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ORIGINAL ARTICLE

Instructional Process of Design-Based Learning Integration on Computational Thinking: A Framework for Effective Teaching in Course of Physics Experiment Design

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Design-Based Learning and computational thinking (CT) are two key components that support each other specifically in the learning process involving the development of experimental design. Both components emphasize the importance of integration between computational thinking and design-based learning to support a creative, innovative and data mining-based learning environment. In this context. The formulation of a holistic instructional process framework by integrating design-based learning and computational thinking is very important. Therefore, this study aims to designing an Instructional Activity Framework of Design-Based Learning Integration on CT. In addition, this study involves design validation and statistical analysis to determine the validity of the design and its effect on the variables of student engagement, computational perspective, and CT process. The instructional process framework was developed using a systematic literature review, validation analysis using the content validity index (CVI), and statistical analysis using a one-sample t-test. This study was conducted in the physics experiment design course with 23 students. The instrument consists of a CVI, student engagement, CT process, and perspective. The analysis showed that the instructional activities of design-based learning integration in CT stages are as follows: (1) Find, define, and develop an idea (abstraction); (2) background research (decomposition); (3) build an artifact (algorithm thinking); and (4) design the final product (generalization and evaluation). An I-CVI/Ave score of 1 means the design check using the CVI was acceptable. Moreover, the result of one sample t-test analysis showed that the implementation of the learning process framework was significantly influenced by student engagement ($p < 0.05$), CT process ($p < 0.05$), and CT perspective ($p < 0.05$). Therefore, these results support the learning process framework, specifically in the physics experiment design course.

KEY WORDS: Computational thinking; design-based leaning; student engagement

INTRODUCTION

Physics learning is challenging for students due to its abstract and complex concepts (Ferdiman et al., 2023). Students often consider physics a complex, theoretical, abstract, and effort-intensive subject. Many students need help solving problems require applying physics knowledge (Korlat et al., 2024). Physics teachers require assistance, primarily because students need a solid foundation in situation analysis and problem-solving. On the other hand, almost all students think that physics is complicated because they must simultaneously compete with various representations such as experiments, formulas and calculations, graphs, and conceptual explanations (Kabigting, 2021). Physics learning activities cannot be separated from laboratory activities or physics experiments. Activities such as physics experiments greatly help students integrate and construct knowledge directly (Alberto et al., 2024; El-Hani et al., 2020). This activity can reinforce physics concepts, develop laboratory skills, and produce an engaging and effective learning experience (Wilcox and Lewandowski, 2016; 2017). In addition, experimental activities can help students provide a contextual learning environment that enhances students' understanding of theoretical concepts through practical applications (Stern et al., 2017).

However, physics experimental activities have various challenges in the implementation process. These challenges include: (1) Students need help applying theoretical concepts to practical experiments. For example, understanding and using boundary conditions in various contexts, such as electromagnetic waves (Ryan et al., 2018); (2) students need help understanding basic physics concepts, which can hinder students' ability to apply theoretical knowledge in experiments. For example, a study showed that activating cognitive methods in physics lessons can improve conceptual understanding. However, many students' challenges related to abstract concepts (Hofer et al., 2018); (3) Students find connecting mathematical models to real-world problems during experiments challenging. This gap between theory and application is especially evident when students try to mathematize physics problems (Niss, 2012); (4) designing experiments involves several sub-skills such as identifying variables, developing procedures, selecting equipment, minimizing errors, and connecting known concepts, and many students finding these tasks challenging (Sujarittham et al., 2019). Students experience challenges in learning physics, which are indicative of their disorganized physics knowledge and prevalent misconceptions regarding various concepts, including force and motion. Some student difficulties in physics learning stem from mathematical skills and attitudes, while research suggests that established intuitive belief systems may also significantly influence their understanding of the subject. Physics knowledge encompasses scientifically developed theoretical frameworks that coherently explain organized concepts. Students often encounter challenges in determining which concepts require modification and which should be retained during the study of physics (Körhasan and Gürel, 2019). In addition, the lack of active and meaningful learning in physics experiments is a significant problem in education, especially in developing countries where resources and trained teachers are limited (Ahmad et al., 2022). Traditional lecture-based and recipe-based laboratory classes often fail to engage students effectively, leading to low understanding and retention of concepts (Kovarik et al., 2022; Menchafou et al., 2023).

Therefore, a learning strategy approach or instructional process is needed; the learning process in physics experimental activities can be conducted according to the context and expected learning objectives. One innovation in the development of experiments in science and engineering is to involve design-based learning in the learning implementation process. Design-based learning is an innovative approach in education that combines project-based learning with design elements oriented towards active learning and meaningful learning (Tsai et al., 2022; Zhang et al., 2020). DBL is implemented by designing projects that utilize technology, such as experiments or simulations, that are integrated with aspects of learning design (Puente and Kroesen, 2020). Using DBL, students will be actively involved in designing, running, and evaluating physics projects using computer simulation/computational tools. DBL enhances students' imagination, creativity, and skills while improving thinking and understanding. Research has shown that students improve systems thinking, transdisciplinary activities, and collaborative skills through DBL (Azizan and Abu Shamsi, 2022). It allows students to understand physics concepts more profoundly and develops design and problem-solving skills. Through learning, students will learn contextual while feeling the direct relevance of physics concepts in everyday, thereby increasing students' motivation and interest in physics subjects (Puente and Kroesen, 2020).

The advantages of the design-based learning strategy are as follows: (1) Its open and multidisciplinary, resembling real-world techniques and professional practices (Gómez Puente et al., 2013); (2) DBL promotes student engagement and motivation by providing hands-on learning experiences and a sense of achievement (Kasliwal et al., 2023); and (3) DBL helps students develop important skills such as creativity, collaboration, and critical thinking (Kasliwal et al., 2023; Xiao et al., 2022). It certainly helps to provide a positive impact if implemented in the learning process. Several studies have used DBL as a meaningful learning strategy, Oo et al. (2024) briefed that DBL significantly increased students' motivation, creativity, and design skills. In the study involving art and design students, students who participated in DBL outperformed their peers in traditional instruction, showing higher achievement motivation and creative performance. In addition, DBL plays an essential role in Science, Technology, Engineering, Arts, and Mathematics education, allowing students to solve real-life problems centered on humans. This method increases students' creative self-confidence and ability to apply interdisciplinary knowledge (Ladachart et al., 2023). Optimization design-based learning in the physics experiment framework is very relevant when associated with activities in constructing physics experiments. However, it must be considered in the era of learning 5.0, physics experiment activities involve more computational processes and programming languages to construct an experimental process. Its activity involves using the internet of thinking, virtual reality, augmented reality, simulation, and modeling to dominate learning activities in the classroom.

