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Analysis of Students' Understanding of Temperature Concepts Based on Diagnostic Test Results: A Discovery Learning Study

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Abstract: This study highlights the low conceptual understanding of students in physics learning, which is often accompanied by misconceptions, especially in the topic of temperature and heat. The purpose of this study is to analyze the improvement of students' conceptual understanding through the application of the Discovery Learning (DL) model. The study used a qualitative descriptive design supported by quantitative data in the form of a pretest and posttest. The subjects were 30 students of class VII-A who were selected purposively. The instrument used was an essay test to measure students' conceptual understanding before and after learning. The results showed a significant increase in students' conceptual understanding, indicated by an increase in scores from the low category in the pretest to the high category in the posttest. The DL model has been proven to be able to increase student activeness, encourage critical thinking processes, and help students build concepts independently through systematic learning stages. In addition, student misconceptions were still found regarding the concepts of temperature and heat that stem from inaccurate initial understanding. The conclusion of this study shows that the application of the Discovery Learning model is effective in improving students' conceptual understanding and reducing misconceptions, making it suitable for use as an alternative for more meaningful learning in physics.

Keywords: Conceptual understanding; Discovery learning; Physics misconceptions.

Introduction

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results. Universities need to produce graduates with a strong conceptual understanding, especially to face the increasing demands of non-routine and interactive work. Today's professionals face a complex environment, characterized by ongoing global change, rapid communication, and rapid technological developments. To address complex problems in this dynamic and information-rich environment, professionals are required to continuously adapt, prioritize, and innovate. Through a good conceptual understanding, they can think logically to analyze and implement appropriate strategies. Furthermore, conceptual understanding also fosters creative thinking skills, enabling them to generate new ideas and strategies (Blickenstaff, 2010). Thus, understanding the concept helps professionals to see problems holistically, not just in parts, so that the resulting solutions are more effective (Ashley et al., 2021).

Conceptual understanding is a fundamental skill that is crucial for students in learning mathematics. A strong conceptual understanding will make it easier for them to solve problems. This way, students are expected to be able to find and present solutions based on their own thinking, without being fixated on a single solution (Phanphech et al., 2019). According to Gilmore and Bryant, conceptual understanding is the ability to understand concepts, operations, and relationships in mathematics. Meanwhile, Duffin and Simpson state that students are said to have conceptual understanding if they are able to: re-explain or express the concepts that have been learned, use the concept in various different situations, and develop various possible outcomes of a concept or a student with a deep conceptual understanding may be able to apply the

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science that has been learned in school to everyday life (Kim & Song, 2009).

The goal of learning physics is for students to truly understand physics concepts. However, there is ample evidence that passing a physics exam does not necessarily mean understanding the material. Furthermore, students with higher working memory capacity generally demonstrate a better understanding of physics concepts. This has several important implications that warrant consideration (Chen & Whitehead, 2009). Physics appears in various ways in many areas of everyday life, and experience allows us to develop some concepts related to physics; however, the concepts that individuals acquire from their past lives may not correspond to some scientific facts. These experiences, which do not correspond to scientific facts, give rise to learning products called misconceptions in the literature (Ozkan & Topsakal, 2020).

Study results Chu et al. (2012) stated that 25–55% of students experience difficulties in applying scientific concepts in everyday contexts. The length of school, the science subjects being studied, and previously studied physics topics correlate with the development of students' conceptual understanding, especially in topics related to heat transfer, temperature scales, specific heat capacity, homeostasis, and thermodynamics. Although students improve their conceptual understanding in subsequent school years, they still experience difficulties in connecting scientific concepts to their experiences in everyday contexts.

Study resultsDilber et al. (2009)showed that conceptual change-based instruction led to significantly better acquisition of conceptual change in projectile motion than traditional instruction. Individuals often have their own understanding of how the world works, which sometimes differs from the prevailing scientific view. Therefore, these understandings are considered unscientific by scientists. Researchers have shown that students often come to class with incomplete or inaccurate prior knowledge, which can hinder their learning of scientific concepts. As a result, students of all ages can have alternative, erroneous understandings in various scientific fields. In recent years, much research has focused on identifying and understanding students' thinking patterns and the difficulties they face in learning various scientific topics. Research also shows that students do not come to class as "blank slates," but already possess their own understandings of how and why phenomena occur in everyday life. During the learning process, students construct understandings based on their backgrounds, attitudes, abilities, and experiences. According to the cognitive model, students strive to construct plausible understandings of events and phenomena from their own perspectives. These understandings, whether correct or incorrect, will influence how they receive and learn new scientific knowledge. Therefore, many studies have been conducted to examine students' alternative understandings of science concepts (Dessie et al., 2023).

