Decomposition as Design-Based Intervention for Problem Based Learning

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***Abstract*— Combining Problem-Based and Computational Thinking in teaching can benefit both teachers and students. The decomposition from computational thinking skill can help computer science students break down complex system design problems into smaller, manageable parts, while considering social factors and different roles of each part. This study proposes a research question to use decomposition as an intervention to observe its effectiveness in problem-solving scenarios. And also observe how structured instructions can impact students' ability to build system design models within problem solving environments. Decomposition is used as a design-based intervention in the process. With Activity theory as a conceptual framework, this work compares the influence of decomposition on modeling problems. This study used a multi-method research approach. Participants were selected using a self-selection method from students who took a modeling course offered jointly by a Knit Space and KLE Technological University. System design problems can play a major impact in designing such problem scenarios. Two social media platforms were given as modeling problems which also have the social context and component roles. 50 student answer sheets were evaluated qualitatively and quantitatively for the study analysis. The collected data was analyzed using various methods, including descriptive statistics, paired t-tests, student feedback, in-vivo coding, and process coding. This analysis focused on both statistical measures and the themes that emerged from the study, particularly higher-order thinking skills. The results support the conclusion that decomposition can help students create better models.**

***Keywords*—computational thinking; decomposition; design-based; problem based learning;**

ICTIEE Track: Pedagogy of Teaching and Learning
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I. INTRODUCTION

EDUCATION environments are driven by simulative and effective teaching and learning pedagogies. These pedagogies act as a framework for designing course contents, to engage students, to design assessments, to facilitate, and most importantly, to provide meaningful experiences. Selecting an appropriate pedagogy can encourage a classroom culture of interaction and adapt to the dynamic needs of the classroom (Shulman, 2005). Pedagogies can help the faculty understand how students acquire knowledge and address their learning styles. Student-centered pedagogies have been popularly researched and explored, and Problem-Based Learning (PBL) is one of the prominent ones among them. Learning should be relevant, meaningful, and effective. Bringing real-world problems into the classroom can help students connect theory with practical applications. A classroom delivery can be influenced by creating meaningful interventions. Interventions are approaches or activities that are designed to address an explicit problem or need and they are often defined within a particular setting (Creswell, 2017).

To create effective learning experiences, teachers should consider the students' needs, their cultural background, and their learning environment. These learning experiences can be improved over time. Design-based interventions can create specific learning environments tailored to the students' needs and learning goals (Anderson & Shattuck, 2012). PBL is a great way to encourage students to learn on their own, think critically, and become lifelong learners (Azer, 2001). In PBL, students learn by working on real-world problems. Research shows that PBL can help students develop higher-level thinking skills (Moallem, 2019). Theories like situated learning, constructivism, and cognitive apprenticeship support PBL (Dennen & Burner, 2008). These theories emphasize the importance of real-world contexts and working together with others to learn. PBL aligns with these principles by giving students real-world problems to solve and encouraging them to work together (Woods, 2012). Through PBL, students can develop and improve their modeling skills. They learn to design, implement, and refine models to address complex challenges.

Being started initially for medical students (Barrows, 1998), PBL is now used in many different fields, from engineering to social work. The main goal of PBL is to help people think critically, solve problems, and learn throughout their lives. As the world becomes more complex, we need professionals who can handle difficult problems. PBL is a great way to prepare students for this. Studies have shown that PBL can lead to deeper learning and create engaging learning environments (Tan, 2021). By giving students real-world problems to solve, PBL helps them connect theory with practice and then better

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prepare for their future careers (Warnock & Mohammadi-Aragh, 2016). When combined with Computational Thinking (CT), PBL can further enhance students' problem-solving abilities. Decomposition, a key skill in CT, can help students break down complex problems into smaller, more manageable parts.

Breaking down a big problem into smaller, easier-to-solve parts is called decomposition. This makes tasks easier to understand and manage. This is a very important skill in many fields, including software engineering and scientific research. There are even special frameworks to help people use decomposition (Rich et al., 2019). Computer science helps us understand and solve complex real-world problems. Models can help us understand how systems work. When we understand the key parts of a model, we can better understand the whole system.