Therefore, thinking skills are needed to accommodate design conditions, especially when integrating computational processes into physics experiment learning activities. The thinking process is crucial for developing an understanding and a coherent flow of thoughts from the initial stages to the final product. This process aims to cultivate critical thinking skills by the standards of the 21st century. This thinking activity can be a computational skill designed in the last few decades. Computational thinking (CT) is a cognitive skill that includes algorithmic thinking, data analysis, problem-solving, and abstraction. CT focuses on a systematic and logical approach to problems, CT allows someone to solve complex problems in a structured involving element of creativity, structured thinking, collaboration, and critical thinking (Boom et al., 2022; Voon et al., 2022). It has been suggested that CT, which involves formulating problems and representing solutions in a computationally executable form, is a fundamental skill for the younger generation (Ningtyas et al., 2024). Thinking computationally is not just utilized in the process of learning computer science, but it has also been incorporated into other courses through the application of the notion of CT. The use of CT has the potential to increase students' capacity for logical reasoning as well as their ability to solve problems (Gultom et al., 2022). Voon et al. (2022) explained that the components of CT consisting of abstraction, decomposition, algorithmic thinking, and generalization are closely related to the ability to solve problems, critical thinking, cooperative thinking, and the use of algorithmic thinking. This aligns with the International Society for Technology in Education (ISTE) 2015 (Sun et al., 2023) that CT consists of five competencies: Problem-solving, critical thinking, algorithmic thinking, cooperative thinking, and creative thinking. CT activities are central to building understanding construction with algorithmic thinking activities. This significantly contributes to the achievement of this century's thinking skills. An example, when CT is integrated into the science curriculum to reflect contemporary scientific practices and support engagement in STEM. For example, the CT *for Science* (CT+S) learning model integrates CT into high school science lessons, students create computational models and analyze data to solve real-world problems such as air quality problems (Krakowski et al., 2024). This activity develops thinking activities that start from abstracting understanding and decomposing needs to solve the needs for existing problems.

CT and design-based learning activities have a stimulating relationship implementation in physics experiments involving a complete process. However, this activity has yet to be explored more deeply regarding structure potential related to design-based learning and CT learning frameworks in the learning process. The stages of design-based learning activities of the CT process provide exciting potential. Integration these two processes is very helpful in understanding construction and project construction. Therefore, the study focuses on structure a framework for learning needs, especially in science or physics experiments. Content design validation is necessary to optimize the learning framework for integrating design-based learning stages and CT activities. This validation aims to assess the relevance and validity of the instructional framework. One part of the validation is content validity. *Content validity* is defined as the extent to which the contents of the instrument reflect the construct to be measured adequately. It is related to the relevance, completeness, and understanding of the measuring instrument to the construct, target population, and context of its use. Content validity is a central aspect in assessing the quality of a proxy-reported instrument, and researchers argue that content validity is the most important aspect of measurement that must be examined before evaluating other aspects, such as reliability, validity, and responsiveness (Phillips et al., 2023). Therefore, considering this, the validation component is the most important point before the learning process framework is worthy of implementation in an instructional process framework or a learning curriculum.

In addition to the validity of the design, it is still important to analyze the variables to determine the extent to which the processes support each other. This is because when a framework is implemented, various variables are used to assess the success of the resulting framework. This study, the framework in the instructional process framework, focuses on the computational procedural and CT perspective about the engagement of students during the learning process of designing physics experiments in class. The learning process of the experiment design course involves a coding process to generate a simulation of modeling the concept of physics concepts in learning. To construct this activity, the engagement of students is very important in supporting the learning process. Student engagement raises to the investment of time, effort, and resources by students and institutions to optimize the student experience and improve learning outcomes; it includes affective, behavioral, and cognitive dimensions (Esposito et al., 2022; Kahu, 2023; Trowler, 2013). Student engagement refers to participation in academic and non-academic activities, a commitment to learning, and a keen sense of belonging to the learning process (Esposito et al., 2022). In student engagement, there are three aspects of keywords: cognitive, emotional, and behavioral engagement. Emotional engagement relates to students' positive emotions in learning activities, including expressing interest and enthusiasm, establishing relationships with others, and forming positive learning attitudes and emotional experiences (Liu et al., 2023). Emotional engagement encompasses a student's responses, including curiosity, boredom, joy, sadness, and worry. Emotional involvement pertains to the degree of students' positive and negative responses to educators, classmates, and academic pursuit (Reflianto et al., 2021). Cognitive engagement relates to self-directed learning, involving shallow and deep learning strategies to understand and retain the material (Liu et al., 2023). Cognitive engagement may be classified into two categories: mental and psychological. The psychological dimension significantly highlights students' motivation and dedication to their studies. The cognitive component consists of self-regulated learning, metacognition, using learning techniques, and strategic thinking and learning (Pradana et al., 2024). Meanwhile, behavioral engagement refers to positive and non-destructive behaviors shown by students, for example, completing academic tasks, complying with discipline, and actively participating in academic activities (Liu et al., 2023). Behavioral engagement encompasses students' attention and effort in the learning process, active involvement with learning materials, willingness to ask questions publicly, and time dedicated to accessing educational resources (Fatawi et al., 2020).

Student engagement in the framework of the learning process is very important. This is because student engagement is the key to every element; with student engagement, the learning process will take place according to the expected outcomes. In the context of physics experiment design courses, student engagement is necessary. In addition to student engagement, CT becomes one of the approaches needed to construct the process of designing physics experiments in modeling/simulating the concepts of physics, which involve many process skills in the form of modeling, simulation, coding, etc. As explained in the previous paragraph, CT is closely related to computer simulation, where students will solve problems using stages such as systematic and logical computer thinking processes. It is very relevant to physics experiment design, considering that the current design has involved many tools in producing interactive visualizations; thus, between the concepts of physics concepts and visuals can be in line to reduce misinformation and misconceptions. In addition, CT, both for perspective and process aspects, involves many dimensions, such as procedural CT involving the stages of abstraction, decomposition, algorithm design, generalization, and evaluation. Meanwhile, the CT perspective or perception is related to cooperative, critical thinking, problem-solving, algorithm thinking, and creativity, as stated in ISTE (2015) (Voon et al., 2022).