Understanding students' initial understanding of scientific concepts has long been considered an important foundation for designing science instruction. However, as science education goals increasingly emphasize understanding concepts and theories rather than simply memorizing facts, a more in-depth analysis of students' conceptual understanding is needed. To achieve this, it is important to examine the extent to which students truly understand physical phenomena at the conceptual level. In this study, we conducted an in-depth analysis of students' understanding of heat conduction using a cognitive model perspective. Furthermore, we proposed a practical and visual method (diagrams) to illustrate the structure of students' understanding in detail. This more detailed analysis not only helps identify common errors in students' understanding but also can more clearly demonstrate differences in understanding between individuals (Chiou & Anderson, 2010).

Discovery learning is a process in which people search for important information in the environment and task coordination space to make appropriate tactical decisions and perform effectively. Therefore, guided discovery refers to the provision of instructions that assist learners in their search for important information, while unguided discovery indicates the absence of such instructions.The discovery learning theory introduced by Jerome Bruner in the 1960s focuses on improving students' ability to acquire new knowledge through direct experience (Bruner, 1960). In this approach, students are encouraged to construct new knowledge, evaluate existing knowledge, integrate existing knowledge with new knowledge, and actively ask questions. This process also fosters risk-taking, problem-solving skills, and the creation of unique learning experiences (Bicknell-Holmes & Seth Hoffman, 2000). In addition, the teacher's role in providing support during exploration activities, such as providing prompt feedback, can help increase the effectiveness of learning while saving students time (Prasad, 2011).

Providing guidance can have a significant impact on the cognitive mechanisms underlying discovery learning (Raab et al., 2011). On the other hand, discovery learning conditions can encourage exploratory problem-solving processes and thus the same learning conditions can result in explicit, verbal (guided instruction) movement learning.(Williams et al., 2002)DL requires students to engage in the process of scientific inquiry (Van Joolingen et al., 2007). When students work in pairs or small groups with the goal of learning together, they need to externalize ideas, negotiate with each other, and construct new shared knowledge. Therefore, collaboration can serve as a support for the performance of the scientific discovery learning process (Saab et al., 2009). In DL, the teacher's role is primarily to help students think, ask questions, and evaluate for themselves. Furthermore, in my experience, when students discover knowledge, they have a better understanding of it, feel ownership of it, and usually find it easier to apply it to various scenarios (Mukherjee, 2015).

DL has regained popularity in recent decades for at least two reasons. First, there has been a shift in education toward student-centered learning rather than teacher-centered learning. DL places greater emphasis on students' efforts to construct their own understanding of a phenomenon through active inquiry (Zachos et al., 2000). Second, the increasing availability of technology encourages the development of sophisticated simulation-based learning environments to support learning (Veermans et al., 2006). DL is a method that helps learners construct and manage their own knowledge. This method requires active engagement and full attention, and usually occurs in problem-solving situations. In the process, learners use prior knowledge and experience to discover basic strategies and understand a concept. Traditional learning theory states that discovery plays a crucial role in understanding abstract concepts and in enhancing students' persistence and creativity (Honomichl & Chen, 2012). Meanwhile, newer theories emphasize that children are active participants in the learning process, not just passive recipients of information. For example, the theory explains that children learn in a manner similar to the scientific method, namely by testing new experiences against pre-existing beliefs or theories. Children also tend to seek the root cause of a phenomenon (Gopnik et al., 2004) and show curiosity when faced with confusing or unusual data (Schulz & Bonawitz, 2007). In DL, the primary task of the learner is to deduce the characteristics of the model underlying the simulation. The learner's basic action is to change the value of the input variable and observe the resulting change in the value of the output variable (Robinson, 2000). Analysis of scientific discovery learning is usually based on models of discovery as practiced by scientists. One such model involves six components (Friedler et al., 1990): defining the problem, stating a hypothesis, designing an experiment, collecting, analyzing, and interpreting data, applying the results, and making predictions based on the results. The aim of this study was to analyze the improvement in students' conceptual understanding through the application of the DL model.