This paper combines the components of decomposition as an intervention for a model design using a design based approach and attempts to understand its influence under PBL. The paper is further organized as follows. Section 2 presents the literature survey. Section 3 presents the research question and research design along with the model. Section 4 presents the results and data analysis. Section 5 presents the discussion and section 6 concludes the paper.

II. Literature Survey

This section provides a comprehensive review of the literature on problem-based learning (PBL), computational thinking (CT), decomposition, design-based research, and modeling. While these areas have been studied separately, they can be combined to create more effective teaching methods in computer science and engineering.

PBL is a transformative teaching and learning approach that emphasizes solving real-world problems, encouraging critical thinking and self-directed learning. Research demonstrates how problem scenarios promote cognitive development and knowledge application (Wood, 2003). Various studies have explored PBL’s influence on learning outcomes and student engagement (Hmelo-Silver, 2004; Yew & Goh, 2016). PBL is highly adaptable, with applications ranging from individual courses to institutional reforms (Chen et al., 2021). Its integration with other frameworks improves critical thinking and problem-solving skills (Nadeak & Naibaho, 2020; Ghani et al., 2021). In computer science, PBL effectively addresses domain-specific challenges, accommodating diverse learning styles (O’Grady, 2012; Islamiat et al., 2024).

CT is a method for solving complex problems using steps like breaking them into smaller parts, identifying patterns, simplifying ideas, and creating clear step-by-step solutions (Wing, 2006). It has proven helpful in improving problem-solving skills in many fields (Jonasen & Gram-Hansen, 2019). Important parts of CT, like analyzing data and creating models, are vital for solving problems in technology and other areas (Saad & Zainudin, 2021). Research has made it easier to teach CT by setting clear goals for different levels of education (Selby & Woollard, 2013). This approach helps learners organize ideas, tackle challenges effectively, and develop creative solutions (Lu & Fletcher, 2009).

Decomposition is one of the prominent parts of CT. It helps students to understand each part of the system and then also understand their interaction (Shute et al., 2017). Decomposition and its integration with PBL has been studied (Aryan et al., 2023). Recent studies propose decomposition as an intervention to refine student reflections, demonstrating how explicit use of decomposition in reflections enhances self-directed learning and critical thinking (Chikkamath et al., 2024). Knowledge structuring and construction within PBL has been discussed and deliberated (Netekal et al., 2022).

Design-based research has been contributory in encouraging educational innovations, although its implementation remains challenging (Bell et al., 2013; Dede, 2005). Modeling, a critical element of CT and systems design, is essential for logical reasoning and decision-making (Van, 1991; Page, 2007). Research presents the need for systematic incorporation of decomposition within modeling to maximize its pedagogical impact (Palts & Pedaste, 2020). Model-integrated computing, explored by Sztipanovits & Karsai (1997), offers a robust framework for addressing complex systems in engineering and education. The integration of PBL, CT, decomposition, and modeling creates a dynamic and effective learning environment. PBL immerses students in real-world challenges, while CT provides a structured framework for problem-solving. Decomposition enhances understanding by systematically analyzing components, and modeling allows students to visualize and simulate solutions. These elements, when combined, help in critical thinking and practical application, as demonstrated in recent studies.

This literature survey accentuates the interdependence of these methodologies, providing a foundation for developing innovative educational practices custom-made to computer science and engineering domains.

III. Research Design

This section presents the research design along with the research question, context, model, problem design, approach, and other associated specifics.

A. Philosophical Assumptions

Every study needs to state its philosophical assumptions and interpretative frameworks. So does this study. The framework for this research is based on pragmatism (Bacon, 2012), which combines both quantitative and qualitative methods to address the research questions effectively. Pragmatism emphasizes the importance of practical relevance and real-world applications, guiding the selection of methods suited to the research problem without strict adherence to fixed protocols. The study’s ontological perspective views decomposition and models as essential elements worth evaluating in the context of PBL. The research uses an inductive approach, building knowledge through insights from researchers and participants. A multi-method methodology integrates qualitative and quantitative techniques to provide comprehensive insights. Both the methods are used to arrive at the results and research questions are designed accordingly.