Various studies have included CT in the physics learning process (Chichekian et al., 2024; Fennell et al., 2019; Gambrell and Brewe, 2023; Handayani et al., 2022; Hurt et al., 2023). However, these studies still need modification, especially in the process framework for designing physics experiments at the university level. Therefore, referring to these conditions, the author became interested in creating a framework of learning process activities involving design-based learning and CT to optimize learning activities, specifically in physics experiment design courses. This study was expected to provide a deep contribution to the instructional design framework of the learning process in physics experiments, considering the learning process that welcomes 5.0 era learning, which involves many activities such as IoT, data, and data science. Therefore, this study is expected to be one of the sources of information that can be used to optimize learning process activities, specifically in the realm of physics experiment design.

RESEARCH PROBLEM

In this study, the research problem is divided into two, namely: (a) How is the framework of Design-Based Learning Integration Instruction on CT in Physics Experiment Design course; (2) How does the validation result of the framework of design-based learning integration instruction on CT in physics experiment design course? (3) How is student engagement influenced by perspective and procedural CT in physics experiment design courses?

METHODS

This study involved three process stages, namely: (1) The stage of structure the framework of instructions of design-based learning integration on CT in physics experiment; (2) the content design validation stage; and (3). examine the implementation of the framework of instructions of design-based learning integration on CT in physics experiment process on student engagement, procedural CT, and CT perspectives.

The process of constructing the Instructions of design-based learning integration on CT in physics experiment framework involves a systematic review that refers to the activities built by (Kitchenham and Brereton, 2013) for research methodology guidelines for systematic reviews. Systematic reviews focus on identifying best practices based on empirical evidence and identifying research gaps. In addition to following the stages of (Kitchenham and Brereton, 2013), data collection activities refer to the method activities in (Saad and Zainudin, 2022). Both sources build systematic review activities that start by defining research questions because these guides achieving research objectives. The methodology generally consists of six (6) steps: identifying objectives, defining keywords, selecting databases, searching literature, scanning and reading titles and abstracts, and synthesizing and writing findings. For example, the objectives of the study are as follows: (1) highlighting researchers' efforts in responding to the latest trends in DBL-CT, (2) mapping the background of recent studies in this area into a coherent taxonomy, (3) investigating the results of DBL-CT implementation by authors in scientific literature, and (4) providing recommendations for appropriate learning strategies, including techniques and tools in implementing DBL-CT. Emphasis on the limitations of this emerging approach is part of the paper's conclusion. In addition, directions for possible solutions to these limitations for interested educational researchers are provided (Saad and Zainudin, 2022). In this process, activities are built from various relevant sources, such as Google Scholar, Science Direct, and other pages that support references related to both sources. After the data are collected, an instructional process framework is compiled from various supporting references to build a learning framework that integrates design-based learning and aspects of CT.

In the preparation of the instructional framework, the process involving design-based learning and CT refers to the stages that have been validated and widely used in several supporting references. However, this framework emphasizes activities to make an understanding of structures in designing physics experiments involving complex computer simulations/computations. The design-based learning stages refer to the stages developed by Matere et al. (2023) and CT (Tsai et al., 2021). The design-based learning stages offered by Matere et al. (2023) consist of (1) identify, define, and develop ideas; (2) background research; (3) construct artifact; and (4) design final product. The selection of these stages is adjusted to the Semester Learning Design and Learning Achievements for designing physics experiments at one of the institutions, namely, the Department of Physics Education, Halu Oleo University, Indonesia (https://pfisika-fkip.uho.ac.id/rps-jurusan-pendidikan-fisika/). Meanwhile, the CT aspects used involve aspects written in the development of the Tsai et al. (2021) instrument, which consists of the stages of abstraction, decomposition, algorithm thinking, generalization, and evaluation. The selection is based on conditions where, according to the report (Voon et al., 2022), these aspects are related to collaborative activities, critical thinking, problem-solving, creativity, and algorithm design; these five elements are the foundation of the physics experiment design process.

The next stage is validation. After successfully compiling the framework of instructions for design-based learning integration on CT in physics experiments, the validation process involves two experts. Yusoff (2019) explained that the minimum number of experts accepted in content validation is two people but recommends six people. Davis (1992) wrote that the acceptance criteria or relevance if involving two expert validations is at least >0.80. The content validation instrument was packaged as validator question items that will assess the learning framework compiled by involving the learning process activity framework, student worksheets, and learning evaluation instruments. The validator will assess question items using a Likert scale of 1-4 with 4 (very good), 3 (good), 2 (quite good), and 1 (poor). The content assessment instrument consists of 12 questions, including learning objectives, learning content, learning activities, resources (learning support), and an evaluation strategy. The results of this assessment are the reference for the content validity index (CVI) analysis, which aims to see the extent to which the instructional framework of the prepared learning process is appropriate or relevant to learning activities (Almanasreh et al., 2019). CVI is an index used to measure the content validity of an instrument (Almanasreh et al., 2019) and is the most widely used. CVI analysis uses a Likert scale dividing into two categories: Values (1 and 2) in the irrelevant category and values (3 and 4) in the relevant category. Values (1, 2, 3, and 4) are the values the validator gives to assess the aspects of the instructional process framework. After mapping these two categories successfully, the analysis was carried out using the formulation presented in Table 1 with the requirement that acceptance is more significant than 0.80 (relevant/appropriate). CVI is classified into two types, namely, item-level CVI (I-CVI) and scale-level CVI (S-CVI). S-CVI is calculated using two methods, S-CVI Average (S-CVI/Ave) and S-CVI Universal Agreement (S-CVI/UA), as presented in Table 1.

After the validation process, the next step involves the implementation of the instructional design framework in the physics experiment design course. The study involved a quasi-experiment with one group-only posttest design. This activity included 1 class with 24 students enrolled in the experiment design course. Learning activities are delivered in 14 meetings with the final intent to see the learners' constraints, CT process, and CT perspective. Learning activities start with learners divided into several groups. Learners will work on projects following the agreed topics. The topics relate to physics concepts such as Ohm's law, parabolic motion, electrical circuits, vibrations, and waves. In this study, students dominantly use Excel spreadsheet-VBA, visual basic for application, python, R-Program, and visual studio code. The research instrument uses a questionnaire as a Likert scale adopted from various references based on the needs that have met valid standards. The instrument is student engagement, which consists of cognitive engagement. Cognitive engagement instrument combines deep learning and shallow learning activities. Cognitive engagement with deep learning adopts instrument research Weng et al. (2023) Cronbach's alpha 0.86 = High, while cognitive engagement for shallow learning adopts (Barlow et al., 2020) with validation results using *CFI* (The *CFA* yielded the following model fit indices *CFI* = 0.965, *TLI* = 0.957, and *RMESA* = 0.041, 90% *CI* [0.033, 0.049], *SRMR* = 0.0436). Meanwhile, the behavioral engagement (Cronbach's alpha value of 0.943) and emotional engagement (Cronbach's alpha value of 0.945) instruments were adopted from research (Li et al., 2023). Student engagement uses a 5-point Likert scale with alternative answer options: (1) never, (2) rarely, (3) sometimes, (4) often, and (5) always.