Method

This study employed a qualitative descriptive design with an analytical approach, aiming to provide an in-depth description and analysis of students' conceptual understanding after implementing the DL learning model. This approach was chosen because the study focused not only on the final results, in the form of grades, but also on the process of developing students' conceptual understanding during the learning activities. Thus, this study was able to provide a comprehensive picture of changes in students' understanding from before to after learning. In addition to using a qualitative approach, this study was also supported by quantitative data in the form of pretest and posttest results, which were used to strengthen the research findings.

The subjects in this study were 30 students of class VII-A. The sampling technique used was purposive sampling, which is a sample selection technique based on certain considerations relevant to the research objectives. The selection of class VII-A was based on the results of initial observations which showed that the class had a relatively low average learning outcome, namely 50.50. This condition indicates that students still experience difficulties in understanding concepts, so this class is considered appropriate to be the subject of research that focuses on improving conceptual understanding through the application of the DL model.

The research instrument used was a conceptual understanding test in the form of 10 essay questions. This test was designed to measure various indicators of conceptual understanding, such as students' ability to re-explain previously learned concepts, relate concepts to other situations, and apply concepts to problem-solving. Essay questions were chosen because they allow students to explore their understanding more deeply than objective questions. Before being used in the research, the instrument underwent a validation process by two experts: a physics expert and a physics education expert. This validation process aimed to ensure that the instrument matched the learning indicators, provided clarity of language, and had a level of difficulty appropriate to students' abilities.

The implementation phase begins with a pretest given to students to determine their initial understanding of the concepts to be learned. Next, the learning process uses the Discovery Learning model. In its implementation, learning follows the main stages: stimulation, problem identification, data collection, data processing, verification, and generalization. In the stimulation phase, students are presented with problems or phenomena related to the learning material to arouse curiosity. Next, students identify the problem and gather relevant information from various sources. In the data processing phase, students analyze the information obtained and then verify the validity of their findings. In the final phase, students draw conclusions or generalizations from the concepts they have discovered. Through this phase, students play an active role in the learning process, so that the concepts they have learned become more meaningful. After the entire learning process is completed, students are given a posttest to measure the improvement in conceptual understanding that has been achieved. The final phase of the research is carried out by processing and analyzing data obtained from the pretest and posttest results.

The data analysis technique used was descriptive analysis, which combines simple qualitative and quantitative approaches. Quantitative analysis was conducted by comparing pretest and posttest scores to determine improvements in student learning outcomes. Additionally, the percentage of students' conceptual understanding was calculated using the rubric.Capriconia & Mufit (2022)which were then categorized into three categories, namely low ($0 < P \leq 30$), medium ($30 < P \leq 70$), and high ($70 < P \leq 100$). Meanwhile, qualitative analysis was conducted by interpreting the results obtained to explain the pattern of increasing conceptual understanding and the factors that influence it. To increase the validity of the data, this study used triangulation techniques, namely by combining various data sources and analysis methods. Triangulation was carried out by comparing test results, the learning process, and the overall interpretation of the data. Thus, the research results obtained are expected to have a high level of validity and credibility, and be able to provide a more accurate picture of students' conceptual understanding after the application of the DL model.

Results and Discussion

Based on the research results obtained through the pretest and posttest activities in Figure 1, there is a significant difference in students' conceptual understanding before and after the implementation of the DL learning model. The data presented shows that, in general, there was an increase in learning outcomes for all students. In the pretest stage, students' initial ability to understand concepts was still relatively low. This is evident from the distribution of scores, which were predominantly in the low to moderate range, namely around 7.3 to 45. Most students obtained scores in the range of 20–30, indicating that students were not able to fully understand the concepts. This condition indicates that before the learning was carried out, students still experienced difficulty in identifying, linking, and applying the concepts that had been learned. The low pretest scores also reflect that previous learning tended to not provide meaningful learning experiences for students. After being given treatment in the form of learning with the DL model, the posttest results showed a significant increase. Student scores on the posttest ranged from 50 to 95, with the majority of students scoring above 75. Some students even achieved very high scores, such as 90, 94, and 95. This improvement indicates a positive change in students' conceptual understanding after participating in the learning process. Further analysis reveals that almost all students experienced an increase in their scores from the pretest to the posttest. For example, some students initially scored low, but then significantly improved after the learning process.

