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Design-based Research as Professional Development: Results of Prospective Teachers' Participation in the Development of Electrical Circuit Augmented Reality Sites for Students to Increase Scientific Thinking Skills

Putri Dwi Agustiningrum[1], Wirawan Fadly[1]*, Primus Demboh[2]

[1]Tadris IPA Department, Faculty of Education and Teacher Training, IAIN Ponorogo, Ponorogo, Indonesia
[2]Ministry of Secondary Education, Cameroon Government, Yaoundé, Cameroon

*Corresponding author: wira1fadly@iainponorogo.ac.id

ABSTRACT This research aims to develop ECARsites, an online site designed to support data-related activities in science learning and to facilitate the implementation of data, computational thinking (CT), and self-directed learning (SRL) practices in a more contextualized and relevant way for students. The approach used design-based research (DBR) methods, focusing on developing high-quality learning products or systems that meet user needs. The study was conducted at MA X in Magetan, Indonesia, involving four middle school science teachers and eighteen middle school students. The research findings showed that DBR can be an effective method of professional development for science teachers, focusing on developing relevant and contextual innovations for students. Integrating data practices, CT, and SRL frameworks into the DBR process facilitated the development of students' scientific thinking skills, leading to a more immersive and appropriate science education for today's digital age. The study highlights the importance of using real data in teaching, involving students in data processing, and supporting teachers in designing and implementing data-driven learning. The study also emphasizes the importance of effective professional development in computational thinking and self-directed learning and the need for investment in long-term professional development programs to prepare teachers for an increasingly technology-dependent world of education.

Keywords Design-based research, Professional Development, Self-regulated Learning, ECARsites

1. INTRODUCTION

Effective professional development for teachers is participatory, long-term, and relevant to their needs (Darling-Hammond, Hyler, & Gardner, 2017). Design-based research (DBR) methods combine research with development. They are often used to create learning innovations, as found in research on using computer media in the learning process (Erwinsyah, Pratiwi & Pautina, 2020). This research uses design-based methods to produce superior learning products. Educator professional development focuses on improving skills, understanding pedagogy, child development, and technological innovations in teaching. It involves continuing education, collaboration with fellow educators, and reflection to improve the quality of education. Effective models for science teacher professional development involve approaches such as the learning cycle (Herrington, Bancroft, Edwards & Schairer, 2016). Collaboration between teachers is essential for sharing expertise and learning and improving student learning outcomes (Bancroft & Nyirenda, 2020; Coenders & Terlouw, 2015).

Augmented Reality (AR) creates a computer-generated environment merging the real and virtual worlds, blurring their boundaries significantly. AR as a system characterized by combining real and virtual worlds, interactive real-time operation, and three-dimensional integration. AR is an advancement of virtual reality technology, differing fundamentally in its relationship with the real environment. The goal of AR is to forge a new environment by blending interactive aspects of both the real and virtual worlds. In essence, AR allows users to perceive the real world while augmenting it with virtual objects. Several studies have explored the utilization of augmented reality in educational contexts. Recent research by Takeshi Yamaguchi and Hiroshi Yoshikawa focuses on tangible learning methods

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employing augmented reality applications (Yamaguchi & Yoshikawa, 2013). The gap in previous research was the lack of exploration of the potential use of Augmented Reality (AR) technology in the context of education in integrating mind-mapping methods to improve learning effectiveness (Erwin, Firsandaya & Erviza, 2013).

This article aims to introduce ECARsites, a digital platform that integrates IPA lessons on Electricity Circuits subbab with augmented reality as a digital learning media innovation to overcome gaps from previous research through Design-Based Research for teachers in long-term collaborative professional development. This research results from collaboration between science teachers, technology educators, and software developers in creating ECARsites for middle school students. With a design time of 3 months and a trial of 3 weeks, ECARsites provides digital materials with a variety of features, including home, which is a homepage that contains the initial appearance of the website, lesson, which is a menu that contains learning materials, augmented reality, which is a menu that contains a 3D display of electrical circuits, videos which contain a collection of learning videos that explain electrical circuit material, a simulation which contains simulations by phet regarding the use of electrical circuits digitally, an assessment which contains practice questions to measure student understanding, a playground which contains educational-based games about electrical circuits, evaluation which contains theory exams on the material contained in google form, discussion room which is a menu used to conduct discussions between teachers and students about learning materials, and attendance which is a menu used for student attendance. Figure 1 displays the homepage of the ECARsites learning center. To support independent learning for high school students to engage in data practices and computational thinking through guided learning. Students conduct physics studies written by prospective teachers by collecting learning analytics for feedback and educational research.

1.1 Conceptual Framework

Conceptual frameworks incorporated into design-based research are those used to develop products or innovations that can improve quality, such as learning products or professional development. The conceptual framework of student learning and innovation relates to teacher competence, educational technology, and digital game-based learning using a website to increase student enthusiasm for learning and achievement (Abid, 2022).

Four integrated conceptual frameworks were used for this study: Design-based research, data practices (Weintrop et al., 2016), computational thinking practices, and self-directed learning. The following section will describe each framework and how it was integrated into the research design, product development, and professional development experiences with teachers.

1.2 Design-Based Research

Design-based research in education focuses on developing high-quality learning products or systems that meet user needs. In this context, design refers to a development approach considering design aspects to create effective and efficient products or systems. Various methods and approaches can be used in this research, such as product, system, or module development (Gunawan, Musthafa & Wahyudin, 2022).

Design-based research is a method that emphasizes an integrated learning design framework that aims to develop effective and efficient learning tools (Suhartini, 2022). This framework guides the form of iterative stages for designing educational products with collaboration. Previously, this framework has been successfully applied for collaborative learning with teachers. Previous studies have shown that this integrated learning design framework has become more sophisticated and complex over time (Bannan, 2013).