Table 1: CVI and formulation (Almanasreh et al., 2019)

CVI indices	Formula
I-CVI (item-level CVI)	I-CVI=(Agreed item)/(Number of experts)
S-CVI/Ave (scale-level CVI based on the average method)	S-CVI/Ave=(Sum of I-CVI scores)/(Number of items) S-CVI/Ave=(Sum of proportion relevance rating)/(Number of experts)
S-CVI/UA (Scale-level CVI based on the universal agreement method)	S-CVI/UA=(Sum of UA scores)/(Number of items)

CVI: Content validity index

Meanwhile, the computational process adopts research from (Tsai et al., 2021) consisting of 19 items that were extracted successfully under the designed five dimensions, with a total explained variance of 64.03% and an overall reliability of 0.91, consisting of sub-components of abstraction, decomposition, algorithm thinking, generalization, and evaluation. Furthermore, for the CT perspective adopted research (Yağcı, 2019) using a five-point Likert scale has a construct consisting of four factors: Problem-solving, cooperative learning, creative thinking, and algorithmic thinking expressed in 42 items. The factor loadings on the scale varied from 0.475 to 0.853. Confirmatory factor analysis conducted to uncover the factorial validity of the scale showed that the Chi-square value ($\chi 2 = 2679.07$; $sd = 815$, $p = 0.00$) was significant. The fitness index values were found to be *RMSA* = 0.0075; *SRMR* = 0.081; *NNFI* = 0.91; *GF*I = 0.90; and *AGFI* = 0.88. Alpha Cronbach's internal consistency coefficient was 0.969. All variables used questionnaires to collect data. The data analysis technique used in the study was one sample t-test. One sample t-test was used to test hypotheses about population averages (Park et al., 2022; Thukral et al., 2023). Interpretation of the results of the one-sample t-test analysis is that the sign (*p*) value is smaller than 0.05.

FINDING

Framework Instructional Process

The implementation of design-based learning in physics experiments was packaged as instructions for design-based learning integration on CT. Instructions of design-based learning integration on CT are a learning approach that integrates design product experiments with CT in its learning process involving digital tools. This approach objectivates to give students a deeper, more meaningful, and relevant learning experience. Through active involvement in designing experimental products, students are requested to build and apply creative ideas in the design process. In this process, students not only hone physics skills but also develop their CT abilities. Student involvement in this learning is crucial to achieving more effective learning goals. By being directly involved in the design process, students can concretely experience the concept of physics and strengthen their understanding of physics.

Through the active involvement of students in physics experiments using the instructions of design-based learning integration on the CT approach, student learning outcomes are expected to improve conceptually, factually, procedurally, and metacognitively. By being directly involved in the process of designing experiments and integrating CT, students have the opportunity to apply physics concepts practically and deeply. It can help students gain a more solid understanding of the subject matter and improve critical thinking, analytical, and problem-solving skills.

In instructions on design-based learning integration on CT, students learn physics concepts theoretically and can apply them in real design contexts. One of the critical elements of instructions of design-based learning integration on CT is the integration of CT, which includes the use of abstraction, decomposition, simulation, generalization, and evaluation and involves CT sub-components in the process of developing experimental products, namely, creativity, critical thinking, cooperative problem solving, and algorithm thinking. The core of instruction-based design-based learning integration on CT instruction involves students designing experimental artifacts to solve unstructured problems by transferring content knowledge into the creative production process. This presents a flexible way for teachers to support the development of students' CT skills in an integrated manner. Some empirical studies have revealed the effectiveness of the DBL approach in secondary education in supporting and improving students' CT-related skills, such as scientific reasoning, cooperative thinking, and problem-solving skills. Therefore, DBL instruction has the potential to enhance students' CT skill development (Li et al., 2023; Saritepeci, 2020; Yin et al., 2020).

Instructions of design-based learning integration on CT emphasize the application of physics concepts in the context of designing experiments. Students learn about theory and how to build student involvement in designing and running experiments relevant to the concepts being studied. It allows students to understand physics concepts more deeply by involving specific thinking skills. Instructions of design-based learning integration on CT also focus on the process that focuses on the result and how a process skill is implemented based on constructivism theory (Huang et al., 2020; Puente et al., 2011). The stages of instruction of design-based learning integration on CT, which include elements of CT as a part of implementing process skills in an experimental design, make this different from previous DBL designs. This is because integration basic CT skills (abstraction, decomposition, simulation, evaluation, and generalization). However, it involves a practical computational process in critical thinking, problem-solving, algorithm thinking, cooperation, and creativity. These five components are based on what International Society for Technology in Education [ISTE] (2011; 2015) suggests and have been widely tested in various CT activities. Quoted from the article by Brennan and Resnick (2012); Matere et al. (2023), it explains that creating a computing environment based on a design learning approach, students can explore instinctive skills and organizational abilities when creating their projects.

Therefore, instruction-based design integration on CT is expected to accommodate the need for experimental design, especially in integrating digital tools into learning. Instructions of design-based learning integration on CT present an alternative learning design that is not boring but offers various process perspectives in its implementation stage. It is important to understand that instruction for design-based learning integration with CT is not a rigid framework but rather a flexible strategy that can be adjusted to facing the various learning needs of students. In addition, the effectiveness of instructions for design-based learning integration on CT can be increased by including additional components. For example, it combines techniques such as advanced organizers to challenge students' understanding (Schnittka and Bell, 2011). In addition, additional scaffolding in the form of computer science encourages better student collaboration and interaction during the design-based learning process for design physics experiments (Chusinkunawut et al., 2021). These additional adaptations and strategies contribute to a more structured and dynamic instruction of design-based learning integration on CT experience, ensuring that design-based learning for design physics experiments remains responsive to learners' evolving needs and challenges.

Instructions for design-based learning integration on CT refer to the constructivist theory its learning process. Based on the constructivist learning perspective (Bächtold, 2013), students construct meaning by interacting with their existing knowledge and new encounters. This process can happen naturally in their environment or be initiated by others, such as parents, teachers, or peers. Here, prior knowledge includes various forms of knowledge, including what students have learned through formal education, experience, and intuitive understanding (Swanson, 2015). Although sharing a constructivist perspective with problem-based learning, instructions of design-based learning integration on CT emphasizes, from a constructionist perspective, that this meaning-making process occurs primarily when students create real products or solutions.