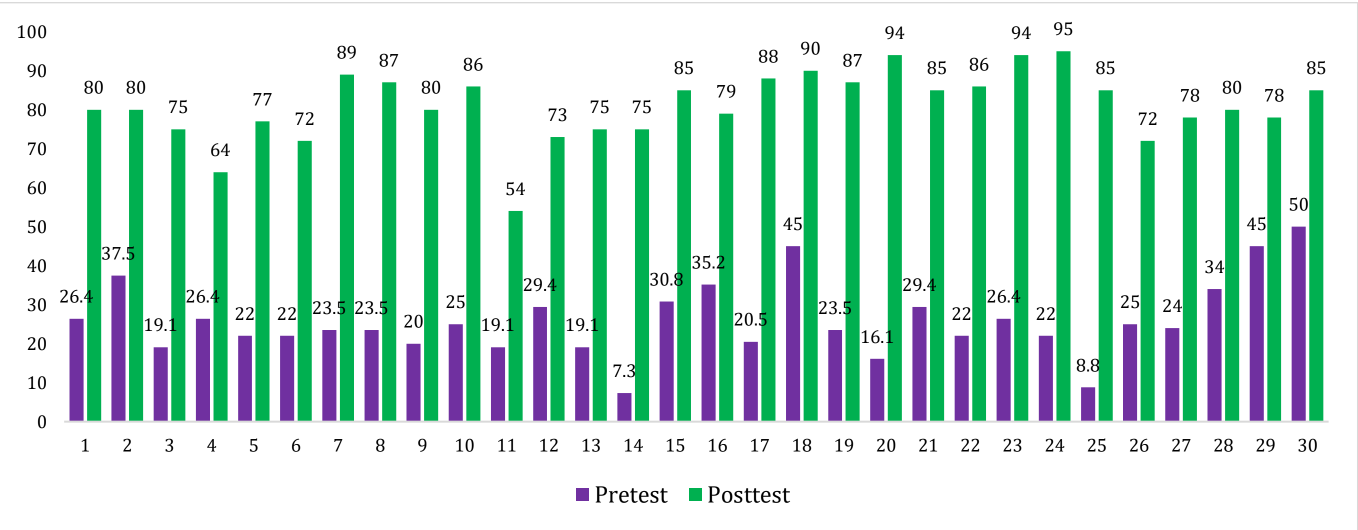

Figure 1. Students' Conceptual Understanding of Temperature and Heat Material

This demonstrates that the DL model is capable of helping students gradually develop conceptual understanding. The learning process, which involves actively discovering concepts, encourages students to think more actively and not simply passively receive information. The DL model is characterized by emphasizing the process of concept discovery by students. In its application, students go through several stages: stimulation, problem identification, data collection, data processing, verification, and generalization. In the stimulation stage, students are confronted with a problem that stimulates curiosity. Next, students identify the problem and gather relevant information. This process provides students with the opportunity to be directly involved in learning. The data processing and verification stages are crucial in building conceptual understanding. At this stage, students begin to process the information obtained and test its accuracy. Through these activities, students not only memorize material but also understand the relationships between concepts. Finally, in the generalization stage, students draw conclusions based on their own findings. This process makes learning more meaningful because concepts are acquired through direct learning experiences. The improvement in learning outcomes also demonstrates that the DL model is capable of increasing student activeness and involvement in the learning process. Students become more confident in expressing opinions, discussing, and seeking solutions to given problems. This results in increased conceptual understanding, as students learn through experience and interaction, not just through teacher explanations. However, some students' progress is less rapid than others. This may be due to several factors, such as differences in initial abilities, levels of motivation to learn, and student engagement during the learning process.

*Next, the results of the interview with students (S13) related to one question asked, namely:*A student conducted an experiment by mixing 200 ml of water at 80°C with 300 ml of water at 20°C in a closed container. After a while, the temperature of the mixture became 44°C. However, based on theoretical calculations, the final temperature should be 48°C. Analyze the possible causes of the difference between the experimental results and the theoretical results, and explain the factors that influence the temperature change in the experiment! The student's answer is: The temperature difference occurs because cold water "absorbs temperature" more than hot water. Cold water has a stronger property in lowering the temperature, so the final temperature is lower than the theory. In addition, temperature can be "lost" due to mixing, so not all the temperature from the hot water is transferred to the cold water.