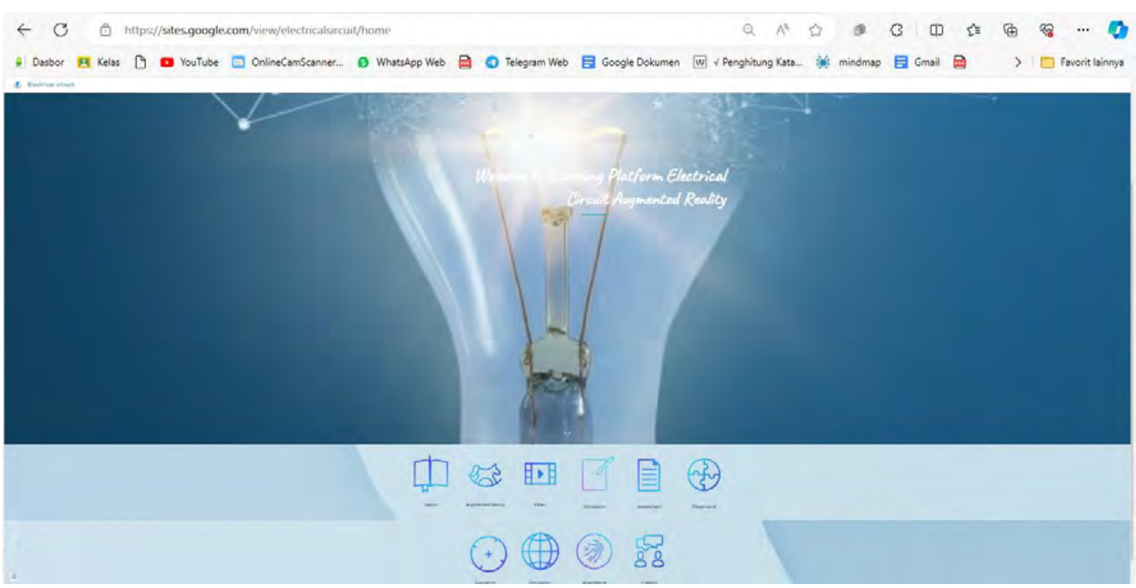

Figure 1 Homepage view of ECARsites learning.

The unified learning design framework supports multiple objectives (knowledge content and instructional content), multiple contexts (data practices, computational thinking, and self-directed learning), and multi-level collaborations (teacher-researcher, software developer-researcher, teacher-student, student-student). The integrated learning design framework has four cyclical phases: information discovery, implementation, local impact, and broader impact.

One of the important stages in design-based research is the information exploration phase (IEP). This phase is the initial step in the research, where the researcher gathers information and data necessary for product development. This phase ensures that the research is well-grounded and relevant to the research topic. During this phase, researchers can identify problems and opportunities during product development (Saputra & Kurniawati, 2021). This phase includes one of the five stages of the ADDIE development model used to develop interactive multimedia learning in high school physics learning (Siregar, 2022). The information exploration phase includes conducting research, gathering information, planning, and developing the first draft (Husni, Abdullah, Ulfiaturruhi & Hadi, 2023).

The information exploration phase has several key objectives. First, to understand the context in which the solution will be implemented. This involves understanding the environment, user needs, and their challenges. Next, identify the problem or challenge that needs to be addressed. This phase also involves collecting data from both secondary and primary sources to support the design process. The researcher can then formulate hypotheses or ideas about possible solutions based on the information gathered. With all this information, the researcher can plan and design a suitable solution (Yenti & Farell, 2021).

All stakeholders are involved in this context to advance knowledge and learning, as design-based research aims to build collaboration. The purpose of the implementation phase (EP) is to learn from the information exploration phase, create an initial overview of the product, and continue conducting small, iterative tests to refine the product to improve the developed product. The local impact phase (LIP) has two objectives: first, to determine how well the product works for the students of the teacher candidates who designed the product, and second, to determine the level of scalability of the product for use in classrooms and elsewhere. This stage is conducted after the product or learning device has been tested and validated in the previous step. Therefore, the real impact of the tested product will be seen. Another purpose of the broader impact phase is to test the product as a whole in the classroom with instructors who were not involved in the design process. However, this article will focus on developing pre-service teachers' knowledge and skills from the information exploration phase, application phase, and local impact phase projects. Specific professional development activities for each phase can be found in the methods section.

1.3 Data Practice Framework

The data practice framework incorporates data collection, analysis, and utilization in professional development. This research focuses on strategies tailored to specific needs and involves identifying needs, analyzing data for strategic design, and monitoring and evaluating their impact (Mustika, 2021).

The data practice framework facilitates data collection, analysis, and utilization to make informed and effective decisions. This framework defines the problem, collects evidence, and establishes the basis for evidence-based action in research. Teachers identify students' needs related to data practices in scientific inquiry. Previous researchers identified five data processing methods used by scientists that are relevant to computational thinking: (a) data collection, (b) data generation, (c) data manipulation, (d) data visualization, and (e) data analysis, establishing these categories to understand better how people use computational thinking and data automation to study science (Weintrop et al., 2016). Data collection uses computer tools for observation and recording. Data generation involves simulation, while manipulation focuses on cleaning and organizing data. Visualization uses tools to describe the data, and analysis uses statistics for interpretation. Teachers and researchers adapted the five data practices according to students' methods of inquiry into creating, collecting, preparing, visualizing, and analyzing. Students need to understand the phenomenon and variables before data collection.

Data-driven practices are still minimal. This phenomenon highlights the urgent need for further research to understand the dynamics of practices involving data teaching and learning. Understanding teachers' teaching methods and how students understand and apply data practices enables the development of more effective strategies to strengthen students' science understanding and critical thinking skills. The implications of this study highlight several key aspects. First, the importance of using accurate data in teaching, which can increase the relevance of concepts for students, deepen their understanding, and increase their engagement in scientific contexts. Second, involving students in data processing, from collection to analysis, allows them to experience the scientific approach, develop analytical skills, and exercise critical thinking. Finally, there is an urgent need to support teachers in designing and implementing data-driven learning, emphasizing the importance of training and providing adequate resources (Gold et al., 2015).

1.4 Computational Framework

Understanding the computational thinking framework is critical for science teacher professional development programs. Computational thinking, or CT for short, brings the concept of problem-solving methods that integrate the skills and limitations of computing into learning approaches (Ansori, 2020). Teachers who apply computational thinking and data practices in teaching provide students with the ability to process and analyze data effectively and understand the relevance of technology in contemporary science. Understanding computational thinking becomes essential as technology becomes more integrated into our lives. Alongside basic skills, computational thinking, including decomposition, pattern recognition and algorithm generation, should be considered an analytical ability. Therefore, incorporating computational thinking into education helps students develop skills that can be applied in various contexts and understand the role of computing in solving modern challenges (Shute, Sun & Asbell-Clarke, 2017). Decomposition in computational thinking is a technique of breaking down complex problems into simpler parts, making it easier for students to solve them in a structured way. Pattern recognition allows students to group similar aspects of a problem based on recurring characteristics, strengthening their understanding. Abstraction helps students focus on important information and ignore irrelevant ones, simplifying problems and improving understanding. Algorithms are a series of precise steps to solve a problem, essential in computer science and problem-solving, providing students with a logical and effective method of dealing with challenges.

Computational thinking, a new concept in science education, emphasizes the importance of science teachers in integrating this concept into teaching. For effectiveness, teachers need systematic professional development, encompassing a deep understanding of computational thinking, its application in science, and evaluating student thinking. This demands training focusing on computational thinking better preparing science teachers. There is a need to revise curricula and strategies so that students understand the connections between science and computational technology more deeply (Angeli & Giannakos, 2020).

While the importance of professional development in integrating computational thinking into teaching is increasingly recognized, ironically, little information is available on effective strategies to support teachers in this endeavor (Jocius et al., 2020). In addition, several other studies have also provided promising evidence for improving teachers' beliefs and knowledge about computational thinking (Adler & Kim, 2018; Bower, Wood, Lai, Howe & Lister, 2017).

