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Enhancing Mathematics Education through Lesson Study Based on Didactical Suitability Criteria: Evidence from Undergraduate Courses

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Abstract
Innovation in mathematics education is essential to improve the quality of university learning, which should not only emphasize cognitive achievement but also broader didactical dimensions. This study aims to implement Lesson Study based on the Didactical Suitability Criteria (LS-DSC) in mathematics education lectures for undergraduate students, and to evaluate its impact on six dimensions of didactical suitability: epistemic, cognitive, interactional, affective, mediational, and ecological. This research employed a descriptive qualitative approach with a lesson study design consisting of three main stages: plan–do–see. The participants included lecturers as facilitators and students as active learners. Data were collected through classroom observation, analysis of students' worksheets, reflective notes, and documentation of learning activities. The data were then analyzed using reduction, presentation, and verification techniques. The findings reveal that LS-DSC effectively enhanced learning quality across all six dimensions. The most significant improvements were observed in the cognitive, affective, and interactional dimensions, which strengthened student participation and learning motivation. The epistemic and mediational dimensions demonstrated consistency in supporting conceptual understanding and the use of appropriate learning resources, while the ecological dimension highlighted the relevance of learning to students' real-life contexts. These results align with constructivist theory and previous studies that emphasize the effectiveness of lesson study in improving mathematics teaching practices. Therefore, LS-DSC can be considered an innovative model that not only improves learning quality but also fosters lecturers' professional development and enriches students' learning experiences.

Keywords: *Lesson Study; Didactical Suitability Criteria; Mathematics Education; Undergraduate Students; Innovative Learning*

1. Introduction

Mathematics education focuses not only on mastering concepts and procedures, but also on how teachers are able to design, implement, and reflect on learning processes that are meaningful to students. In this context, teacher professional development is an urgent need so that the quality of learning continues to improve in accordance with the development of the times and global challenges (Lewis, 2016, Fernandez & Yoshida, 2012).

Increased professionalism teachers need to be supported through collaborative and reflection-based strategies, not just one-way training that is theoretical in nature (Dudley, 2013, Huang & Shimizu, 2016).

One of the model of teacher professional development that has been widely adopted in various countries is **Lesson Study (LS).** Lesson Study, which originated in Japan as *jugyō kenkyū*, is a collaborative approach in which teachers jointly plan, observe, and reflect on real learning in the classroom (Lewis & Perry, 2014, Stepanek et al., 2007). Through LS, teachers can deepen their understanding of students' thinking processes and find more effective and contextual learning strategies (Cerbin & Kopp, 2006, Fujii, 2016).

LS is usually carried out through a repetitive cycle consisting of three stages, namely **Plan, Do, and See**. In the *Plan* stage, the teacher collaboratively designs the lesson; *the Do* stage is carried out with one of the teachers teaching and the other observing; while the *See stage* becomes a space for critical reflection on the advantages and disadvantages of the learning process carried out (Lewis, 2016, Dudley, 2013). Through this cycle, teachers not only improve the learning plan, but also strengthen a culture of continuous professional reflection (Huang & Shimizu, 2016, Fernandez & Yoshida, 2012).

On the other hand, **the Didactic Suitability Criteria (DSC)** is an evaluative framework born from the *Onto-Semiotic Approach (OSA)* in mathematics education. DSC is used to assess the quality of didactic appropriateness of a learning process through six main dimensions: epistemic, cognitive, interactional, mediative, affective, and ecological (Godino et al., 2007, Pino-Fan et al., 2018). This tool assists teachers in assessing whether the learning designed and implemented really supports the achievement of students' overall learning goals (Breda et al., 2018, Godino et al., 2017).

The epistemic dimension of DSC, for example, focuses on the quality of the mathematical content presented; the cognitive dimension emphasizes on conformity with the student's initial knowledge and abilities; while the interactional dimension assesses the quality of communication and discussion in the classroom. In addition, the mediative dimension is related to the use of learning resources, the affective dimension measures student motivation, and the ecological dimension assesses the suitability of learning with the curriculum and the context of the educational environment (Godino et al., 2017, Pino-Fan et al., 2018). With this framework, teachers have a systematic foundation in conducting instructional reflection.