The explanation for why this answer is a misconception is due to a misunderstanding of the concepts of temperature and heat. Temperature is not something that can be absorbed or lost, but rather simply indicates the degree of heat of an object. In the mixing process, what is actually transferred is heat (thermal energy), not temperature itself. Furthermore, the assumption that cold water is "stronger" in lowering the temperature is also incorrect, because temperature changes are determined by the mass of the substance, its specific heat, and the existence of heat exchange with the surrounding environment. Differences between theoretical and experimental results generally occur due to several factors, such as heat lost to the environment, the container that also absorbs heat, and possible inaccuracies in the temperature measurement process.

The results of interviews with students (S13) showed that students still experience misconceptions in understanding the concepts of temperature and heat. Students assume that cold water "absorbs heat" more and has a stronger property in lowering temperature, and assume that temperature can be "lost" when mixed. This indicates that students' conceptual understanding has not been formed scientifically, because students are not able to differentiate between the concept of temperature as a measure of heat and heat as energy transfer. This misconception indicates that students are still using prior knowledge that is not in accordance with scientific concepts. In the context of learning, this condition emphasizes the importance of implementing the DL model, which provides opportunities for students to discover concepts through direct experience and the process of inquiry. Through stages such as stimulation, data collection, and verification, students can test their own understanding and reconstruct erroneous concepts into more scientific ones. Thus, DL plays an important role in improving students' conceptual understanding, because it emphasizes not only the final result, but also the thinking process. This model helps students identify misconceptions, correct misconceptions, and construct concepts of temperature and heat more accurately and meaningfully.

Furthermore, students' ability to follow each DL stage also influences the results. Students who are active and fully engaged tend to experience more significant improvements than those who are less active. Overall, the results of this study indicate that the implementation of the DL model has a positive impact on students' conceptual understanding. The increase in scores from pretest to posttest is an indicator that student-centered learning can help students understand concepts more deeply. Thus, the DL model can be used as an effective learning alternative to improve the quality of learning, particularly in the aspect of conceptual understanding. This is evidenced by students' answers to the following questions:

Explain how to measure the temperature of a substance using a thermometer? The students' answers are as follows: 1) Insert the tip of the thermometer into the substance, wait until the temperature is stable, then read the scale on the thermometer (S-3); 2) Dip the thermometer into the substance without touching the walls of the container, wait a few moments, then read the result (S-30); 3) Make sure the thermometer is clean, insert it into the substance, let it stand until it does not change, then record the temperature (S-15); 4) Use a thermometer by inserting the tip into the substance, wait until it shows a fixed number, then read the temperature (S-20); 5) Insert the thermometer into the substance, wait until the mercury stops moving, then read the temperature on the scale (S-10).

Based on this description, it can be concluded that the use of the DL model not only improves student learning outcomes quantitatively but also improves the learning process to be more active, creative, and meaningful. Therefore, this model is highly relevant for implementation in learning aimed at improving students' conceptual understanding. This aligns with the view Hung & Jonassen, (2006). Conceptual understanding and computational skills in physics are two important cognitive abilities that shape students' problem-solving skills. These two abilities are not mutually exclusive; rather, they are interrelated and complementary. Conceptual understanding helps students explain physical phenomena qualitatively and concretely, while mathematical equations are used to explain them quantitatively and more abstractly. With a good conceptual understanding, students can structure a problem, thereby finding solutions more effectively and effectively. Meanwhile, computational skills serve as a tool for implementing or completing these solutions. Most importantly, the ability to combine and harmonize these two aspects is key to students developing expert-like physics problem-solving skills. Students exposed to structured problem-solving strategies have been found to demonstrate a better conceptual understanding of physics and are more likely to adopt a conceptual approach to problem-solving (Gaigher et al., 2007).

Besides that, study by Riaz et al. (2020) A study investigating the effects of Discovery Learning-Scientific Community Laboratories (DL-SCL) and traditional non-DL-SCL laboratories on students' conceptual understanding in Physics-1 laboratory found that using a conceptual approach to learning measurement techniques, including the concept of uncertainty, was beneficial. During the lab, students were asked open-ended questions and had to design experiments and collect and analyze data. Students using this reformed laboratory scored higher on physical measurement questionnaires and demonstrated better conceptual understanding when comparing data sets. All of these teaching approaches and materials have incorporated elements of constructivist theory by reforming the more traditional, passive, lecture-based teaching approach to a more student-centered, active approach. These newer approaches are collectively referred to as interactive engagement methods.