These findings emphasize the importance of effective professional development in computational thinking and that explicit instruction helps teachers integrate it into the curriculum. Previous research (Ketelhut et al., 2020) shows the benefits of a long-term approach to professional development in this area. After a year-long program, elementary school teachers showed significant progress in integrating computational thinking. This highlights the need for investment in long-term professional development programs to prepare teachers for an increasingly technology-dependent world of education.

1.5 Self-directed Learning Framework

During the information exploration phase, this research highlighted the need for a systematic approach in designing learning tasks on the ECARsites platform, adopting the self-directed learning (SRL) framework as the methodology. SRL is a cyclical process by which students actively organize their learning to achieve personal goals, including motivation, goal setting, progress tracking, and reflection. Viewed from a social cognitive perspective, SRL involves three stages: anticipation (setting goals and plans), implementation (applying plans and monitoring progress), and self-reflection (assessing achievements and considering strategies for the future). This approach promotes active, student-centered learning, enhances critical thinking, and strengthens metacognitive skills.

By using a self-directed learning framework, students can learn independently and improve their ability to understand and apply scientific concepts in everyday life. In addition, students can improve their critical thinking skills creativity, and develop scientific knowledge (Johan, Mayub & Wardana, 2021).

Professional development studies on using self-directed learning frameworks in science teaching contexts focus on two essential aspects: learning materials for teachers and teaching methods that promote the development of students' self-directed learning skills (Kramarski & Kohen, 2017). The duration of professional development programs varies from a few hours, as done by previous researchers (Barr & Askell-Williams, 2020; Tran, Capps & Hodges, 2022) to around 100 hours (Michalsky & Schechter, 2018). Short-term professional development programs aim to align teachers' understanding of the self-regulated learning framework with existing theories, while long-term programs focus more on development. They are developing teachers' skills in applying self-regulated learning framework strategies in teaching (Adler & Kim, 2018).

Some studies involved teachers in direct teaching practices (Barr & Askell-Williams, 2020; Kramarski & Kohen, 2017), while other studies create opportunities for teachers to share their experiences in implementing self-directed learning (Erin, Peters-Burton, Goffena & Stehle, 2020; Peters-burton & Botov, 2016). All professional development programs achieve some degree of success in achieving their learning objectives. Previous researchers (Barr & Askell-Williams, 2020; Kramarski & Kohen, 2017), engaged four secondary school science teachers in a 12-week (8-hour) researcher-led professional learning community. The results of this study showed that content knowledge according to the self-regulated learning framework, pedagogical content knowledge, and constructivist beliefs steadily increased in 3 out of 4 teachers.

Therefore, this study highlights the effectiveness of different professional development approaches in helping teachers integrate self-directed learning frameworks into science teaching.

1.6 Integration of conceptual framework

Design-based research provides indispensable guidance in developing comprehensive professional development and enhancing ideas that support the product development of ECARsites. This approach combines research methods with product design, providing insights for improvement and effective teaching strategies. A priority on continuous design literacy ensures that products are continuously improved based on user feedback, making them more relevant and effective in supporting learning at ECARsites.

During the exploration phase, the research team emphasized the importance of a strong conceptual framework for data practices, computational thinking, and self-directed learning. The team sought to integrate data practices into student learning tasks with continuous innovation. Computational thinking, such as decomposition and abstraction, was considered strategic to maximize student engagement in data practices. For example, with decomposition, students can separate phenomena into simpler components, while abstraction helps find relationships between variables. Using Self Regulated Learning, students design action plans for data collection exercises, track their progress, and reflect on the results, improving their understanding of data practices. Computational thinking and self-directed learning are the basis of problem-solving (Peters-Burton & Botov, 2016). Computational thinking and self-directed learning are seen as the basis of problem-solving, which helps integrate ideas into the context of data and practice materials. As ideas derived from the conceptual framework were discovered and refined during the design-based research process, we posed key research questions:

"What patterns emerged regarding data practice learning, computational thinking practice, and self-directed learning during the three phases of design-based research during the design of the augmented reality electrical circuit website?".

This question directs our attention to understanding and identifying key models that can help develop more effective teaching and learning processes using data in physics learning.

2. METHOD

The research design in this study utilized design-based research methods. Design-based research, with design experiments as its primary practical method, can be characterized as an inter-disciplinary 'mixed methods' research approach conducted 'in the field' that has both applied and theory development objectives (Reimann, 2011). The first three DBR phases of understanding, designing, and developing provided a solid foundation for the research. These phases supported the teachers' journey towards a common end goal: the development of ECARsites, an online tool specifically designed to support data-related activities in science learning. ECARsites was designed to integrate computational thinking and self-directed learning as key enablers. This approach aims to facilitate the development of students' computational thinking and self-regulation skills using scientific data, thus bridging the gap between science and computer science in the learning process. Qualitative and quantitative data were collected through careful information gathering in three different phases of DBR. These mixed data sources were collected separately and deliberately designed to complement each other to ensure the authenticity and reliability of the research results. Triangulation was used to compare and validate results from different data types, providing a more comprehensive view. In addition, data from these various sources were effectively integrated throughout the research process, allowing the researcher to create a deeper and more detailed picture of the complex research topic. Efforts to minimize bias in this study were made through careful strategies. Using various data sources covering diverse perspectives, collecting representative cross-sectional data, and enhancing reliability through assessment by multiple independent reviewers were some of the steps taken to ensure the accuracy of the search results. In addition, the "member check" method was also used to verify the research results by involving the student teachers themselves. Figure 2 displays the research flow. Therefore, this comprehensive effort aims to ensure that the research results are presented accurately and reliably and provide a more comprehensive view for the professional development teachers who are the subject of this study (Maxwell, 2018).

2.1 Participants

Four middle school science teachers and eighteen middle school students will be treated with data practice, CT, self-directed learning, and teaching experience using parasite media.

2.2 Description of Three Weeks of Professional Development

In the study's first week (IEP), teachers underwent two days of intensive training on computational thinking data practices and self-directed learning. They studied each aspect separately and incorporated them in lesson planning for the lessons they taught, using tools such as planning templates and task analysis tools from previous research. (Peters-Burton, Rich, Kitsantas, Laclede, & Stehle, 2022) This study aimed to implement this lesson on the ECARsites platform. Teachers teach pre-designed lessons within the classroom. They then met in thematic study groups to discuss student learning outcomes, review course