The integration of LS with DSC is a potential strategy because the two complement each other: LS provides a collaborative forum for planning, implementing, and reflecting on learning, while DSC provides a more detailed and directed evaluative measurement tool for the didactic quality of learning (Breda et al., 2018, Godino et al., 2017). Thus, teachers not only learn from the teaching practices of their peers, but also understand how epistemic, cognitive, and affective aspects interact with each other in creating effective mathematics learning (Pino-Fan et al., 2018, Godino et al., 2017).

Previous research has shown that the use of LS can improve teachers' understanding of students' thinking as well as encourage a culture of critical reflection oriented towards continuous instructional improvement (Lewis & Perry, 2014, Cerbin & Kopp, 2006). On the other hand, the application of DSC helps teachers evaluate the didactic suitability of a learning in a more structured way, so that reflection is not only subjective but also based on accountable criteria (Godino et al., 2017, Breda et al., 2018).

In Indonesia, the implementation of LS has been adopted in several teacher professional development programs, mainly through the cooperation of universities and schools. Studies show that LS is effective in improving teachers' pedagogical skills and student learning outcomes, although a more adaptive model is still needed to be implemented widely and sustainably (Saito et al., 2006, Fujii, 2016). With the addition of DSC as a reflective framework, LS activities can be more directed in evaluating the instructional quality that occurs in the classroom.

1.1. Lesson Study (LS) Concept

Lesson Study (LS) is a model of teacher professional development that originated in Japan and was later widely adopted in various countries, including Indonesia. According to Lewis (2002), LS is a collaborative approach in which teachers jointly plan, implement, and reflect on learning to improve the quality of teaching practice. This model emphasizes the teacher's learning process on how students learn, so that learning improvement is sustainable (Fujii, 2014). The stages in LS are generally known as the *Plan–Do–See cycle*, which is a joint planning (*plan*), the implementation of learning by one teacher while the other observes (*do*), and joint reflection to find the strengths and weaknesses of learning (see) (Takahashi & McDougal, 2016). Thus, LS is not just a teaching strategy, but a means of developing teacher professionalism based on collaboration.

1.2. Didactic Suitability Criteria Concept (DSC)

Didactic Suitability Criteria (DSC) is a set of criteria used to assess the didactic quality of a learning process. Godino et al. (2007) explained that DSC aims to evaluate the extent to which a learning process is in accordance with the characteristics of mathematical knowledge, student needs, and socio-cultural context. The main dimensions in DSC include epistemic, cognitive, interaction, affective, ecological, and didactic mediation aspects, which together provide a comprehensive picture of learning appropriateness (Godino, 2013). In practice, DSC helps teachers and researchers to identify didactic potential and learning barriers, so that it can be used as an instrument for reflection and learning improvement (Pino-Fan et al., 2015). Therefore, DSC is more appropriately seen as a tool for evaluating the quality of learning, not the learning method itself.

1.3. LS with DSC (LS–DSC) integration

The integration of LS with DSC emerged as an effort to strengthen the role of reflection in the LS cycle through the use of more systematic and measurable criteria. If LS functions as a collaborative forum for teachers to improve learning, then DSC provides an analytical framework to assess the extent to which the learning is appropriate didactically (Rico & Lupiáñez, 2008). Thus, LS-DSC is not intended as a new learning model for students, but rather as a model of teacher professional development that emphasizes criteria-based reflection. Through this integration, teachers can more easily identify weaknesses in aspects of planning, implementation, and learning outcomes, as well as design improvement strategies that are more targeted (Godino et al., 2017). The potential benefits of LS–DSC are not only limited to improving teacher professionalism, but also to the quality of students' learning experiences that become more meaningful because teachers are able to adapt strategies to real needs in the classroom.

1.4. Previous Research

A number of studies have shown the effectiveness of LS in improving teacher professionalism and learning quality. In Indonesia, Saito et al. (2006) found that LS is able to encourage teachers to be more reflective and collaborative in designing learning. Meanwhile, research by Hartono & Widjaja (2019) shows that LS can improve the pedagogic skills of mathematics teachers, especially in understanding students' difficulties. On the other hand, research on DSC is still relatively new in Indonesia. The study of Pino-Fan et al. (2018) emphasized that the use of DSC in mathematics learning evaluation can provide detailed information related to material suitability, teaching strategies, and student responses. However, research that explicitly integrates LS and DSC is still rare, especially in the context of Indonesian education. This research gap opens up opportunities to examine in depth how LS-DSC can be implemented as an innovative approach in the professional development of mathematics teachers in the country.

