et al., 2023) or practicum (Hidayah et al., 2022), students' worksheets (Sulistiani & Agustini, 2022) including scaffolding (Auliyani et al., 2023; Haidar et al., 2020), and digital technology (the Digital Analysis Tool-Assisted Real-World Inquiry (Digita-RI), Nurohman, 2021). This synthesis of inquiry-based learning strategies aims to focus more on learning objectives.

*IBL for Science Process Skill*

The study conducted was devoted to the application of IBL, therefore the main learning outcomes from this practice were skills in conducting inquiry or SPS. Inquiry abilities are reported to be well improved in the application of guided inquiry (Goeltz & Cuevas, 2021) and inquiry developed with model-based steps (Jimenez-Liso et al., 2022). Guidance carried out using diagram I directs students according to the steps of inquiry, therefore diagram I is found to be able to improve students' abilities in inquiry (Akkuzu & Uyulgan, 2017). Other guidance is also carried out using a computer. Increased inquiry abilities also occur in the application of IBL using computers (Fang et al., 2016), including computational modeling (Wagh et al., 2017) or computer-based games. In contrast to games or computer applications that guide the whole inquiry process, story (Saleh et al., 2020)telling used to motivate students in inquiry learning (Peleg et al., 2017) (Peleg et al., 2017) found that story telling did affect students' inquiry abilities, but teachers were still reluctant to use fictional stories in science classes.

Science process skills are targeted by research in the articles reviewed both overall (Indawati et al., 2023; Iswatun et al., 2017; Juniar & Sianipar, 2022) and specifically on certain skills or understanding of inquiry (Muntholib et al., 2022). However, more national articles (24 of 40) targeted learning outcomes other than these science process skills. Some of the learning outcomes are laboratory skills (Hidayah et al., 2022), generic science skills (Taofiq et al., 2018), learning achievement (Sulistiani & Agustini, 2022)), understanding concepts (Salim & Hidayati, 2020), critical thinking (Miftakhurrohmah et al., 2023; Ramdani et al., 2021; Saputri et al., 2023; Verawati et al., 2021) to motivation (Dani et al., 2021) and self-efficacy (Hakim et al., 2023). Several articles also mention learning outcomes as targets for implementing IBL(Priyasmika, 2021; Sari et al., 2023) without further explaining what the intended learning outcomes are.

In addition to highlighting inquiry skills or SPS as a whole, several studies have focused on particular SPS

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*Observing*

The amount of data or information that students can obtain and the guidance provided in this process does not automatically improve students' ability to evaluate. Sahnaz (2018) conducted a study focused on observing skill. Students' unfamiliarity with interacting with the media used to guide them can actually become an obstacle for students (Belland et al., 2019). Students who are not familiar with computers will find it difficult to find information and take longer to get used to it.

*Questioning and predicting*

Asking is at the heart of inquiry. Students' ability to ask questions should be a focus in IBL. Although, this ability must be trained independently. Bielik and Yarden (2016) used inquiry-oriented learning to improve students' ability to ask questions and found

that students' ability to ask questions could only be improved by student-centered, dialogic, and interactive learning. Therefore the teacher should be able to implement dialogic and interactive inquiry. Ritonga dan Istiyono (2023) argued that asking question can be improved by IBL

On the other hand, the hypothesized ability was reported to be enhanced by 3DTG-assisted IBL (Chen et al., 2018). The findings also show that 3DTG facilitates hypotheses exploration and adjustment.

Another form of predictive and questioning ability is modeling ability. Modeling is one of the practices required in eight scientific inquiry practices. Models have a central role in the work of scientists, and are an important component of science and engineering practice (Gray & Rogan-Klyve, 2018). There are two articles related to IBL that focus on models, namely Model-based Inquiry, MBI (Gray & Rogan-Klyve, 2018)and Modeling in the Primary Grades (MPG) (Samarapungavan et al., 2017). Both of these studies concluded that the learning process carried out can teach students to develop and use models.

*Planning and carrying out investigations*

The aim of learning chemistry is to develop the ability to practice inquiry-based laboratories to do real science (Zemel et al., 2021). As the aim of scientific inquiry practice, research regarding learning strategies also places designing experiments as the focus of IBL implementation. The ability to design experiments is considered the core of inquiry that must be mastered by students. This study found articles that became the ability to design and carry out experiments more than any other focus.

IBL implementation is carried out by (Kodani & Koga, 2021)and (Szalay & Tóth, 2016) emphasizes the ability to design experiments. The learning carried out provides opportunities for students to design their own experiments to inquire about laboratory activities. The result is an increase in the ability to design experiments that are not related to gender (Szalay & Tóth, 2016)as well as teaching students this ability to improve students' critical thinking and argumentation skills which are important for the process of scientific inquiry (Kodani & Koga, 2021). By focusing on the ability to plan and carry out investigations, (Crujeiras-Pérez & Jiménez-Aleixandre, 2017) implemented a strategy of planning and carrying out scientific investigations (PCOI). This study found that students' ability to plan and implement them depended on the teacher's familiarity and guidance. Different things are found by Silva and Galembeck (2016)the possibility that students can work autonomously in designing, conducting, and interpreting experiments. Students perform better on less guided activities.