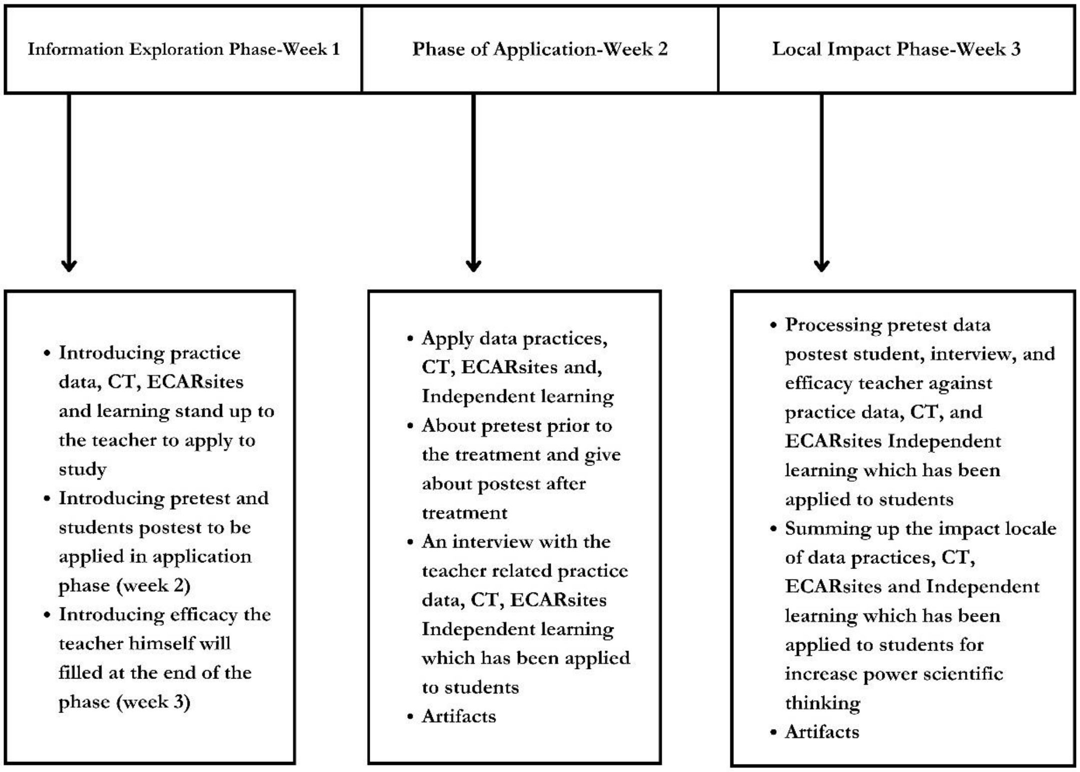

Figure 2 Timeline for collecting data sources over three weeks.

materials, and discuss the application of data, CT, and SRL practices in their classrooms. At this point, the researcher also conducted a needs analysis with teachers to determine their preferences for the professional development structure and content during the study's second week.

In Week 2 (EP) of the study, teachers and researchers participated in a professional development program to reflect on lesson outcomes, review course materials, and explore computational thinking and self-directed learning. They discussed the integration of CT and SRL in data practices, reflections on student learning, and design ideas for the ECARsites platform to improve learning design on the site.

Week 3 (LIP) of the development process transforms regular lessons into ECARsites-compliant lessons. During this period, lessons based on the ECARsites platform were piloted by teachers in real contexts involving small groups of students. The aim was to obtain valuable feedback that would be used to improve the effectiveness of teaching using ECARsites in the future.

2.3 Data Source

Various data sources were used in this study, including (a) assessments of knowledge and application of data practices, computational thinking, and self-regulated learning; (b) measures of self-efficacy related to data practices, CT, and SRL; (c) surveys exploring familiarity, value, and use of data, CT, and SRL; (d) interview sessions; and (e) analyzing products in the form of designed lesson plans. The importance of these data sources lies in the fact that they were studied and measured multiple times over the three weeks of the study as an integral part of the research design.

Knowledge and Application Tests for Data, CT, and SRL Practices

In this study, each teacher underwent a series of focused and separate tests to measure their understanding and application of data-related practices, computational thinking, and self-directed learning. These tests were conducted with creativity and care to ensure valid results. The tests were administered at the beginning and end of the professional development period, and each included two versions, pre- and post-program development, to avoid potential threats to the validity of the results. To measure understanding of CT, SRL and data practices, teachers were given open-ended questions that allowed them to define and explain these concepts in detail. For example, questions such as "Please provide a definition and complete description of the concept of CT. Use the space provided below for a detailed explanation. Then, the assessment is carried out using a paragraph describing the situation of students who have difficulty learning science. After reading the vignette, teachers were asked to identify the data, CT practices, and SRL by highlighting a portion of the text and explaining the interpretation. In addition, teachers were asked to develop specific actions they could take to encourage CT practices and improve students' SRL. Teachers' responses were assessed using rubrics designed to measure their depth of understanding, such as measuring depth of comprehension, vocabulary proficiency, and the quality of their responses. Two researchers conducted The review process independently, and differences arising from the review were discussed and coordinated collectively. It is important to note that the differences detected in these assessments were minimal and often reflected variants with mid-level scores.

Familiarity, Use, and Value of Data, CT, and SRL Practices by Teachers

The level of familiarity, use, and value of each concept was measured using a 3- 3-point Likert scale of three levels (1 = not often, 2 = quite often, 3 = very often). The questions in this scale were designed to explore teachers' perceptions of how often and to what extent they integrate these concepts into their teaching. For example, one of the questions is, "How often do you apply computational thinking concepts in your teaching?". This scale includes ten items for each component of SRL (such as goal setting, task analysis, motivation, time management, organizing, help-seeking, anxiety control, self-monitoring, self-reflection, and adaptive behavior), five items for the CT component (such as decomposition, pattern recognition, abstraction, algorithm generation, and automation) and five elements for the data practice component (such as data generation, data collection, data preparation, online data visualization, and data analysis). Using this scale, the researcher can measure the extent to which teachers perceive the use and value of these concepts in their teaching practices.

Self-efficacy Towards Data, CT, and SRL Practices

A self-efficacy scale with a Likert range of 0 (not confident) to 100 (very confident) was used to measure teachers' confidence in applying data practices, computational thinking, and self-directed learning. The scale was developed and refined in collaboration with four secondary school teachers. After collecting initial data, the research team refined the instrument to be more specific. The scale consists of five questions about data practices, five about computational thinking, and ten about self-directed learning. An example question is how confident teachers are in designing lessons to allow students of different abilities to collect data. Teachers were asked to evaluate their confidence in two different contexts. (a) when working with students who are considered to have a high level of learning difficulty (lower bound of efficacy) and (b) when working with students who are considered successful or competent (upper bound of efficacy). Therefore, for each item, teachers reported their confidence level in data, CT, and SRL practices in different learning contexts.

Interview

We conducted individual semi-structured interviews with teachers at the end of each stage of our three-stage DBR. Each interview focused on a particular aspect of teaching, specifically data practices, computational thinking, and self-directed learning. The first stage focused on data practices, CT and SRL. The second stage addressed teaching data practices, CT, and efforts to support students in SRL. Finally, the third stage focuses on the small-scale implementation of ECARsites for teaching data practices, CT, and supporting students in SRL.