B. Research Question

Interventions are actions or strategies that are used to make improvements or changes in a specific situation. The problem in the context is to design an effective problem-solving process and decomposition used as an intervention for it. The research questions for the study is

RQ: How do instructions using computational thinking's decomposition as an intervention influence problem-solving PBL scenarios where students build system design models?

This question is analyzed quantitatively and qualitatively. We hence further divide this into two parts.

RQ1: What are the statistical patterns and trends in students' problem-solving performance after applying decomposition techniques in system design assignments?

RQ2: What are students experiences and insights when using decomposition to approach system design challenges during PBL scenarios?

The study aims to explore with and without explicit usage of decomposition as an intervention point while students build models for the real-time platforms.

C. Context of the Study

This study is carried out on second-year computer science students from KLE Technological University who took a summer course. The course was jointly organized by Knit Space and KLE Technological University. It was a non-graded certification/audit course. The 50-hour course was a mix of online and in-person classes. It focused on how to think in models, a skill that's important for computer science graduates. The course used a teaching method PBL, which involves solving real-world problems. It also included elements of CT. The course had in-class and take-home assignments. The learning had several activities which were designed based on real world experiences.

D. Sampling Methods

96 students attended the course. Out of these, 50 students agreed to be part of the study. These students were told how their information would be used for research purposes and they agreed to participate. The sampling method used was self-selection (Wainer, 2013). Self-selection sampling is a non-probability sampling method where participants choose to be part of a study, often by responding to the call made. An open invitation was given to the students and those interested and who agreed upon were made to be part of the study.

E. Activity Theory - Conceptual Framework

This work uses activity theory as a conceptual framework (Engeström, 2014). Activity theory, a sociocultural framework, examines human activity as a complex system of interactions (Kaptelinin, 2014). It emphasizes context, culture, and social relationships in shaping behavior and learning. This framework provides a perspective for understanding how individuals interact with their environment and learn. It has been used as a framework to analyze and redesign work (Engeström, 2000). Activity theory has a division of labor which helps one to understand the responsibility of each stakeholder. While decomposition involves breaking down complex problems into smaller parts, activity theory emphasizes the social and cultural context in which these activities occur. This helps us understand the system better. When we understand the big picture and how different parts of a problem interact, students can break down complex problems into smaller, easier-to-solve parts (Roth, 2004).

F. Study Model

The model used for the study is presented below in Figure 1. Using the concept selected, a problem is identified which has inherent decomposition in it. Usually they are found in system design problems and are effective ways to under decomposition.

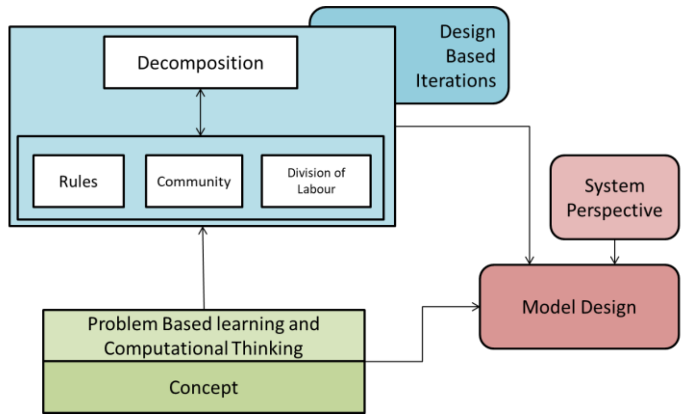

Fig. 1: Model for decomposition using the activity theory

The designed model captures the system perspective and this is done with and without the intervention of decomposition. With the intervention, we use rules, community, and division of labor in association. Rules are norms that guide the activity. Community is the context where operations are taking place. Division of Labor defines the roles and responsibilities.