1.5. Research Conceptual Framework

The integration *of Lesson Study* (LS) with *Didactic Suitability Criteria* (DSC) is built on the basis of the need to improve the quality of mathematics learning through criteria-based reflection. LS is understood as a teacher's professional development cycle that involves *the Plan–Do–See* stage (Lewis, 2002; Fernandez & Yoshida, 2004). Meanwhile, DSC is present as a set of evaluative dimensions that allow for a more in-depth analysis of the didactic suitability of a learning, covering epistemic, cognitive, interactional, affective, ecological, and mediating aspects (Godino, 2013; Batanero, 2019).

This idea of integration was born from the view that teachers' reflections in LS are often general and less directed. With DSC, reflection can be focused on specific indicators that reflect the quality of learning, so that the results are more objective and in-depth (Llinares & Krainer, 2006; Ponte, 2017).

Thus, LS–DSC not only emphasizes on collaborative cycles, but also presents reflective measurement tools that can guide teachers to understand the strengths and weaknesses of the learning being implemented.

Conceptually, the integration of LS and DSC is depicted in Figure 1. This model shows that LS as a forum for teacher collaboration is enriched by DSC as an analysis instrument. This criterion-based reflection process is ultimately expected to be able to produce an improvement in the quality of mathematics learning, both from the side of teachers and students.

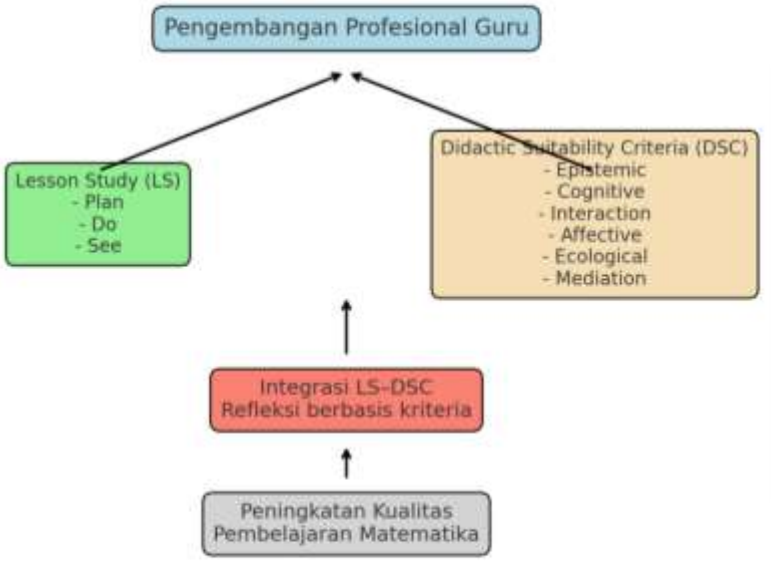

Figure 1. *LS–DSC Research Conceptual Framework*

However, the integration of LS and DSC has not been extensively explored empirically in Indonesia, so there are still research gaps that need to be bridged. The collaborative use of LS and DSC as an evaluative instrument has the potential to give
19 birth to a more comprehensive model of teacher professional development and in accordance with the challenges of 21st century mathematics education (Godino et al., 2017, Lewis, 2016).

Thus, research on the integration of LS and DSC in
3 the professional development of mathematics teachers is important. This research not only
34 provides theoretical contributions in the field of mathematics education, but also offers practical benefits for teachers in improving the quality of learning in a collaborative, reflective, and sustainable manner in accordance with local needs and global challenges (Fernandez & Yoshida, 2012, Pino-Fan et al., 2018).