Artifacts

During this research process, we also regularly collected the progress of the ECARsites product at the end of each week. In the first week, we focused on collecting offline lesson plans and CT integration materials using the developed task analysis tool (Peters-Burton, Rich, Kitsantas, Laclede, & Stehle, 2022). This process involved teacher collaboration to develop lesson plans that included learning standards, clear learning objectives, and learning components of the 5E model (engage, explore, explain, elaborate, evaluate) and assessment rubrics that measure student learning outcomes. This reflects our efforts to integrate CT into teaching and create richer and more meaningful learning experiences. During the three weeks of research, we have collected and tracked the development of this ECARsites product to ensure our innovation continues to evolve and align with our goal of improving student learning.

2.4 Data Analysis

Over three weeks, we conducted a careful and systematic data analysis. This approach involved integrating qualitative and quantitative data to understand the relationships between different elements of the research. We examined the themes in the scale responses and conducted a code and category analysis in the teacher interviews and artifacts collected during the research process. In this way, we could present our results in more detail and understand the changes and developments that occurred over the three weeks of the study.

Qualitative Analysis

In conducting this research, we considered the interviews and artifacts we collected from all teachers as case studies representing each stage of DBR. We viewed these interviews and artifacts as an invaluable source of qualitative data to understand teachers' data practices, CT, and SRL development. To analyze these data, we applied an a priori coding approach, which led to the creation of codebooks with clear definitions for five data practices (creating, collecting, preparing, visualization, and analysis), CT methods (decomposition, pattern recognition, abstraction, algorithmic thinking), and SRL processes (such as goal setting, metacognitive monitoring, and self-assessment). We traced the codes that appeared in our data.

To maintain accuracy in the coding process, the researchers independently coded 30% of the interviews and artifacts we had. We then held a collaborative meeting to discuss and agree on the codes used. The results of this discussion served as a guide for coding the rest of the interviews and artifacts. In addition, we also implemented a mutual verification process, where each programmer verified the code created by the other programmers to ensure its correctness. This was done by reviewing a randomly selected 20% of the interviews and artifacts.

Quantitative Analysis

Since our data met the conditions of normality and homogeneity, we chose to use inferential statistics, descriptive statistics, and visual presentations to explore and infer trends in teacher learning. Using statistical tests, such as the t-test, we can make stronger inferences about the effectiveness of learning methods or teacher professional development over the study period. In addition, visual aids still play an essential role in our analysis, identifying patterns and providing a clear and intuitive way of drawing meaningful conclusions from the data.

Mixed Method Analysis

After analyzing the qualitative data from the interviews, which highlighted how teachers applied data-driven approaches to facilitate scientific thinking, and the quantitative data that qualified normality and homogeneity, researchers integrated all these findings into the Design-Based Research (DBR) framework. For example, when the quantitative data showed a significant increase in post-test scores compared to the pretest, we referred to the interviews to explore how teachers' application of technology and data-driven approaches contributed to this change. Conversely, when the interviews highlighted the use of advanced technologies such as Augmented Reality, we examined the quantitative data to see if there was a correlation with the understanding of computational thinking frameworks. This comprehensive approach allowed us to understand better what changes occurred during the study period and why.

3. RESULT AND DISCUSSION

3.1 Result

Practice Data

As expected, these secondary school teachers already implemented data- and technology-driven approaches. However, they did not always explicitly use the terms "computational thinking" or "scientific thinking" (Weintrop et al., 2016), As described at the beginning of the interview. However, the results of the computational thinking framework understanding measurement tool showed that students had a fairly good understanding of the concept after implementing the intervention or treatment, as shown by the increase in post-test scores in the quantitative data. Teachers began to use the term more explicitly to their students, helping to facilitate the understanding and practice of scientific and computational thinking.

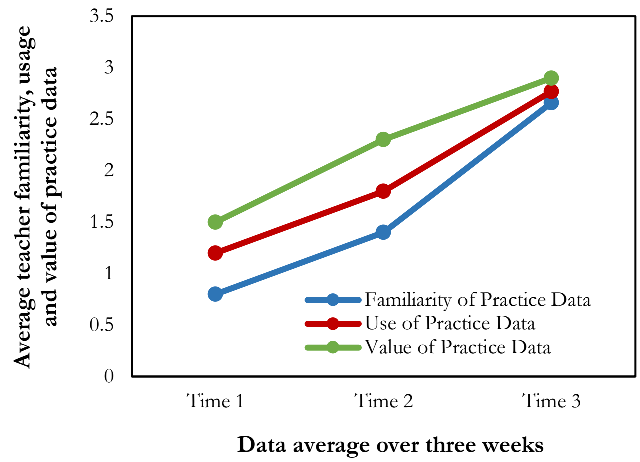

Figure 3 Average teacher familiarity, usage and practice scores data across DBR phases.

Information Exploration Phase

Before starting the professional development phase through Research-Informed Design, these secondary school science teachers were already quite skilled in using data-driven approaches and technology in their teaching. This finding aligns with the interview results at the end of the IEP, which showed that teachers used the terms 'scientific thinking' and 'computational thinking' more often. They are strong in creating and analyzing data but cannot prepare it. One respondent said they sometimes provide ready-made data to students because the collection process takes time.

The interview results during the information exploration phase show how teachers design data-driven learning. Learning objectives are clearly defined, and appropriate datasets are selected. Students are assisted in data analysis, inference, and presentation. Teachers collect data from exams, assignments, and projects. The results are analyzed to find patterns, and if many students have difficulty with certain concepts, the teaching approach is changed. Learning resources include textbooks, online resources, software, and specialized materials. Evaluation is done by comparing student results before and after implementing data-driven methods, and the results are used to adjust learning. Teachers continuously update their knowledge, collaborate, and seek support from the school.

In this context, the IEP has played an important role in facilitating teachers' professional development, particularly in integrating scientific thinking and data practices into their teaching practice. Figure 3 displays teachers' responses to using and valuing all data practices. The actions at times 1, 2, and 3 occurred over 3 Weeks.

Implementation Phase

In the application phase, teachers apply the understanding from the data that has been collected to improve the learning process. Teaching methods are adjusted if students struggle to grasp concepts, and additional materials are provided. Evaluation of data-driven learning helps adjust lesson plans, provide additional support, and enrich student experiences. Teachers explain the relevance of data in real life, emphasize the importance of understanding data, and try to make learning more enjoyable. Positive feedback is given to students to increase motivation. Teachers collaborate with other teacher teams, attend trainings, and update their technological knowledge, all to emphasize the importance of data-driven skills in the real world. A physics teacher emphasizing the need to have data-driven learning:

"If we want to dive into computational thinking and self-regulated learning that focuses on data, we need the support to ensure students can access and collect data."

An informatics teacher added her perspective on the change of focus in the data-driven approach, "There is a big difference when the data presented to students is virtual. It allows them to look at the data from different perspectives."

Overall, during the EP, teachers started to feel more confident in applying scientific thinking principles to data practices and computational thinking, although there were some challenges in implementation.