Two unfavorable attitudes have been shown to influence discovery learning; one is a laziness to think and assume the impossibility of discovery, and the second is to regard discovery as merely a glance at something. These two learning attitudes severely hinder the effects of guided discovery instruction (Shieh & Yu, 2016).

Conclusion

The implementation of the DL model has demonstrated effectiveness in improving students' conceptual understanding of temperature and heat. Through learning stages that emphasize the discovery process, students are encouraged to actively observe, analyze, and independently draw conclusions about concepts. This makes learning more meaningful because students not only receive information but also construct their own understanding. Furthermore, students' active involvement during the learning process contributes to improved critical thinking skills and the ability to relate concepts to real-world situations. Furthermore, this study also revealed that students still have misconceptions, particularly those stemming from inaccurate initial understandings. Therefore, the role of teachers is crucial in identifying and correcting these misconceptions through appropriate learning strategies. Overall, the DL model not only improves learning outcomes but also improves the quality of students' conceptual understanding in a more in-depth, systematic, and sustainable manner.

Based on the research findings, it is recommended that teachers implement the DL model as an alternative learning strategy to improve students' conceptual understanding, particularly in materials that have the potential to give rise to misconceptions. Teachers also need to identify students' initial understanding before learning and provide appropriate guidance during the discovery process to ensure effective learning. Furthermore, the regular use of diagnostic questions can help detect student misconceptions early. Further research is recommended to examine the application of the DL model to other physics materials or combine it with other learning approaches to achieve more optimal results.

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References

Ashley, S., Schaap, H., & Bruijn, E. de. (2021). Exploring differences between international business undergraduates' conceptual understanding. *Studies in Higher Education*, *46*(6), 1041–1054. https://doi.org/10.1080/03075079.2019.1672642

Bicknell-Holmes, T., & Seth Hoffman, P. (2000). Elicit, engage, experience, explore: Discovery learning in library instruction. *Reference Services Review*, *28*(4), 313–322. https://doi.org/10.1108/00907320010359632

Blickenstaff, J. C. (2010). A framework for understanding physics instruction in secondary and college courses. *Research Papers in Education*, *25*(2), 177–200. https://doi.org/10.1080/02671520802382904

Capriconia, J., & Mufit, F. (2022). Analysis of concept understanding and students ' attitudes towards learning physics in material of straight motion. *Jurnal Penelitian Pendidikan IPA*, *8*(3), 1453–1461. https://doi.org/10.29303/jppipa.v8i3.1381

Chen, W. C., & Whitehead, R. (2009). Understanding physics in relation to working memory. *Research in Science and Technological Education*, *27*(2), 151–160. https://doi.org/10.1080/02635140902853624

Chiou, G. L., & Anderson, O. R. (2010). A multi-dimensional cognitive analysis of undergraduate physics students' understanding of heat conduction. *International Journal of Science Education*, *32*(16), 2113–2142. https://doi.org/10.1080/09500690903258246

Chu, H. E., Treagust, D. F., Yeo, S., & Zadnik, M. (2012). Evaluation of students' understanding of thermal concepts in everyday contexts. *International Journal of Science Education*, *34*(10), 1509–1534. https://doi.org/10.1080/09500693.2012.657714

Dessie, E., Gebeyehu, D., & Eshetu, F. (2023). Enhancing critical thinking, metacognition, and conceptual understanding in introductory physics: The impact of direct and experiential instructional models. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7), 1–15. https://doi.org/10.29333/ejmste/13273

Dilber, R., Karaman, I., & Duzgun, B. (2009). High school students' understanding of projectile motion concepts. *Educational Research and Evaluation*, *15*(3), 203–222. https://doi.org/10.1080/13803610902899101

Friedler, Y., Nachmias, R., & Linn, M. C. (1990). Learning scientific reasoning skills in microcomputer-based laboratories. *Journal of Research in Science Teaching*, *27*(2), 173–191.

