Design of Problem Case Studies and Reflections for a Problem Based Learning Course

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***Abstract*— Problem Based Learning dates back to medical sciences from 1960's and has influenced several domains for the design of effective student-centered learning systems. Problems play a major role in a problem based learning classroom sessions. One of the effective ways of problem delivery is using case studies. An effective case study can act as a bridge to construct knowledge between known and unknown. This work uses pragmatic approach for research design and answers the research question on 'what are the effective ways to design the case studies and reflections in a problem based learning classroom'. The context of the study was second year students from computer science and nature of the course was algorithmic. Total sampling was used in the process with informed consent. After identification of the threshold concepts and writing the learning outcomes, case studies were designed to meet the learning objectives. A template for case study was designed using activity theory as a theoretical framework in support with constructivism. Mixed method approach was used for data analysis. Statistical inferences were used for quantitative data analysis. Process coding and in-vivo coding were used for qualitative data analysis. Using the research design four case studies was analyzed and inferences are drawn on how to design effective case studies. The method has a positive feedback from students as indicated in the feedback survey. Though the process requires additional effort from the faculty in design of case study and reflections, it can benefit the students in becoming self-directed and life-long learners.**

***Keywords*—Case Studies; Problems; Problem Based Learning; Reflections; Outcomes**

***JEET Category*—Research**

I. INTRODUCTION

THE theoretical foundations and knowledge construction of Problem Based Learning (PBL) pedagogy roots back to the medical domain from the 1960s. Influenced by theoretical foundations of constructivism, cognitive flexibility theory, situated cognition, social learning theory, apprenticeship, experiential learning, inquiry based learning etc., PBL centers on solving real-world problems and complex challenges. The McMaster University where the PBL originated has experimented on several fronts to meet the learning objectives. Inquiry was one of the essential skills in clinical practice for a doctor when confronted with a patient (Barrows, 1990). To support the free inquiry in clinical practice for training and use in teaching and evaluation, simulated patients and other human simulations were used promoting problem as a vehicle to develop problem solving skills (Barrows, 1987). The university had practices where the tutor did not give a lecture, or said what exactly to read or announced if a direction to solve the problem taken by students were right or wrong. The tutor becomes one of the students and passes on the class preparation methods and means on to the students (Barrows, 1988). Case studies and problems were the major drivers for the classroom.

Of the two kinds of classrooms, teacher-centered and student-centered, in teacher-centered, instructor has a dominant role who delivers information passively and students sit and listen. In student-centered, they participate actively in their education process which mostly is team based learning at different levels of student involvement. Both have their own merits and demerits. Most modern pedagogies lean towards student-centered approaches and PBL is one among them. By using real world dilemmas and problems, students are usually encouraged to develop a deeper understanding of the scientific principles of the problem domain. Student-centered approaches help students become self-directed and life-long learners. They help to improve critical and analytical thinking, making students effective problem solvers (Colliver, 2000). The pedagogy has evolved integrating with learning styles and has been characteristically adapted into numerous other domains over a period of time. Problem being the major driver in the process is known to be an effective tool as justified and supported in the literature.

A problem can be realized in several ways and case studies are one of them. In the education context, it is essential to bridge the gap between theory knowledge and practical context. Students must have the ability to apply the knowledge into practical scenarios and in professional practice. This helps them develop the required essential skills to solve the real-life challenges. Case studies are effective tools to achieve this objective. The approach of using case studies enhances student engagement and critical thinking towards problem solving making the classes relevant and meaningful (Popil, 2011). Case studies can help in designing in-depth examinations of

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the selected problems. They can help to design problems that can reveal complex patterns and processes that are involved in the complicated scenarios. They can help students to connect to the relevant theoretical frameworks by providing context-specific insights.

One of the major objectives to use case studies is to make students self-directed and life-long learners. This can be achieved by writing relevant reflection questions for the designed case studies. Reflections play a major role in making students towards think in a specific direction. It is necessary for one to contemplate their thought process where they connect the theoretical knowledge to the real-world applications. Reflections help students to develop meta-cognitive skills as well (Goupil & Kouider, 2019). It becomes responsibility of the instructor to design effective reflections to achieve the desired learning objectives. In the regards, it becomes crucial to write appropriate learning objective. This study discusses on writing learning objectives, designing case studies and further writing reflection points to achieve the desired learning outcomes.