2. Method

22 This study uses a qualitative approach with *a lesson study* design based on *didactic suitability criteria* (LS–DSC). This approach was chosen because it is suitable for exploring in depth the learning process that takes place in the classroom and identifying didactic suitability that arises from the interaction between lecturers and students. Through the *Plan-Do-See* cycle which is enriched with *the dimension of didactic suitability*, this research is oriented towards improving learning practices and improving the quality of the lecture process.

2.1. Research Subject and Location

The research subjects are a lecturer in the Mathematics Learning Strategy course and a 5th semester student of the Mathematics Teaching Study Program. The selection of subjects is carried out purposively on the grounds that lecturers have experience in implementing learning innovations, while students are prospective mathematics teachers who are taking core courses related to learning strategies. The research location is in the lecture room of the campus, which allows observations to be carried out authentically in an academic environment.

2.2. Research Procedure

The research procedure follows a *lesson study* cycle consisting of three main stages, namely *Plan, Do,* and *See*.

Tabel 1. LS–DSC Research Procedure

Phase	Main Activities	Fokus Didactic Suitability Criteria (DSC)
Plan	- Designing lesson plans and learning tools based on course outcomes - Discussion between lecturers and researchers to map potential student learning barriers. - Developing DSC-based observation instruments.	*Epistemic, Cognitive, Ecological*
Do	- Implementation of learning in the classroom. - Observation of lecturer-student interaction. - Use of learning media and Student Worksheets (MFI).	*Interactional, Affective, Mediational*
See	- Collaborative reflection between lecturers, researchers, and observers. - Analysis based on the six dimensions of DSC. - Developing improvement recommendations for the next cycle.	*All DSC dimensions*

a. Plan: The lecturer and the researcher design a learning plan that is oriented to the learning outcomes of the course and integrates didactic suitability criteria (epistemic, cognitive, interaction, affective, ecological, and mediational).
b. Do: The learning plan is implemented in the classroom by involving students as participants. At this stage, direct observation of learning interactions is carried out.
c. See: Reflection is carried out collaboratively between lecturers, researchers, and observers using the DSC framework as a reference to analyze the advantages and disadvantages of the lecture process.

This procedure is carried out in several cycles until significant improvements in learning practices are obtained.

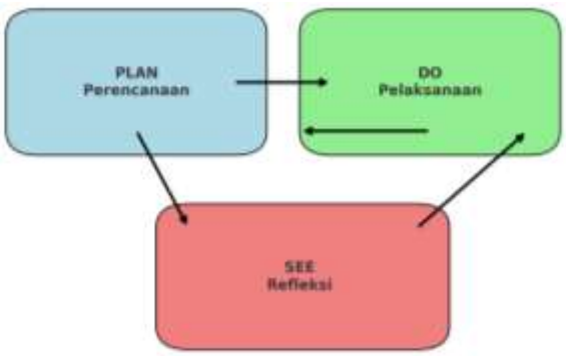

Figure 2. *Research Procedure*

2.3. Data Collection Techniques

Data is collected through several techniques, namely:

a. Observation: to record the activities of lecturers and students during the lecture process.
b. Interview: to explore the experiences, perceptions, and reflections of lecturers and students on the implementation of LS-DSC.
c. Documentation: lecture notes, lesson plans, student worksheets, and video recordings of learning.

2.4. Research Instruments

The research instruments are in the form of observation guidelines, interview guidelines, and didactic suitability analysis (DSC) rubrics. This rubric refers to six main dimensions, namely: (a) epistemic suitability, (b) cognitive suitability, (c) interactional suitability, (d) affective suitability, (e) ecological suitability, dan (f) mediational suitability.

The didactic suitability analysis (DSC) rubric was the primary instrument used to convert qualitative data from observations, interviews, and worksheet analysis into the quantitative scores presented in Figure 3. This rubric employed a 5-point assessment scale for each of the six dimensions, defined as: 1 = Very Low Suitability, 2 = Low Suitability, 3 = Moderate Suitability, 4 = High Suitability, and 5 = Very High Suitability.

Following each cycle, the rubric was completed by the researchers (acting as observers) and the lecturer during the *See* (reflection) stage. For instance, on the 'Interactional' dimension, a score of '2' was assigned in Cycle I because discussions were "dominated by a few active students," whereas a score of '4' was assigned in Cycle II when participation was "more balanced." The final scores shown in Figure 3 represent the consensus score agreed upon by the researchers and lecturer after reviewing all collected data for that cycle.