Implementation Instructions of Design-Based Learning Integration on CT in Physics Experiment Design Course

Instructions of design-based learning integration on CT, learners are actively involved in design activities that require learners to design, implement, and evaluate experimental products while considering theoretical and practical aspects of the subject matter. A deep reflection process is used to explore a deeper understanding of the concepts learned and to connect learning experiences to real life. Through this experience, learners gain new knowledge and develop critical, creative, collaborative, and innovative thinking skills. As said in the section on the conceptual framework, the instructions for design-based learning integration on CT are based on constructivism theory. This section uses activated prior knowledge in the initial learning design. In this context, learning design begins with activating students' prior knowledge. This activation is important because it allows students to link new concepts to the framework of knowledge they have based on their experiences and observations in various sources of information. By activating prior knowledge, students can gain a solid foundation to understand the content better and more directly.

Instructions for design-based learning integration on CT rooted in constructivist theory emphasize the activation of prior knowledge in the initial learning design (Nugroho, 2017). It aligns with the concept of incorporating prior knowledge into the learning process, as Diligenti et al. (2017) suggested. Abdulwahed et al. (2008) refined this by suggesting a model that divides the project learning process into sub-processes, allowing for integrating prior knowledge at each stage. The instructions for design-based learning integration on a CT framework involve activating prior knowledge to build a conception of understanding and support the learning process. Activated prior knowledge is a key factor in learning, influencing cognitive strategies. Wetzels et al. (2011) found that the effectiveness of activation strategies was influenced by prior domain knowledge, with mobilization being more effective at lower levels and perspective-taking at higher levels. In addition, Dong et al. (2020) demonstrated that cognitive load and help-seeking strategies mediated the positive impact of prior knowledge on learning engagement. Yuksel (2012) underlined the importance of assessing and activating prior knowledge, Kostons and Van der Werf (2015) highlighted the beneficial effects of activating prior metacognitive knowledge on text comprehension. These studies collectively underline the important role of activated prior knowledge in shaping the use of cognitive strategies in the learning process.

The first stage of instruction in design-based learning integration on CT is identifying, defining, and developing ideas (Figure 1). At this stage, the construction of knowledge related to the project to be worked on involves the know, what, and learn (KWL) method in the form of mind mapping. The stage's basis is the knowledge construction stage related to constructivism theory. This is because DBL with the KWL method involves problem-solving, inquiry, and understanding related to idea development (Puente and Kroesen, 2020). Ladachart et al. (2023) explained that design-based learning is considered suitable for constructionism as an extension of constructivism. In a constructivist learning approach, students construct meaning through interactions between prior knowledge and new experiences, whether these interactions come about independently in the student's physical environment or through social introductions from others such as parents, teachers, or peers. Prior knowledge includes knowledge students bring to

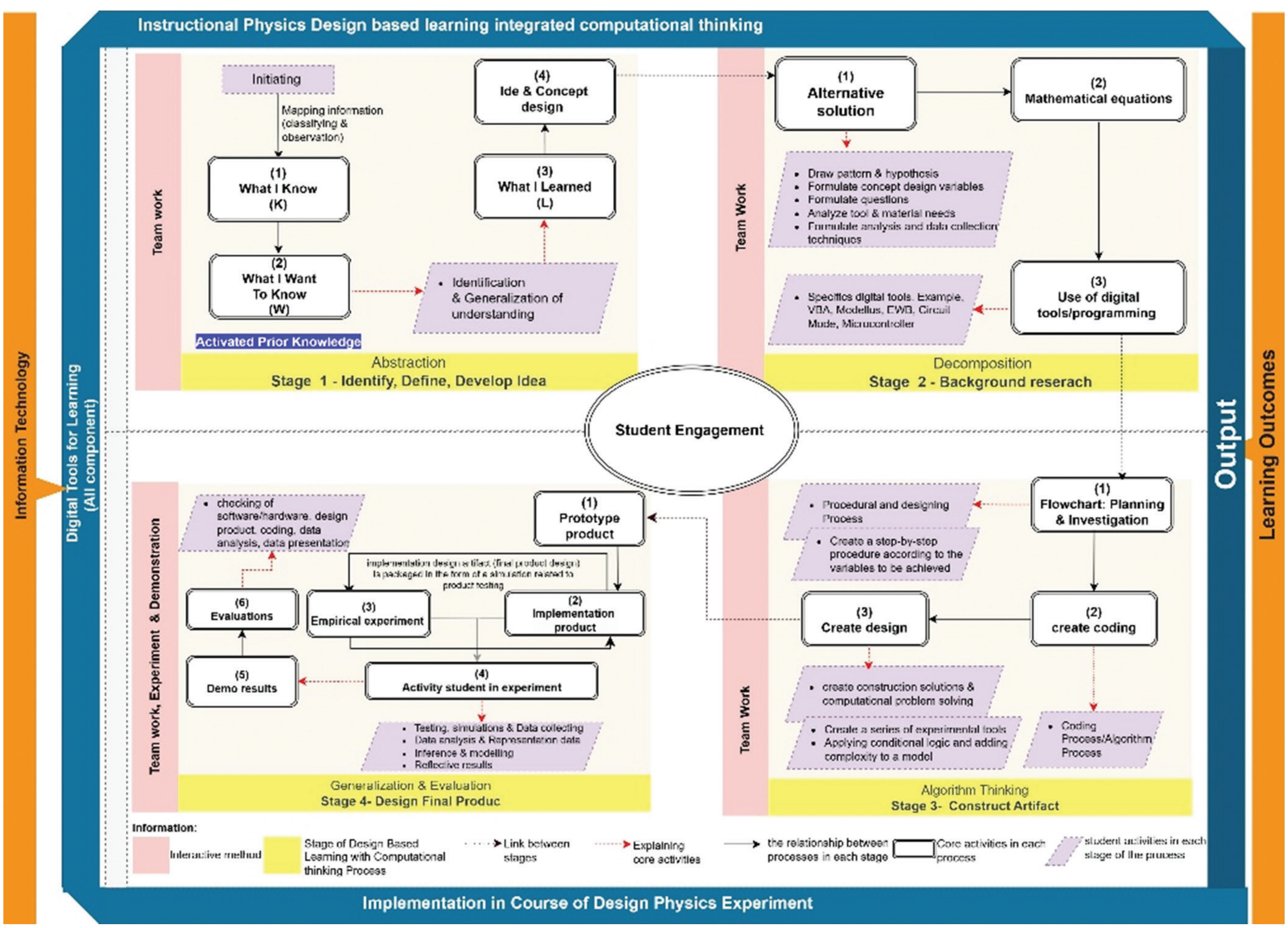

Figure 1: Framework of instructional process design-based learning integration on computational thinking in physics experiment courses

their learning, including knowledge gained through formal education, cultural experiences, and intuitive knowledge. While sharing constructivist views on learning with problem-based learning, DBL highlights, from a constructionist perspective, that the process of meaning-making through the interaction between prior knowledge and new experiences is particularly emphasized when students are involved in creating things (Ke, 2014; Parmaxi and Zaphiris, 2014; Zhang et al., 2020). At this stage, students will be involved in various sources of supporting information, such as journal articles, books, YouTube videos, and relevant sources of information, to build design ideas. At this stage, students will also explain the possibility of various types of potentials and variables that will be the focus of the design.