G. Problem Design

Two problem scenarios (also interchangeably used as case studies) were designed to test the influence on models. The selected case studies were LinkedIn and Twitter platforms. Each of them was evaluated for ten marks.

Question 01: Model the LinkedIn platform. Write a short description of the platform, followed by its model and description of the model

Question 02: Model the Twitter platform. Divide and decompose the system into different parts that constitute its holistic working. Use this decomposed knowledge to design the model. Write a short description of the platform, followed by its model and description of the model.

The first question asked the students to build the model LinkedIn and the second one explicitly stated to decompose Twitter and then model it. Both system design problems have the same level of complexity and require the same amount of effort. The trigger points in the case studies are designed to guide students' focus toward critical components of system modeling. For instance, in the Twitter case study, trigger points included prompts such as, "Identify key processes driving trending topics" and "Analyze how real-time updates influence user interactions." These prompts encouraged students to break down the system into fundamental elements like algorithms, analytics, and user preferences.

H. Design-Based Research Iterations

Usually in design-based research, we use several iterations. For the considered problems, the problem was viewed in three iterations (Reimann, 2010). The process aims to bridge the gap between theory and practice by creating practical solutions by generating new knowledge. It brings together the theories and knowledge in repeated iterations. For the considered decomposition, the problem was viewed in three iterations. The three iterations are presented in Table 1 below.

TABLE I
PROBLEM ITERATIONS AND VIEW

Iteratio n	Theme	Purpose
1	Exploration	Explore the problem to understand the behavior and operations
2	Model	Explore the problem to model it
3	Refine	Explore the model to analyze it

IV. RESULTS AND DATA ANALYSIS

This section presents the results and data analysis of the two modeling exercises that students carried with the underlying principles of decomposition. The data analysis is presented in the sections of quantitative and qualitative.

A. Quantitative Analysis

Table 2 below presents the descriptive statistics for the two case studies.

TABLE II
DESCRIPTIVE STATISTICS OF CASE STUDIES

Descriptive	Case study 1	Case study 2
N	50	50
Missing Values	0	0
Mean	6.08	7.01
Median	5.75	6.75
Standard Deviation	1.75	1.66
Variance	3.07	2.74
Minimum Value	3.00	4.00
Maximum Value	10.00	10.00
Skewness	0.376	0.338
Strd. Error Skewness	0.337	0.337
Kurtosis	-0.627	-0.615
Std. error kurtosis	0.662	0.662
Shapiro-Wilk W	0.951	0.945
Shapiro-Wilk p	0.039	0.021

Of the 50 data values present for each group, there were no missing values. Small standard deviation and variance from the above table indicate that the data points in a case study scores are clustered closely around the mean. Smaller values mean that they are relatively similar to each other and there is a consistent pattern in the data. They are tightly grouped and specify high reliability or precision. Given that the skewness values of the two datasets, 0.376 and 0.338, indicate that both datasets are moderately positively skewed. Positive skewness means the tail on the right side of the distribution is longer. This suggests that there are a few larger values in the dataset that are pulling the mean to the right. Kurtosis values of both are negative given by -0.627 and -0.615 and this indicates that both datasets are platykurtic. Platykurtosis means the distribution is flatter and has more extreme values (outliers) compared to a normal distribution.

For case study 1, The Shapiro Wilk W value is 0.951 which indicates a reasonably good fit to a normal distribution (Razali & Wah, 2011). But the p-value is 0.039, which is very low and hence we reject the null hypothesis. Therefore, despite the good fit indicated by the W value, we conclude that the data in case study 1 is not normally distributed. Similarly, for case study 2, the W value is 0.945 and p is 0.021. The data in case study 2 is also not normally distributed. Since both case studies exhibit non-normal distributions, we use non-parametric statistical tests for analysis. These tests do not rely on the assumption of normality.

The histogram for case study 1 data can be seen in Figure 2 below.