2.5. Data Analysis Techniques

The data was analyzed using the Miles and Huberman interactive analysis model which included three stages, namely: (a) data reduction, (b) data presentation, and (c) conclusion/verification. The analysis is focused on how the implementation of LS-DSC can reveal potential improvements in the lecture process, both in terms of learning strategies and student responses. The validity of the data is strengthened through the triangulation technique of sources and methods.

3. Results and Discussion

3.1. Results

The implementation of *lesson studies* based on *didactic suitability criteria* (LS-DSC) in the lectures of Tadris Mathematics was carried out in two cycles. Each cycle consists of three stages, namely *Plan, Do,* and *See*.

In the **Plan stage**, lecturers and researchers design learning tools by paying attention to the learning outcomes of the Mathematics Learning Strategy course. The tools prepared include Lecture Implementation Plans (RPP), Student Worksheets (MFIs), and DSC-based six-dimensional observation instruments. The results of the analysis show that the integration of DSC helps lecturers in mapping potential student learning barriers, especially in the epistemic (understanding of basic concepts of learning strategies) and cognitive aspects (the level of difficulty students in applying concepts to classroom scenarios).

The **Do stage** is carried out in the classroom by involving 5th semester students. The results of the observation show that lecturer-student interaction is more active than ordinary lectures. Students seemed enthusiastic about using MFIs, discussing in small groups, and responding to lecturers' questions with a variety of answers. From the DSC's perspective, the interaction and affective dimensions stand out, as students not only engage in intellectual discussions, but also show a positive attitude towards innovative learning.

At the **See** stage, reflection is carried out jointly by lecturers, researchers, and observers. Reflection shows an improvement in the quality of learning from the first cycle to the second cycle. In the first cycle, it was found that learning media did not support the mediation aspect so that some students still had difficulty understanding MFI instructions. However, in the second cycle, after improvements, lecturers managed to add more interactive visual media so that the mediation dimension increased significantly. In addition, the ecological dimension also received attention through more effective time management and more conducive classroom arrangements.

In general, the results of the study show that LS-DSC is able to reveal the advantages and disadvantages of learning in a more systematic manner. The six dimensions of DSC have proven to be a comprehensive indicator in evaluating the appropriateness of learning didactic.

3.2. Discussion

The results of this study are in line with the findings of Godino (2013) and Batanero (2019) who emphasize that *didactic suitability criteria* are an effective conceptual framework for evaluating the learning process matematika. The application of LS-DSC allows learning reflection to be carried out not only based on subjective impressions, but through structured indicators. This is proven when lecturers are able to identify specific epistemic and cognitive aspects that are obstacles for students, then make improvements in the next cycle.

In addition, this study strengthens the studies of Lewis (2002) and Fernandez & Yoshida (2004) who stated that *lesson study* is a collaborative approach that can improve the quality of learning through cyclical reflection. The integration of DSC in *lesson studies* provides a new, sharper dimension in analyzing didactic suitability. Thus, LS–DSC can be seen as an innovative model that is relevant to the needs of mathematics education in college.

Increasing student interaction and positive attitudes in learning is also in line with the study of Rachmawati & Widjajanti (2021) which emphasizes that learning innovations based on collaborative reflection are able to increase student motivation and involvement. Therefore, LS-DSC not only improves the quality of didactic, but also encourages the growth of an active and reflective learning culture among prospective mathematics teacher students.