Local Impact Phase

During the local impact phase, with the integration of learning into ECARsites, teachers customize lessons to deepen students' understanding of scientific thinking. Although data practices must be strengthened, other activities fit the ECARsites framework. While teachers understand scientific thinking, they tend not to engage students fully. As expressed by the Physics Teacher: "Using ECAR sites, we focus on data collection and generation; manipulation is sometimes done, but we usually look at and analyze data in the context of scientific thinking". Teachers' understanding, application, and evaluation of all aspects of scientific thinking remained consistent and high throughout the process. At the same time, their confidence in applying scientific thinking was also very high.

Computational Thinking

Teachers gain innovative approaches by integrating computational thinking into ECARsites in the context of secondary school science. While there were varied perceptions of how computational thinking should be applied, teachers generally saw it as essential but challenging, particularly in hybrid and online learning. However, over time, with the support of ECARsites, they deepened and increased their confidence in integrating it into the science curriculum. This integration supports students' computational thinking and deepens their understanding of science and analysis.

Information Exploration Phase

During this phase, teachers were allowed to explore computational thinking with the help of ECARsites as a learning medium in the context of secondary school science. This phase was explicitly designed to support teachers' professional development in computational thinking.

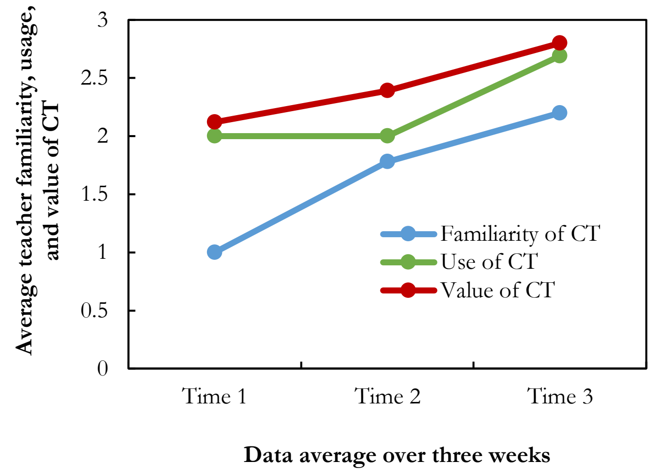

Figure 4 Average teacher familiarity, usage, and CT scores across DBR phases.

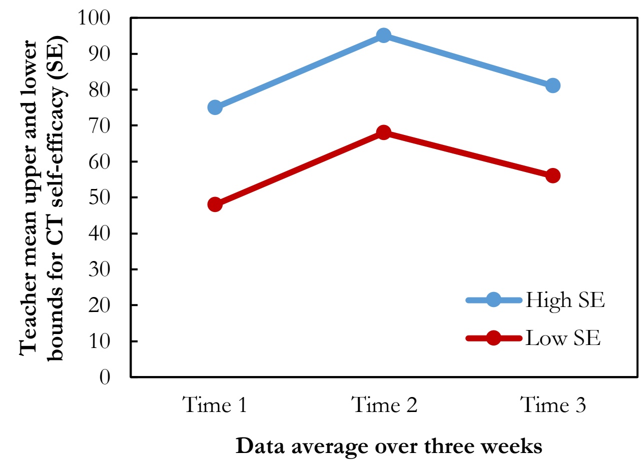

Figure 5 Teacher mean upper and lower bounds for CT self-efficacy across DBR phases

The data analysis shows that the teachers significantly improved their understanding and knowledge of computational thinking. Through training, discussions, and practical classroom applications, they began to see how computational thinking can be applied in science teaching to improve students' conceptual understanding and scientific thinking skills.

Teachers' familiarity with computational thinking increases over time. Initially, they were less familiar with science and tended to prioritize other concepts in teaching. Many of them only had a basic understanding of the concept. However, after going through the IEP phase supported by ECARsites, their perception of computational thinking changed. As the Physics Teacher expressed, "For me, the most important aspect of computational thinking is how we approach and solve real-world problems. ECARsites provided insight into how to integrate this into science teaching."

From the data Figure 4 and 5, it can be seen that their familiarity with computational thinking increased significantly after the IEP. In addition, their confidence in implementing scientific thinking also increased, as seen from the increase in self-efficacy scores. They began to feel more comfortable and confident in implementing computational thinking practices in the classroom. ECARsites, with their features and tools, played an important role in supporting this transition, enabling teachers to practice computational thinking in relevant and authentic contexts.

Implementation Phase

In the EP phase, teachers focused on strengthening their understanding of students' computational and scientific thinking while working together to design and implement lessons that integrated both concepts through ECARsites. This phase aimed to support teachers' professional development in both areas.

The data analysis showed that the teachers faced challenges when they first tried to integrate scientific thinking and computational thinking into their lessons using ECARsites. Their self-efficacy declined in the early stages of implementation, especially when trying to align the two concepts. One physics teacher said, "Integrating scientific and computational thinking through ECARsites has been challenging. Although I see great potential in both concepts, I need to ensure that students understand the basics of each concept before combining them."

With time and training, teachers became more comfortable and confident in combining scientific and computational thinking. Despite initial hurdles, their self-efficacy increased. As the learning progressed, the application of both concepts in lesson plans increased, suggesting that the right support enabled teachers to integrate both approaches in the curriculum with maximum use of ECARsites.

Local Impact Phase

In the LIP Phase, teachers integrate computational thinking into their lesson plans using ECARsites. During this phase, they act as teachers and learners, understanding how ECARsites can support instruction and integration of computational thinking in the context of electrical circuit lessons.

The analysis showed that the teachers' self-efficacy related to computational thinking increased along with using ECARsites. Referring to the researcher's data, teachers A, B, C, and D increased their confidence in integrating computational thinking into teaching, especially after using ECARsites.

Furthermore, from the data analyzed, the teachers' familiarity with computational thinking and the frequency and value of its application remained at a high level. This indicates that ECARsites have effectively supported the integration of computational thinking into their lessons.

In addition, teachers also began to more actively incorporate concepts of abstraction and algorithmic thinking into their lessons. This can be seen in their lesson plan artifacts, which emphasize key aspects of computational thinking.

Self-Directed Learning

Throughout the three phases of DBR, teachers increasingly understood the importance of SRL in supporting students' understanding of electrical circuit material, especially when integrated with data practices and computational thinking. Using ECARsites, teachers witnessed how augmented reality technology can increase student engagement and promote self-regulated learning.

In the context of electrical circuits, SRL allows students to actively explore and understand concepts, allowing them to set the pace and direction of their learning. Using ECARsites adds an interactive and immersive dimension to this process, allowing students to visualize and interact with electrical circuit concepts in an augmented-reality environment.

Informed Exploration Phase

Before the IEP phase, students' pretest results showed their initial understanding of electrical circuit material through SRL with an average pretest score of 49.3. However, students' understanding of SRL electrical circuit material increased after using ECARsites as learning media during the IEP phase. The post-test results showed an average score that increased to 67.8.