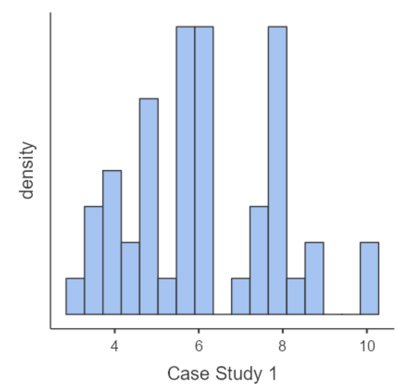

Fig 2: Histogram for case study 1

Histogram for case study 2 can be seen in Figure 3 below.

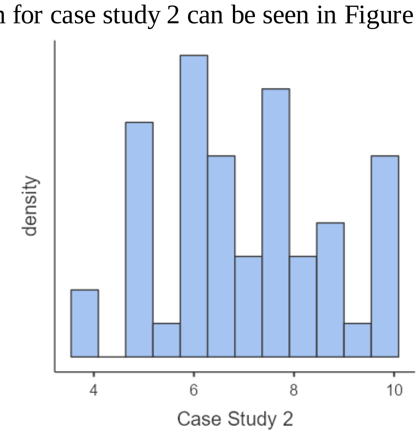

Fig 3: Histogram for case study 2

The histograms for Case Study 1 and Case Study 2 reveal distinct differences in score distribution. Case Study 2 shows a noticeable improvement in mean scores (7.01 compared to 6.08 in Case Study 1), indicating enhanced performance when decomposition was utilized. The smaller standard deviation

(1.66 vs. 1.75) in Case Study 2 suggests less variability in student performance, reflecting a more consistent understanding of the modeling tasks.

The theoretical quantiles versus the standard residuals graph (Q-Q plot) for both case studies together can be seen in Figure 4 below. It helps to visually compare the quantiles of the observed data with the quantiles of the theoretical distribution. If the data points fall close to a straight line on the Q-Q plot, it suggests that the observed data follows the theoretical distribution. The deviation from normality observed in the plot, as corroborated by the Shapiro-Wilk test results (p-values of 0.039 and 0.021 for Case Studies 1 and 2, respectively), justifies the use of the Wilcoxon test. This deviation highlights how decomposition introduces complexity that affects performance variability but does so in a structured manner, facilitating targeted learning outcomes.

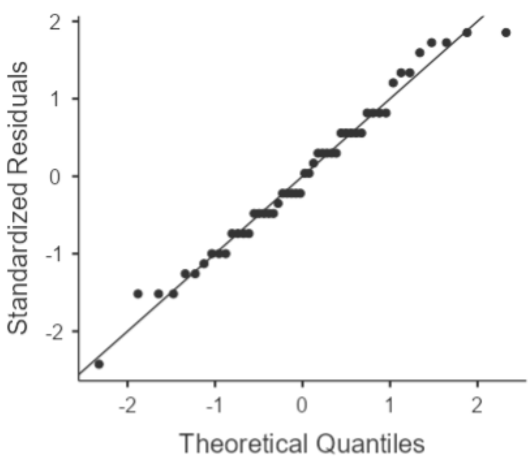

Fig 4: Q-Q plot for two case studies combined

We hence formulate the hypothesis for the paired t-test as follows:

H_0: There is no significant difference between the two groups

H_1: There is a significant difference between the two groups

A non-parametric Wilcoxon paired samples t-test was carried out on the data (Cuzick, 1985). The results are presented in Table III below.

TABLE III
WILCOXON TEST RESULTS

Attribute	Value
Statistic	247
P value	0.002
Tied pairs	4

W value of 247 is the test statistic calculated by the Wilcoxon signed-rank test. A higher W value generally suggests a larger difference between the paired samples. A positive W value generally suggests that the observations in one group tend to be larger than those in the other group. While the test provides information about the direction of the difference between the two related groups, its principal interpretation lies in the p-value. A p-value of 0.002 is highly significant. The p-value of 0.002 is smaller than the common significance level of 0.05. This means that we reject the null hypothesis. Therefore, based on this test, we can conclude that there is a significant difference between the two related groups considered for the study even after having 4 tied common pairs. Case Study 2, which incorporated decomposition, shows an improvement of approximately 0.93 points in mean scores compared to Case Study 1. This finding highlights the practical impact of decomposition, demonstrating its effectiveness in guiding students to construct more comprehensive and systematic system models.