Table 1. *Summary of LS–DSC Implementation Results Based on DSC Dimensions*

DSC Dimensions	Findings of Cycle I	Improvements in Cycle II	Final Results
Epistemic	Students experienced epistemic barriers, specifically struggling to differentiate between core pedagogical concepts. As noted in the Cycle I reflection, students "confused the definitions of 'learning strategy,' 'method,' and 'model.'" In Cycle II, the lecturer provided concrete examples, which clarified these distinctions and reduced the barrier.	The lecturer added concrete examples of the implementation of mathematics learning strategies.	Students' understanding is more directed, epistemic barriers are reduced.
Cognitive	In Cycle I, students' worksheets showed difficulty connecting theory to practice. For example, one worksheet merely defined 'Cognitive Load Theory' but failed to explain how it applied to a classroom scenario. After scaffolding was implemented in Cycle II, a student worksheet demonstrated more systematic work, outlining "a step-by-step example of managing intrinsic load for a complex algebra problem.	MFIs are repaired with gradual instructions (scaffolding).	Students are able to do assignments more systematically.
Interactional	Group discussion in Cycle I was "dominated by two active students in the front row, while other groups remained silent," according to observation notes. After implementing role rotation in Cycle II, observation notes reflected a more balanced interaction: "All groups contributed, and the role of 'speaker' successfully rotated, ensuring wider participation.	The lecturer added rules for discussion and rotation of roles in the group.	Student participation increases, interaction is more balanced.
Affective	The passive attitude in Cycle I was evident. In Cycle II, student enthusiasm visibly increased. This was supported by interview data, where one student remarked, "The use of visual media and the group rotation made the class more engaging. I felt more motivated to participate because my opinion was needed for the group task.	Lecturers use interactive media and short ice breaking.	Students are more enthusiastic, positive attitudes towards learning are increasing.
Ecological	Time management is not effective, discussion activities often go through allocation.	Lecturers improve time management and limit the duration of discussions.	Time is more controlled, classes are more conducive.
Mediational	Learning media does not help the understanding of MFI instructions.	Lecturers add visual media (slides, charts, and video examples).	Student understanding increases, mediation barriers decrease.

1 Figures: The results of the implementation of the *Lesson Study for Didactic Suitability Criteria (LS–DSC)* model show a significant increase in each dimension of *the Didactic Suitability Criteria*.

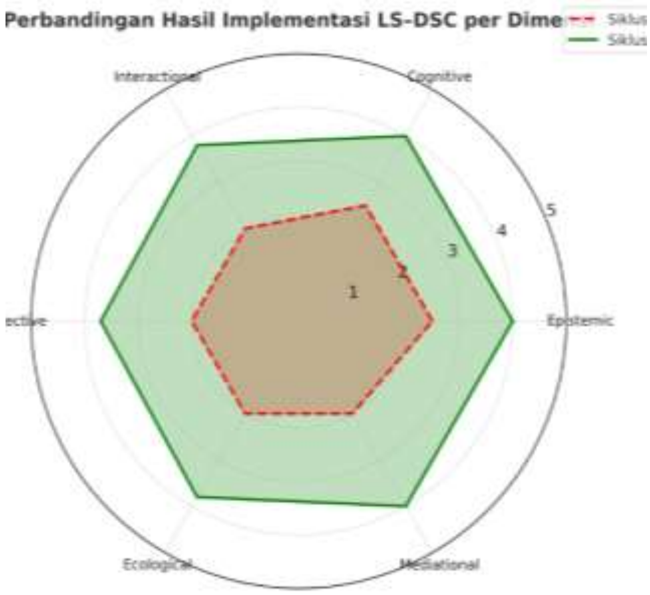

Figure 3. *comparison of LS–DSC results in each dimension between Cycle I and Cycle II.*

The radar diagram shows that in **Cycle I**, student achievement is still in the low to medium category, with an average score between 2.0–2.5. Epistemic barriers can be seen from students' difficulties in understanding learning concepts, cognitive barriers that arise when relating theory and practice, and interactional barriers can be seen from the dominance of discussion by only a few students. Likewise, affective, ecological, and mediation aspects still need strengthening.

However, after improvements were made in **Cycle II,** the results showed consistent improvement in all dimensions. The **epistemic dimension** increased significantly from 2.5 to 4.0 after being given a concrete example of the application of learning strategies. The **cognitive** dimension also increased from 2.5 to 4.0 with scaffolding in MFIs. In the **interactional** dimension, student participation which was originally low (2.0) increased to 3.8 thanks to the rules of discussion and role rotation. Similarly**, the affective dimension**, which originally tended to be passive (2.0) increased to 3.7 due to the variation of the interactive methods applied.