In Table 1, the case is explained that the number of samples is 18 students; then we read the results of the Shapiro-Wilk test, and the sig results are 0.152 and 0.278 this means sig >= 0.05 then H0 is accepted so that the sample comes from a normally distributed population.

In Table 2, the sig value = 0.481, which means > 0.05, meaning that the two values in the pretest and post-test are not significantly different, meaning that the variance of the two values being compared is the same (homogeneous).

From Table 3, the Paired Samples Statistic above, it can be seen that the average pretest score before treatment is 49.33 with a standard deviation of 25.321. And the average post-test score after treatment is 67.78 with a standard deviation of 22.678, which can be sought for correlation.

From Table 4, the results of Paired Samples Correlation show that the correlation between the two variables is -0.950, and the significance is 0.000 (sig<α), this indicates

Table 1 SPSS data analysis test of normality

	Class	Shapiro-Wilk		
		Statistic	df	Sig.
Student Learning Outcomes	Pre-test	.917	16	.152
	Pre-test	.943	20	.278

*. This is a lower bound of the true significance
a. Lilliefors Significance Correction

Table 2 SPSS data analysis test of homogeneity of varience

		Levene Statistic	df1	df2	Sig.
Student Learning Outcomes	Based on Mean	.508	1	34	.481
	Based on Median	.342	1	34	.563
	Based on Median and with adjusted df	.342	1	32.931	.563
	Based on trimmed mean	.484	1	34	.491

that there is a correlation between the pretest before treatment and the post-test after treatment.

From Table 5 of the Paired Samples Test results above, it is known that if the probability or significance is 0.000 <0.05, then H0 is not accepted, meaning there is a difference in the pretest value before treatment and post-test after treatment for students.

The researchers' data analysis showed a significant difference between the pretest and post-test scores, confirming the effectiveness of ECARsites in improving students' understanding of electrical circuit materials through SRL, especially when integrated with data practices and computational thinking.

The teachers who facilitated the implementation of ECARsites, observed that this platform allows students to be more active in their learning process. It allows students to explore, understand, and apply concepts independently. Through ECARsites, students gain a deeper understanding and learn how to combine it with data and CT practices in the context of electrical circuits.

Thus, through the application of SRL with the help of ECARsites, students showed significant progress in their understanding, as reflected in the improvement of their scores from the pretest to the post-test.

Table 3 SPSS data analysis paired samples statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Before treatment	49.33	18	25.321	5.968
	After treatment	67.78	18	22.678	5.345

Table 4 SPSS data analysis paired samples correlations

		N	Correlation	Sig.
Pair 1	Before treatment & After treatment	18	.950	.000

Implementation Phase

During the EP phase, teachers actively began integrating SRL concepts into their teaching practices with the help of the ECARsites platform. This phase was designed to allow teachers to experience combining SRL with data practices and computational thinking in the classroom. The interviews conducted at the end of this phase revealed that the teachers viewed SRL as a critical component of their teaching process.

With the support of ECARsites, they can more easily integrate SRL into their learning, providing students with more significant opportunities to organize their learning and develop critical thinking skills.

Some challenges emerged as teachers attempted to integrate SRL into their learning. While some teachers felt that they had successfully provided students with opportunities to self-regulate their learning, others felt that they needed more support and resources to do so effectively, as seen in Figure 3 in Figure 6.

Based on Figure 7, teachers' self-efficacy towards SRL showed fluctuations during the EP phase. Despite facing

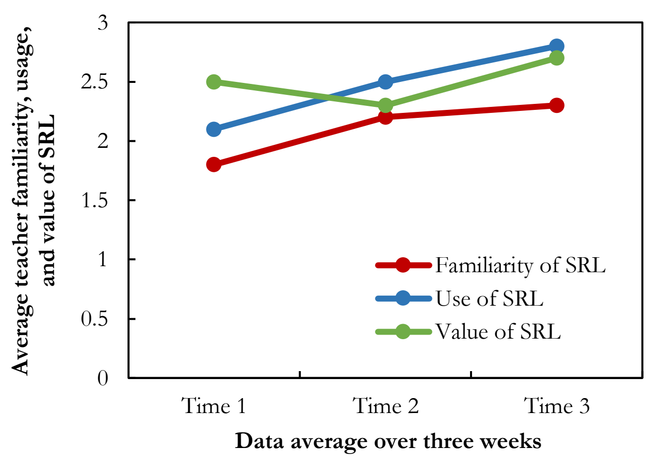

Figure 6 Average teacher familiarity, usage, and SRL scores across DBR stages.

Table 5 SPSS data analysis paired samples test

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of The Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Before treatment - After treatment	-18.4444	8.031	1.893	-22.438	-14.451	-9.744	17	.000

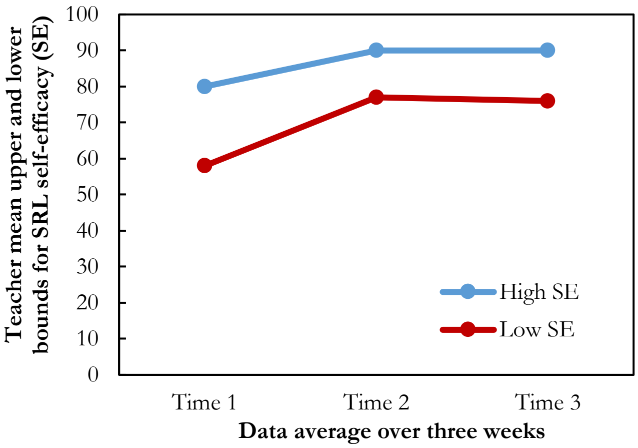

Figure 7 Teacher mean upper and lower bounds for SRL self-efficacy across DBR phases.

challenges, their confidence in supporting SRL in the classroom remained consistent. This shows the importance of ongoing support and training for teachers as they seek to integrate concepts such as SRL into their teaching practices.

Local Impact Phase

During the LIP phase, teachers explored and integrated ECARsites as a learning tool to enhance students' SRL and facilitate the application of scientific thinking. From the data analysis, it was seen that teachers' familiarity with, use of, and value of SRL showed significant improvement.

In addition, the difference between the upper and lower bounds of teachers' self-efficacy for SRL narrowed throughout the DBR phase. This suggests that teachers were more confident in supporting SRL for students they perceived to be academically challenged than supporting students who were superior.

Midway through the LIP phase, with the use of ECARsites, teachers emphasized their desire to provide more opportunities for students to reflect on their learning, especially when applying concepts in data practice. This shows how much teachers value independent and reflective learning.

Not only that, the use of ECARsites also facilitates students' application of scientific thinking. The teachers noticed that with enhanced SRL through ECARsites, students were better able to explore, formulate questions, plan investigations, and draw conclusions based on evidence, all key aspects of scientific thinking. Thus, SRL with ECARsites enhances students' ability to self-regulate their learning and facilitates the development of their scientific thinking.