A feedback question was asked for both case studies measuring the model effectiveness on a five-point Likert scale (Joshi et al., 2015). For case study 1, the question was “You explored LinkedIn with a model perspective. How effective was it in terms of learning?” The result is presented in Figure 5 below.

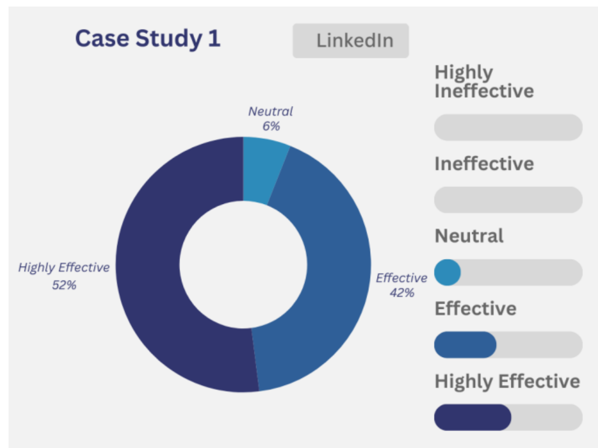

Fig 5: Feedback for LinkedIn case study

For case study 2, the question was “You explored the Twitter Platform with a model perspective. How effective was it in terms of learning?” The results of 50 students are presented in Figure 6 below.

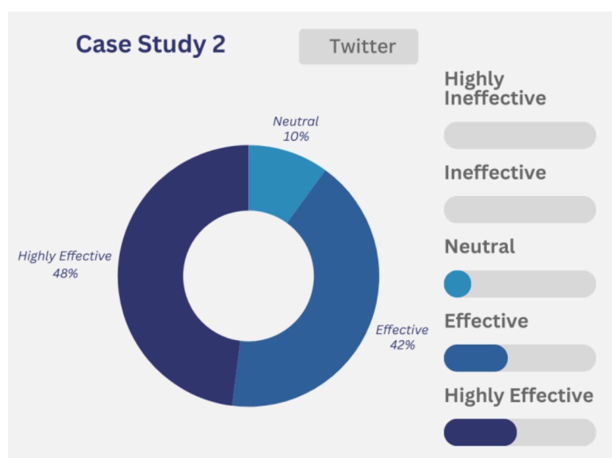

Fig 6: Feedback for twitter case study

As we can see from both figures, the learning effectiveness of both case studies is the same varying by a small margin between effective and highly effective.

B. Qualitative Analysis

The students' answer sheets were analyzed using two methods: in-vivo coding and process coding (Saldana, 2014). In-vivo coding involves directly using the exact words from the answers, while process coding involves categorizing the answers based on a specific framework. A few examples of the assigned codes for case study 1 are presented in Table IV below.

TABLE IV
CASE STUDY 1 CODES

Phrase	Code
Allows users to interact with others	INTERACT
People are profiles	REPRESENTATION
People come together based on professional interest	AGGREGATE
Each stakeholder has a role	ROLE
It’s a platform for organization	GROUP
There is user engagement in various ways	ENGAGEMENT
There are many other pages	EXPLORE
We may take recommendations when at need	FEATURE
It prepares our mind for work day	INITIATE
Platform to find professional related things	PROFESSIONAL
Options for users to control who can see their information	PRIVACY
Notifications move from being created to delivered and viewed	PROCESS
Houses different forms of data	DATA
Used for business connections	CONNECT
It has several components to it	PARTS
We can get analytics	FEATURE

The assigned codes for case study 2 are presented in Table V below.