The **ecological** dimension related to time management also showed an increase (2.0 → 3.8) after lecturers optimized the allocation of discussion activities. Finally, the **mediational** dimension has increased considerably from 2.0 to 4.0 through the use of visual and digital media to support MFIs. Thus, it can be concluded that **LS-DSC is effective in reducing didactic barriers and improving the quality of the learning process of Tadris Mathematics students as a whole**.

Improving the quality of learning through the implementation of *Lesson Study for Didactic Suitability Criteria* (LS–DSC) indicates that this approach has a strong theoretical foundation. The results of the study showed significant improvements in the epistemic, cognitive, interactional, affective, ecological, and mediation dimensions. This confirms that the integration of LS with DSC is able to answer classical problems in mathematics learning, namely the existence of *didactic obstacles* (Brousseau, 1997; Godino et al., 2007).

From the perspective **of didactic theory**, the improvement of the epistemic and cognitive dimensions proves the importance of structured content analysis. Godino & Font (2010) emphasize that the epistemic quality of teaching materials contributes directly to student understanding. By adding concrete examples and *scaffolding*, lecturers are able to adapt the material to the student's *zone of proximal development* (Vygotsky, 1978), thereby reducing excessive cognitive load as stated in *Cognitive Load Theory* (Sweller, 1994).

In terms of **collaborative learning**, increasing student interaction confirms Fujii's (2016) findings that *lesson studies* are effective in creating a culture of collective reflection. Role rotation and discussion rules encourage more equal participation, in line with the concept *of social constructivism* (Cobb & Yackel, 1996) which states that knowledge is built through social interaction. This also reinforces the results of the research of Isoda (2015), who found that students' active involvement in *lesson studies* strengthens conceptual understanding and improves mathematical communication skills.

37 3 The affective dimension that shows an increase in student enthusiasm can be explained through the framework *of Self-Determination Theory* (Deci & Ryan, 2000), where a teaching strategy that provides space for autonomy, competence, and social connectedness will increase intrinsic motivation. 13 These results are consistent with the research of Toh (2020), which found that a variety of media and interactive approaches are able to foster students' positive attitudes towards mathematics learning.

From the ecological aspect, the effectiveness of time management shows the relevance of the theory of classroom management put forward by Fernandez (2002), that careful planning in *lesson studies* contributes to the achievement of learning objectives within the available time limits. The improvement of the mediation dimension through the use of digital media is also consistent with the findings of Yerushalmy (2014) who stated that visual representation supports the transition from abstract to concrete concepts in mathematics learning.

In general, the results of this study show that LS-DSC is not only a model that focuses on improving teaching practices, but also builds **integrative linkages between didactic theory, social constructivism, classroom management, and educational technology**. 17 Thus, this study enriches the literature on the effectiveness of *lesson study* which was previously largely focused on improving the quality of teacher teaching (Lewis, 2002; Fernandez & Yoshida, 2004), by adding *the dimension of didactic suitability* as an evaluation benchmark.

4. Conclusion

1 This study concludes that the implementation of *Lesson Study* for *Didactic Suitability Criteria* (LS-DSC) in the lectures of Tadris Mathematics students has proven to be effective in improving the quality of the learning process. The application of LS-DSC through *the plan–do-see cycle* which 1 focuses on the analysis of six dimensions *of didactic suitability* (epistemic, cognitive, interactional, affective, ecological, and mediational) is able to reduce didactic obstacles previously faced by students.

Author Contributions

Researchers play a role in designing research ideas, developing methodology designs, and coordinating the implementation of lesson studies. Data analysis and interpretation of results are carried out together with the preparation of a comprehensive article manuscript. All authors contribute equally in the preparation of literature, manuscript writing, revision, and approving the final manuscript for publication.

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Ethical Statement

This research has been carried out by paying attention to the ethical principles of educational research. All lecturers and students who are the subjects of the research have been given an explanation of the objectives, procedures, and benefits of the research and expressed their consent to participate voluntarily (informed consent). The data obtained is kept confidential and is only used for academic purposes. This study did not involve experiments that had the potential to harm participants and did not cause a conflict of interest.

Conflict of Interest Statement

The author states that there is no potential conflict of interest either financially or non-financially that could affect the results of research and writing of this article. The entire research process and manuscript preparation is carried out independently for academic purposes only.

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