The need for guidance in planning and carrying out investigations is also the basis for the development of the media. One of them is computer-based media developed by Van Riesen et al. (2018). Research using media called The Experiment Design Tool (EDT) with three different types depending on students' prior knowledge found that there was no difference in results in the use of media types, but instead on students' prior knowledge. Another form of media is a module developed by Goodey & Talgar (2016). The results show that the module can improve students' experimental thinking skills, thinking skills which form the basis for developing students' abilities to plan and develop investigations. MeanwhileHikmawati et al. (2020) found that student's learning outcome can be increased through observation, experiment, or investigation

*Processing, analyzing data and information*

Students' ability to convey arguments is a form of processing skills, analyzing data and information. The ADI learning model and its modification, MADI, places argumentation as the focus of the model. The application of both shows that students' ability to argue can be improved (Çetin, 2021; Chen et al., 2019;). The increase in students' ability to argue can be seen from the structure of the argument, the content (content) of the argument, and the writing mechanism (Çetin & Eymur, 2017). Apart from ADI, POGIL was also reported to improve students' argument skills (Stanford et al., 2016). It has been reported IBL can improve students' argumentation skill (Fitri et al., 2022; Hasnunidah et al., 2022; S. Rahayu et al., 2020; Salsabila Utami et al., 2022), and scientific reasoning (Yulianti & Zhafirah, 2020)

This is the impact of teacher guidance in POGIL guiding students to use the evidence they get from laboratory work (Moon et al., 2017).

*Evaluating and reflecting*

One form of the ability to evaluate and reflect is to determine the value of an information or fact obtained. Research on the application of IBL shows that IBL can enhance this ability (Pambudi & Novita, 2020). Research (Jimenez-Liso et al., 2022)shows that student engagement increases in evaluating their experimental designs. The same thing was found by Gao dan Lloyd (2020), with the application of CLIP which succeeded in inviting students to use their knowledge to analyze their own experimental errors. The application of EDI which is based on the skills of giving explanations also shows a reduction in student misconceptions (Lu et al., 2018)because students can self-evaluate the concepts they understand.

*Communicating results*

The ability to communicate can be realized in the form of verbal or written. Writing is one of the most requested forms of communication as a result of IBL laboratory processes and classes. To guide students in recording and communicating the results of their inquiry, Lawrie et al. (2016) used a wiki as a laboratory notebook. Wiki is used jointly by students in groups and collaboratively. Therefore wikis can be used to analyze student engagement, collaboration processes, and skills students acquire in collaborative groups.

*Levels of Inquiry: Free and Guided*

The role of teachers and students in the learning process can determine the level of IBL, namely traditional (confirmation), structured, guided, and open (Banchi & Bell, 2008). In fact, there is no one strategy or set of learning characteristics that are considered the most effective for teaching inquiry or scientific practice because science skills have many perspectives (National Research Council, 2012). However, National Research Council (2012)adding at least science learning that provides students with opportunities for various scientific activities and scientific thinking, including inquiry and investigation, collection and analysis of evidence, logical reasoning, and communication and application of information is expected to be able to develop science skills. The review of articles conducted found that there were more articles using guided inquiry-based learning. There are only seven articles that use independent inquiry and three articles that combine both or vary from guided to independent inquiry.

Free inquiry in the studied articles was implemented primarily with the aim of encouraging students to design their own experiments (Silva & Galembeck, 2016; Szalay & Tóth, 2016), including in interdisciplinary classes (Burkett & Dwyer, 2019). Both in the form of ordinary experiments in the laboratory (Kodani & Koga, 2021), online learning (Destino & Cunningham, 2020) or in a higher level, namely open-ended research (Kapon, 2016), although this form of research project can also be carried out using guided inquiry (Greer et al., 2021). Another goal that makes researchers apply free inquiry is to increase student involvement in inquiry activities (Burkett & Dwyer, 2019). The research Jeon et al. (2021) follows the progress of student involvement by providing gradual inquiry from guided to free. By applying free inquiry, (Silva & Galembeck, 2016) was found that students had better activities, although it was also realized that some skills could not be carried out entirely independently, still at various levels of autonomy. It is contra to the finding of Balgopal et al. (2017). Their research shows that guided inquiry leads to higher learning outcomes in both student comprehension and performance. It is supported by (Kang, 2022) who conclude that guided inquiry has a positive effect on Science Literacy, while open inquiry has a negative effect. These was also found by (Cairns, 2019) and (Lehtinen et al., 2019), that teacher's guidance is needed in the inquiry process . One form of guidance or assistance provided by the teacher in the IBL process is by providing media. Therefore, almost all of the research using media in IBL uses guided inquiry. Clear guidance also comes through POGIL frame. The implementation of IBL models such as ADI, MADI, EDI, PCOI, DEOI, and CLIP in the articles studied is also carried out in the guided inquiry frame, including the application of new things such as control variables. skills, CVS (Stender et al., 2018), case-based learning (Cresswell & Loughlin, 2017) and learning outside the classroom such as science camps (Leblebicioglu et al., 2017).

The level of inquiry most frequently reported by national journals is guided inquiry. As many as 31 out of 40 articles stated that guided inquiry could provide significant results on the desired learning outcomes. There is only one article that actually uses free inquiry in the learning process. His research shows that the free inquiry learning model can significantly improve student learning outcomes. Meanwhile, Three articles examine further the differences between structured, guided, and open inquiries. The results show that the implementation of the open inquiry model led to a higher increase in creative thinking skills (Ramdani et al., 2021). Although (Salim & Hidayati, 2020) emphasized that there was no interaction between the level of inquiry and the desired learning outcomes

## Conclusion

The research studied was dominated by the application of IBL as a learning strategy. With the consideration to learning strategies that can be used to teach scientific inquiry or scientific practice. It can be concluded that various learning strategies are needed to support the attainment of these skills. For learning that focuses on scientific practice is still relatively new in Indonesia using guided rather than open inquiry

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**Conflicts of Interest**
The authors declare no conflict of interest

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