TABLE V
CASE STUDY 2 CODES

Phrase	Code
Allows users to interact with others	INTERACT
People are profiles	REPRESENTATION
People follow preferred trends	TRENDS
Digital town square	HOLISTIC
Limitations has not made in unpopular	LIMITATIONS
It encompasses all the steps a user will experience	PROCESS
Interactions are actions	ACTIONS
There are algorithms that can fit based on widely used for news updates,	ALGORTIHMS
Does the trend analysis	TREND
We can view the metrics present in the system along with statistics	ANALYTICS
Better engagements can be designed	ANALYTICS
Real-time updates are facilitated	DYNAMIC
Connects people from around the world	SOCIAL
Uses targeting algorithms to display promoted data	PROCESS
understand the user's preferences	PREFERENCES
Subscription service offering extra features	SERVICE
Each stakeholder has a role	ROLE

When analyzing the codes generated for both case studies, a clear distinction in their depth and complexity emerges. The codes in Table IV, derived from Case Study 1, primarily focus on identifying individual components, such as INTERACT, REPRESENTATION, and DATA, which indicate a foundational understanding of the platform's structure. While these codes demonstrate students' ability to recognize distinct features, they lack an exploration of the relationships between components.

In contrast, the codes from Table V, corresponding to Case Study 2, reflect more sophisticated problem-solving and higher-order thinking. Codes such as TREND, DYNAMIC, and PREFERENCES illustrate students’ ability to analyze interactions within the system and understand its dynamic nature. The presence of codes like ALGORITHMS and ANALYTICS showcases their capability to evaluate and construct advanced components of the model, moving beyond identification to synthesis and evaluation.

The comparison shows how using decomposition in Case Study 2 helped students understand the system better. Students could identify individual parts of the system and how they were connected. This led to more complete system models. This difference shows how decomposition can help students think more deeply and solve complex system design problems.

V. DISCUSSION

The quantitative results validate that there is a significant difference between both methods. Using decomposition as an intervention is positively different and effective than not using it. Along with that, several themes originated from the in-vivo and process coding.

In both case studies, the systems were decomposed into different parts. They were analyzed as their parts. However, when design-based decomposition was used with three iterations, students' analysis was deeper. The second case study can achieve higher-order thinking and realize more than level 3, be it Bloom’s or SOLO taxonomy. Students progressed from analysing individual components to synthesizing them into an interconnected model, showcasing skills such as evaluating dynamic interactions and integrating algorithms into functional designs. For example, when mapping real-time updates to system analytics, students demonstrated critical thinking and applied their insights to create structured solutions. This aligns with the advanced stages of Bloom’s taxonomy, including "Evaluate" and "Create," and the relational and extended abstract stages of SOLO taxonomy, where students not only connect components but also generalize their understanding to new contexts. These outcomes illustrate the role of decomposition in enabling learners to transcend surface-level comprehension and achieve complex cognitive goals.

If a faculty intends to achieve higher-order learning outcomes, then the mechanism used for Case Study 2 can serve the purpose. When students are thinking about real-time updates being facilitated, they are thinking about dynamic systems. Though this holds good for both case studies, it was more evident in the second one because of the trigger point. If they can map to algorithms and analytics, which happened for Case Study 2, they are evaluating and constructing. Even when we observe the codes generated for two case studies, the codes of Table V are of higher order than those of Table IV. It shows that the thinking of students concerning both case studies, and the second one in particular, is qualitatively effective. Students were able to see the parts and also the holistic perspective in the second one along with its interactions. Because of the activity framework, the second case study also covered the social aspects. The roles were identified. The algorithms for each of them were identified. The task done by each stakeholder was also analyzed. When the trigger is provided to look at each component when it is explicitly mentioned, it becomes the major ingredient of the study and it is evident from the qualitative analysis.

Conclusion

This study highlights how teaching students to break down complex problems into smaller parts – decomposition, can improve their problem-solving skills. When combined with PBL and CT, decomposition helps students think critically and achieve better learning outcomes. Clear guidelines and examples, or trigger points, assist students in understanding different system components. The research, using both quantitative and qualitative data, demonstrates the effectiveness of this approach and provides teachers with a practical framework to design meaningful and engaging learning experiences.

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