Integration of Data, CT, and SRL Practices

Analyzing how teachers integrate data, CT, and SRL practices through ECARsites provides an in-depth understanding of effective approaches in the design of multifaceted yet integrated professional development. Based on data analysis from interview transcripts and observations, we found several key points:

a) At the initial stage, teachers felt challenged to incorporate the three components in learning. However, with the concrete examples and illustrations from ECARsites, they felt more confident, and their initial concerns were alleviated. For example, the physics teacher mentioned that ECARsites helped her see how CT and SRL can be applied to improve students' understanding in a science context.
b) The teaching context, such as the learning platform used, can influence how teachers prioritize data practice, CT, and SRL. Biology teachers revealed that when using ECARsites, the focus is more on applying CT and concept understanding, while SRL becomes a support in the process.
c) Collaboration in creating and implementing ECARsites as a co-education product motivates teachers to continue developing their skills. As expressed by the informatics teacher, collaboration with fellow teachers in designing and implementing ECARsites in the classroom gave her new and deeper insights into how to promote students' scientific thinking through SRL.

Thus, integrating data practices, CT, and SRL through ECARsites plays an essential role in teacher professional development to support students' scientific thinking through the SRL approach.

Information Exploration Phase

During the IEP phase, teachers learned how to integrate data, CT, and SRL practices in middle school science-using ECARsites. The platform provided illustrations and examples that made it easier for teachers to understand the integration of the three components. Initially, teachers felt overwhelmed, but their confidence increased with live demonstrations from ECARsites. They began to see how data, CT, and SRL practices are interconnected and how they can be applied to improve students' understanding of science. ECARsites played an important role in determining how teachers prioritize between the three components. With the features available at ECARsites, teachers can more easily adapt and choose the approach that best suits the needs of their students. Collaboration was key to the success of this phase. Through discussions and cooperation with fellow teachers, they shared ideas, strategies, and experiences in implementing ECARsites in the classroom. This collaborative process improved their understanding of the material and motivated them to continue learning and developing themselves. Overall, the IEP phase through ECARsites successfully prepared teachers for the challenges of integrating data, CT, and SRL practices in science teaching, aiming to improve students' scientific thinking through the SRL approach.

Implementation Phase

In this phase, teachers actively integrated data, CT, and SRL practices in the classroom with the support of ECARsites. The analysis showed significant improvement in teachers' understanding and application of the three components. ECARsites made it easy for teachers to present complex concepts interactively and engagingly, supporting scientific thinking through SRL. Although there were challenges in integrating the three aspects, teacher collaboration and professional development program support made it easier to solve. As a result, teachers are more confident and effective in using ECARsites to support student learning.

Local Impact Phase

During the Local Impact phase, teachers reflected on implementing data, CT, and SRL practices with the support of ECARsites. The data showed an increase in teacher self-efficacy in all three components. Using ECARsites, teachers saw students become more engaged and proactive in scientific thinking-based learning through SRL.

Many teachers found ECARsites made integrating data practices, CT, and SRL easier, making the delivery of materials more relevant. While there were initial challenges, ongoing support and collaboration among teachers accelerated successful adoption. By the end of the phase, teachers better understood how to combine the three aspects to enhance the student learning experience.

3.2 Discussion

During the three weeks of design-based learning, teachers' understanding of data, CT, and SRL practices, especially in ECARsites, improved significantly. Through the DBR phase, teachers increasingly understand how to integrate the three aspects to enrich students' scientific thinking and learning with the SRL approach.

Teachers' adoption of ECARsites in their teaching has facilitated the implementation of data, CT, and SRL practices in a more contextualized and relevant way for students. The platform makes it easier for students to explore scientific thinking authentically. Physics and biology teachers who initially found it difficult now feel more confident with the support of ECARsites and see an increase in student engagement.

The application of CT and SRL in the classroom improved students' understanding, problem-solving, and critical thinking skills. The results emphasized the importance of developing CT for long-term integration among teachers (Ketelhut et al., 2020). This can be seen from the pretest and post-test results, which show increased student understanding. In interviews, chemistry, and informatics, teachers saw changes in how students approached problems with a more analytical and reflective approach.

Finally, through DBR, teachers become better equipped to facilitate SRL in the classroom, seeing the importance of teaching students to organize their learning, especially in the context of scientific thinking. With ECARsites, students' SRL skills improve, influencing their understanding of the material and essential life skills for the future. Research shows long-term professional development is necessary for teachers to implement SRL successfully (Adler & Kim, 2018; (Barr & Askell-Williams, 2020; Kramarski & Kohen, 2017). This study confirms that teachers' awareness of SRL increases from the exploration to the implementation phase, and their understanding of supporting students' SRL grows in the local impact phase, prioritizing SRL over CT.

A mixed-method research based on Design-Based Research (DBR) proved effective in developing ECARsites, a digital learning innovation designed to support data-related activities in science learning. Through the research phases of information exploration, implementation, and local impact, this study successfully integrated the concepts of computational thinking (CT) and self-directed learning (SRL) with contextualized and relevant science learning practices. The information exploration phase helped identify user needs and learning environments, ensuring that the ECARsites were relevant and based on real challenges faced by teachers and students. Next, the implementation phase facilitates collaboration between teachers, students, and developers to refine the ECARsites based on feedback. This ensures that the tools support effective teaching practices and enhance students' learning experiences. In the local impact phase, evaluation of the use of ECARsites showed improvements in teacher learning and professional development, with students experiencing more in-depth and contextualized learning of science materials.

Aspects of scientific thinking skills in ECARsites, including the ability to process data and the application of computational thinking, ensure that the tool is appropriate for the indicators it measures, supporting the development of students' scientific thinking skills. The integration of CT in ECARsites helps students solve complex scientific problems through decomposition, pattern recognition, abstraction, and algorithm development. In addition, by facilitating self-directed learning, ECARsites allow students to organize their learning, an essential aspect of scientific thinking. Through self-directed learning, students are expected to not only passively receive knowledge but also be active in learning and scientific discovery. In conclusion, this study confirms the importance of the design and implementation of data- and technology-driven learning tools in supporting science education that is more contextualized and relevant to the needs of students and teachers in the digital age and highlights the contribution of ECARsites in facilitating rich and interactive learning experiences for students.

4. CONCLUSION

This research shows that the Development Design (DBR) approach can be effective in professional development (PD) for science teachers by involving them in creating lessons and learning tools such as ECARsites. Teachers can learn, apply, and reflect on new learning strategies in three weeks. Collaboration between teachers, researchers, and software developers is also important to this PD. Although examining only the initial three phases of DBR, the study provides insights into applying Computational Thinking (CT) and Self-Regulated Learning (SRL) to improve student data practices. Future studies may further explore the use of CT in support of other science practices through ECARsites or emerging new technologies.

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