Gaigher, E., Rogan, J. M., & Braun, M. W. H. (2007). Exploring the development of conceptual understanding through structured problem-solving in physics. *International Journal of Science Education*, *29*(9), 1089–1110. https://doi.org/10.1080/09500690600930972

Gopnik, A., Sobel, D. M., Danks, D., Glymour, C., Schulz, L. E., & Kushnir, T. (2004). A theory of causal learning in children: causal maps and bayes nets. *Psychological Review*, *111*(1), 3–32. https://doi.org/10.1037/0033-295X.111.1.3

Honomichl, R. D., & Chen, Z. (2012). The role of guidance in children's discovery learning. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*(6), 615–622. https://doi.org/10.1002/wcs.1199

Hung, W., & Jonassen, D. H. (2006). Conceptual understanding of causal reasoning in physics. *International Journal of Science Education*, *28*(13), 1601–1621. https://doi.org/10.1080/09500690600560902

Kim, M., & Song, J. (2009). The effects of dichotomous attitudes toward science on interest and conceptual understanding in physics. *International Journal of Science Education*, *31*(17), 2385–2406. https://doi.org/10.1080/09500690802563316

Mukherjee, A. (2015). Effective use of discovery learning to improve understanding of factors that affect quality. *Journal of Education for Business*, *90*(8), 413–419. https://doi.org/10.1080/08832323.2015.1081866

Ozkan, G., & Topsakal, U. U. (2020). Determining students' conceptual understandings of physics concepts. *Shanlax International Journal of Education*, *8*(3), 1–5. https://doi.org/10.34293/education.v8i3.2908

Phanphech, P., Tanitteerapan, T., & Murphy, E. (2019). Explaining and enacting for conceptual understanding in secondary school physics. *Issues in Educational Research*, *29*(1), 180–204.

Prasad, K. S. (2011). Learning mathematics by discovery. *Academic Voices: A Multidisciplinary Journal*, *1*(1), 31–33.

Raab, M., Masters, R. S. W., Maxwell, J., Arnold, A., Schlapkohl, N., & Poolton, J. (2011). Discovery learning in sports : implicit or explicit processes ? *International Journal of Sport and Exercise Psychology*, *7*(4), 413–430.

Riaz, M., Marcinkowski, T. J., & Faisal, A. (2020). The Effects of a DLSCL approach on students conceptual understanding in an undergraduate introductory physics lab. *Eurasia Journal of Mathematics, Science & Technology Education*, *16*(2), 1–8.

Robinson, W. R. (2000). A view of the science education research literature : scientific discovery learning with computer simulations. *Journal of Chemical Education*, *77*(1), 17–18.

Saab, N., van Joolingen, W. R., & van Hout-Wolters, B. H. A. M. (2009). The relation of learners' motivation with the process of collaborative scientific discovery learning. *Educational Studies*, *35*(2), 205–222. https://doi.org/10.1080/03055690802470357

Schulz, L. E., & Bonawitz, E. B. (2007). Serious fun: preschoolers engage in more exploratory play when evidence is confounded. *Developmental Psychology*, *43*(4), 1045–1050. https://doi.org/10.1037/0012-1649.43.4.1045

Shieh, C., & Yu, L. (2016). A study on information technology integrated guided discovery instruction towards students' learning achievement and learning retention. *Eurasia Journal of Mathematics, Science & Technology Education*, *12*(15), 833–842. https://doi.org/10.12973/eurasia.2015.1554a

Van Joolingen, W. R., De Jong, T., & Dimitrakopoulou, A. (2007). Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning*, *23*(2), 111–119. https://doi.org/10.1111/j.1365-2729.2006.00216.x

Veermans, K., Van Joolingen, W., & De Jong, T. (2006). Use of heuristics to facilitate scientific discovery learning in a simulation learning environment in a physics domain. *International Journal of Science Education*, *28*(4), 341–361. https://doi.org/10.1080/09500690500277615

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Anticipation skill in a real-world task: Measurement, training, and transfer in tennis. *Journal of Experimental Psychology: Applied*, *8*(4), 259–270. https://doi.org/10.1037/1076-898X.8.4.259

Zachos, P., Hick, T. L., Doane, W. E. J., & Sargent, C. (2000). Setting theoretical and empirical foundations for assessing scientific inquiry and discovery in educational programs. *Journal of Research in Science Teaching*, *37*(9), 938–962. https://doi.org/10.1002/1098-2736(200011)37:9<938::AID-TEA5>3.0.CO;2-S