The second stage of instruction for design-based learning integration with CT is background research (Figure 1). This activity involves teamwork in building alternative solutions, compiling mathematical equations, and selecting tools/programming for the initial design. In this second stage, alternative solutions contain a process that starts from (1) formulating design concept variables, (2) drawing patterns and hypotheses, (3) formulating questions, (4) analyzing tool and material needs, and (5) formulating analysis techniques and data collection. After this process is formed, the following process involves mathematical equations, tools that will be used, and initial design estimates. An example of tool selection in the learning activity framework image can be a visual basic for application or the like. Then, mathematical equations can be involved in mathematical equations used to build concepts; mathematical equations will be the foundation or in the development of physics instruments/experiments. A simple example is building a simple harmonic motion experiment that must be supported by a mathematical equation such as a wave equation, either a first- or second-order wave equation, damped oscillatory motion, or something similar. At this stage, the variables to be developed are clear, and what will be done has begun to be designed. When developing a wave experiment, the variables must have been formulated, for example, constant variables (k), Wavelength (λ), etc.

The third stage is related to constructing artifacts (Figure 1). Learning activities are carried out in groups through teamwork involving the algorithm design process. Learning activities at this stage involve three sub-activities, each with its form or pattern. The three sub-activities are (1) flowchart: Planning and investigation, (2) create coding, and (3) create design. Activities in the flowchart: planning and investigation where students will compile the design of process activities by involving a series of algorithm thinking patterns in the form of a flowchart so that students have clear stages when the process of developing the experiment design will be carried out. A simple example is when students compile a physics experiment design with the topic of "simple harmonic motion;" in this process, students compile a series of processes from the beginning of the work to the final stage. Activities will be carried out when students have completed Stages 1 (Identify, Define, Develop Idea) and Stage 2 (Background Research). Students will find it easy to compile an algorithmic pattern for the experimental design development process at this stage because they have succeeded in compiling a design concept and the solution that will be worked on.

The fourth stage is the final product design (Figure 1). This stage related to generalization and evaluation. In the final product design stage, students will refine the product developed based on the evaluation results from the previous stages. In this context, generalization involves students' ability to build a process by coding data to articulate evidence from a process (Tofel-Grehl et al., 2022). Meanwhile, Psycharis and Kotzampasaki (2019) wrote that generalization is related to the ability to expand specific applications to broader applications. For example, when students have to use the law of exponential decline in an RC circuit and understand that the same mathematical function also applies to the rate of nuclear decay. This activity involves procedural and metacognitive processes when implemented in a classroom learning environment (Markandan et al., 2022).

Apart from the generalization aspect of the final product design, evaluation is also very important to see the achievement between goals and results. In this context, evaluation relates to verification, problem-solving, and debugging (Handayani et al., 2023). Furthermore, Handayani et al. (2023) explained that evaluation refers to testing, checking, and ensuring that the solutions align with observation data and experimental results. The evaluation process allows algorithmic solutions to be used in various possibilities and is appropriate for completion. Chongo et al. (2021) wrote that evaluation is a process that ensures that solutions, be they algorithms, systems, or processes, are reasonable and by objectives. Therefore, this evaluation process involves indicators as a reference. This reference will be used for assessment so that the achievement of the aspects made by students can be seen. In summary, the activities of teachers and students are presented in Figure 2.

A design-based learning model combined with CT exercises is shown in Figure 2. The learning process begins from the initial stage of constructing ideas and designs using the KWL and mind mapping approaches, followed by developing solutions through design variable formulation, tool analysis, and data collection techniques. Students then build artifacts through flowchart simulations, coding, and design creation to produce a final product in the form of a prototype or product implementation that is evaluated. The teacher acts as a facilitator, feedback provider, and evaluator, supporting student activities from the learning input process to producing appropriate output. This model emphasizes integrating CT in learning procedures to train students to solve problems systematically.

Results of the CVI Analysis

The CVI analyses 12 question items with 5 main aspects: Learning objectives, learning content, learning activities, resources (learning support), and evaluation strategy. The results of the *CVI* analysis are presented in Table 2.

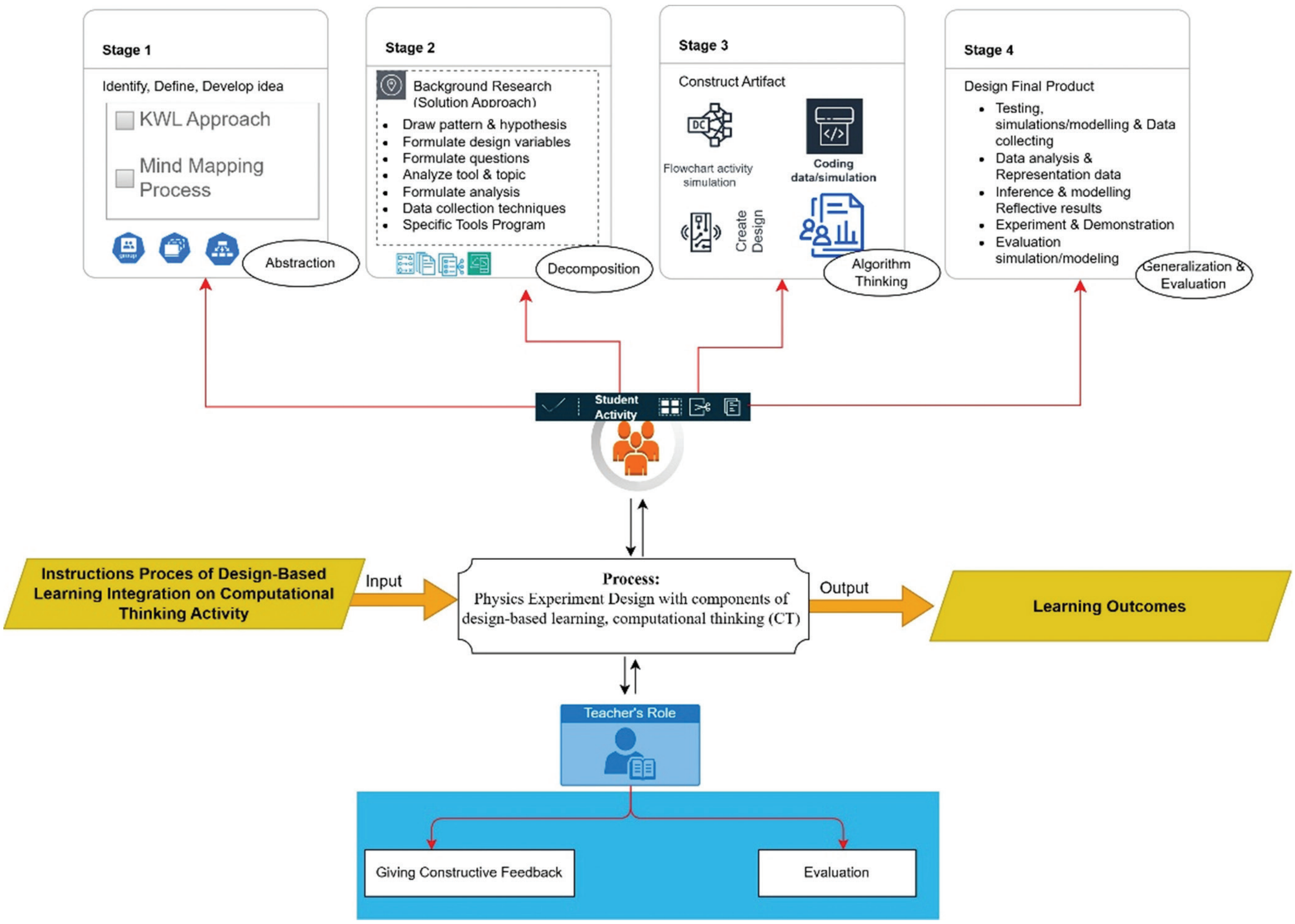

Figure 2: Summary of student and lecturer activities from common activities in Figure 1

As explained in the method section, the *CVI* analysis categorizes the validation value into two parts: The irrelevant transformation value 0 with the validator assessment indicator, namely, the value 1–2, and the relevant transformation value 1 with the validator assessment indicator, namely, the value 3–4. Based on the results of the validator assessment in Table 2, it was obtained that both validators gave a value to each question item in the range of 3 and 4 so that the value of the transformation results in EA' and EB' was stated as a value of 1, which is generally in the relevant category. The results of the Design-Based Learning Integration on CT in physics experiment framework analysis are in the relevant category with an *S-CV1* value of 1 with a minimum standard value of 0.80. Based on what the validators said, the tool used in the design-based learning integration on CT in the physics experiment framework has good content validity. An *S-CVI* value of 1 indicates that both validators consider all items on the instrument relevant. It means that the instrument can measure aspects intended to be measured in the context of developing CT skills in physics experiments. This high validity is essential for ensuring that the data collected from the instrument is reliable for the study's objectives, with a minimum standard value set at 0.80, this result also indicates that the instrument has met the criteria for very satisfactory validity.

Results Analysis of the Implementation of Framework Instructional Process on the Variables Student Engagement, CT Process, and Computational Perspective

Based on the learning activity framework in Figure 1, student engagement is a very important activity to support learning in the physics experiment design course. Student engagement appears in all aspects of design-based learning and CT to produce output through modeling or simulation using the principles of CT. This study's engagement aspects include cognitive, behavioral, and emotional aspects. Meanwhile, the computational process uses the components of abstraction, decomposition, algorithm thinking, generalization, and evaluation. On the other hand, the computational perspective involves a collaborative process, algorithm design, creativity, and problem-solving. The selection of elements is consistent with the recommendations of International Society for Technology in Education [ISTE] (2015). The selection of these elements was based on the assumption that when designing physics experiments, it should be based on problem-solving, and when doing the design, it should be based on student creativity. The activity preparation process involves algorithm

Table 2: Results of the CFI analysis

Aspect	Item questions	EA	EB	EA'	EB'	EA	I-CVI	Category	S-CVI
Learning objectives	Have the learning objectives of IPB-DBL been formulated clearly and specifically?	3	4	1	1	2	1	Relevant	1
Learning content	Is the learning content relevant and supports the achievement of learning objectives?	4	4	1	1	2	1	Relevant	1
Learning activities	Are the learning activities designed to increase active engagement, CT and student outcomes?	4	3	1	1	2	1	Relevant	1
	The instructional design that is prepared can apply the knowledge of mathematics, science and computer science and engineering and CT contexts	3	3	1	1	2	1	Relevant	1
	Instructional design can be used to conduct experiments, analyze, and interpret data	4	4	1	1	2	1	Relevant	1
	Instructional design can be used to design a system, device, component or process	3	4	1	1	2	1	Relevant	1
	The instructional design can be used for group multidiscipline	3	3	1	1	2	1	Relevant	1
	Instructional design can be used to identify, formulate and solve engineering problems	3	4	1	1	2	1	Relevant	1
	Instructional design that is prepared can understand professional responsibility and ethics	4	4	1	1	2	1	Relevant	1
	Instructional design can train the ability to communicate effectively	4	3	1	1	2	1	Relevant	1
Resources (learning support)	Are educational resources in the form of tools in accordance with the needs and support the learning process?	3	3	1	1	2	1	Relevant	1
Evaluation Strategy	Are evaluation strategies designed to accurately measure the achievement of learning objectives?	3	4	1	1	2	1	Relevant	1
SUM of I-CVE							12		
I-CVI/Ave							1		
Category							Accepted		
SUM of CVI/UA							12		
I-CVI/UA							1		
Category							Accepted		

CFI: Content validity index, CVI: Content validity index, CT: Computational thinking

design and is still done in a cooperative form in the team. The results of the descriptive analysis are presented in Table 3.

This shows that in the framework of core learning activities, students' cognitive engagement has the most dominant role compared to other aspects of engagement. The high mean value of cognitive engagement (M = 3.87) reflects that students show better concentration, deep analysis, and analytical skills during the learning process. On the other hand, although behavioral engagement was also relatively high (M = 3.81), it reflects more on students' active participation in learning tasks, such as completing assignments, following instructions, and interacting with peers. As for emotional engagement, which is in last place with a value of M = 3.55, it indicates that affective aspects, such as pleasure, enthusiasm, and emotional connection to the learning process, still need more attention to be improved. These results indicate that in designing physics experiments by implementing the learning process framework, the influence of Instructional Process Design-Based Learning Integration on CT involves high cognitive engagement. It is based on the fact that when students conceptualize physics concepts, most students involve cognitive to solve the problems given. The study found that cognitive engagement activities in the learning process are very important because students engage cognitive skills in completing each stage of learning when completing simulations or modeling the design of physics experiments. This result was supported by the results of the CT perspective, where problem-solving has the highest value (M = 3.80), which indicates that in designing physics experiments, students look for the root of the problem related to physics concepts and try to do modeming. After students succeed in finding problem-solving, students compose modeling/simulation of physics experiment design looking at the creativity process (M =.70), and modeling activities involve algorithm thinking (M =3.67) to structure the modeling stages and are performed cooperatively in groups. Meanwhile, in terms of computational process, the evaluation aspect has the highest mean value (M =3.90), followed by abstraction (M =3.77) and decomposition (M =3.71). These results indicate that the components are integrated by involving the problem-solving and algorithm processes (flowchart systematically) to produce modeling/simulation results per the expected physics concepts.

Several studies support this finding that cognitive engagement is an important component of CT. Cognitive engagement has been shown to significantly influence the development

Table 3: Descriptive analysis results

Variable	Sub-variablef	*N*	Mean (*M*)	Standard deviation	Standard error mean
Student Engagement	Cognitive engagement	23	3.87	0.32	0.07
	Emotional engagement	23	3.55	0.60	0.13
	Behavioral engagement	23	3.81	0.67	0.14
CT Process	Abstraction	23	3.50	0.56	0.12
	Decomposition	23	3.71	0.63	0.13
	Algorithm design	23	3.77	0.60	0.13
	Generalization	23	3.70	0.63	0.13
	Evaluations	23	3.90	0.43	0.09
CT Perspective	Problem solving	23	3.80	0.45	0.09
	Cooperative	23	2.97	0.74	0.15
	Algorithm thinking	23	3.67	0.52	0.11
	Creativity	23	3.70	0.58	0.12

CT: Computational thinking

Table 4: Results of one sample t-test analysis

Variable	Sub-variable	t	df	Sig. (2-tailed)
Student Engagement	Cognitive engagement	57.936	22	0.000
	Emotional engagement	28.255	22	0.000
	Behavioral engagement	27.370	22	0.000
CT Process	Abstraction	30.192	22	0.000
	Decomposition	28.062	22	0.000
	Algorithm design	29.922	22	0.000
	Generalization	27.961	22	0.000
	Evaluations	43.643	22	0.000
CT Perspective	Problem solving	40.209	22	0.000
	Cooperative	19.196	22	0.000
	Algorithm thinking	33.839	22	0.000
	Creativity	30.664	22	0.000

*Sig =p < 0.05

of computational skills, which are essential for problem-solving in physics experiments. A study found that cognitive engagement has stronger predictive power for CT than behavioral engagement (Liu et al., 2023). Integrating CT in physics laboratories can improve students' understanding and application of physics concepts. One study investigated incorporating engineering design into a traditional physics laboratory, encouraging CT through activities such as algorithm design and debugging. The results showed that students improved problem decomposition and abstraction skills, which are critical for physics experiments (Lopez-Parra et al., 2023). The studies support the findings from the one-sample t-test analysis results (Table 4).

Based on the analysis of one sample t-test Table 4, it was found that the implementation of the instructional process design-based learning integration on CT framework in the physics experiment design course showed significant results on the average of each sub-variable with a significance value smaller than 0.05. It is reported that the implementation of the process framework in Figure 1 has an average effect on student engagement ($p < 0.05$), CT process ($p < 0.05$), and CT perspective ($p < 0.05$). These findings support previous studies that DBL encourages critical thinking, creativity, and problem-solving skills, leading to deeper cognitive engagement. Indeed, this type of engagement is essential for improving CT skills (Liu et al., 2023). DBL has been shown to significantly increase student engagement by making learning more interactive and fun. Students who engage in DBLs report higher levels of motivation, interest, and sense of accomplishment, which are critical to sustaining engagement. DBL also has a positive impact on CT processes. Students develop important CT skills such as problem decomposition, algorithmic thinking, and abstraction by engaging in design-based projects. These skills are essential for solving complex problems and are enhanced through DBL activities' iterative and reflective nature. The dual-process model, which combines design and CT, allows students to tackle problems from multiple angles, enhancing their ability to think critically and creatively (Kasliwal et al., 2023; Kelly and Gero, 2021; Weng et al., 2023).

CONCLUSION AND RECOMMENDATION

Based on the explanation has been presented a framework instructional process design-based learning integration on CT in physics experiment courses with settings (1) identify, define, develop ideas – abstraction, (2) background research-decomposition, (3) construct artifact-algorithm thinking, and (4) design final product – generalization and evaluation. This activity involves the core activities of design based learning and computational thinking process components to support learning performance from the physics experimental design process. Apart from that, another conclusion was design-based learning integration on CT in physics experiment framework CVI analysis is in the relevant category with an S-CV1 value of 1 with a minimum standard value of 0.80. Meanwhile, the results of implementation analysis and statistical test using one-sample t-tests found that instructional process design-based learning integration on CT in physics experiment has a significant effect on student engagement ($p < 0.05$), CT process ($p < 0.05$), and CT perspective ($p < 0.05$). Student engagement sub-variables, namely, cognitive engagement ($p < 0.05$), emotional engagement ($p < 0.05$, and behavioral engagement, have an average effect. Similarly, the sub-variables of CT process abstraction ($p < 0.05$), decomposition ($p < 0.05$), algorithm design ($p < 0.05$), generalization ($p < 0.05$), and evaluation ($p < 0.05$). This finding also reported that the sub-variables of CT perspective of problem-solving ($p < 0.05$), cooperative ($p < 0.05$), algorithm thinking ($p < 0.05$), and creativity ($p < 0.05$) had an average effect when implemented with instructional process design-based learning integration on CT.

For further researchers, there is still a wide-open space to conduct more in-depth studies related to instructional process design. Although this study has been carried out on an external scale, it only presents the analysis results on a small scale so that other studies for researchers can use it in the context of other studies. Then, this study can be related to STEM, especially in the context of IoT, according to current learning needs. However, this study needs to pay attention to time because the study was carried out within 1 semester, so the design of a simple project needs adjustment. In addition, in the study, the role of lecturers/teachers is needed as facilitators to assist the learning process; this is because during the learning process with this process framework, sometimes students experience confusion in compiling specific tools that involve coding, so feedback from lecturers is necessary to support the success of this process framework.

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