Hence, designing good case studies and reflection points is important in PBL because they help students think critically and learn better. Clear and relevant case studies guide students to work on real-world problems, building their problem-solving abilities. Reflection points allow students to link what they learn in theory with practical applications. This research aims to explore effective ways to create case studies and reflections that improve student learning in PBL. This paper is further divided into following sections. Section 2 presents the literature survey. Section 3 presents the research design. Section 4 presents the study model. Section 5 presents the results and data analysis. Section 6 presents the discussion and Section 7 presents the conclusion.

II. Literature Survey

The literature survey presents the classics and contemporaries from the sub-domains of problem based learning, writing learning outcomes, case studies and reflections.

PBL, though originates from medical domain, has been widely used in every other domain for teaching and learning including engineering. Several universities have also developed their own frameworks depending on the need and context considering the demographic and cultural challenges. One day many problems approach was used in delivery of a model thinking course leading to increased course outcomes (Hegade, 2019). Software factories have been created to effectively teach software engineering course using PBL (Dos Santos, 2009). To promote the reusability and interoperability of the PBL trial, a design driven approach was used for computer science courses (Garcia-Robles, 2009). PBL was used in analog electronic course and was observed to that group which used PBL methods had better research skills, confidence and group working skills, leading to meet the employer expectations (Arman, 2019). Usage of concept maps has been experimented in electrical for a problem based laboratory course evaluating meaningful learning and habits of mind (Bledsoe & Flick, 2012).

The Kanban method (Ahmad et al., 2013) has been incorporated with PBL in manufacturing courses, leading to improvements in various stages of project development tasks and enhanced group communication (Balve et al., 2017). In industrial informatics courses, PBL has been used to enhance learnability and soft skills (Calvo et al., 2017). PBL also serves as a model to bridge the gap between abstract mathematics and real-world engineering applications (Christensen, 2008). In civil engineering, specifically in transportation courses, PBL has encouraged active learning, lifelong learning, and a research-oriented perspective (Ahern, 2010), as well as improved learning outcomes through project-based tasks (Hamoush, 2011). The advantages, such as increased motivation and knowledge retention, as well as the challenges, including effective delivery and implementation, have been examined for PBL in biomechanics (Clyne & Billiar, 2016). Additionally, PBL has been applied across computing and programming courses through various strategies and approaches.

Research has extensively explored the writing of learning outcomes. A practical guide on drafting and applying them has been developed (Kennedy, 2006), while approaches to writing outcomes by understanding key risks and critical points have also been studied (Popenici & Millar, 2015). Learning outcomes, which define what students can achieve after a course, need to be tailored to the course's goals and requirements (Jenkins & Unwin, 2001). Studies have further examined how reading, writing, and listening contribute to effective learning outcomes (Güldenpfennig et al., 2023). Instructors can use taxonomies like Bloom's, SOLO, and Dublin to craft effective learning outcomes.

Case studies are similarly powerful in achieving targeted learning outcomes. Designing case studies is a research method on its own (Yin, 2003), with their benefits widely recognized (Tsang, 2014). Numerous theories have been built from case study research (George & Bennett, 2005). Combining case studies with PBL supports the development of technical and professional skills (Warnock & Mohammadi-Aragh, 2016). Different problem-development taxonomies within PBL are analyzed to select the best approach for each case (Jonassen, 2011), while using case studies to teach real-world issues has been thoroughly documented (Raju & Shankar, 1999).

Case studies are enriched through reflections, which act as prompts for deeper and broader exploration. Reflections have been used to build expertise (Andrews, 1999) and, despite some challenges in teaching and learning contexts, have been examined through a literature survey presenting a multilevel perspective (Chan & Lee, 2021). They also contribute to efficient, certified decision-making processes (Boutin, 1997). Additionally, the practice and impact of reflections themselves have been explored (Bandura, 1990), with experiences often distilled into meaningful insights through reflective processes (Daudelin, 1996).

As observed and reviewed through the literature, there are gaps for designing problem scenarios and case studies for

effective delivery of the PBL classroom. Based on the nature of the course, an appropriate case study has to be designed for the concept. It is also challenging to design an ill-structured case study which is proven to be effective for the PBL classroom. Along with a case study, the reflections and trigger points are also perplexing. This study takes the case studies, reflections and learning outcomes and integrates them into one single framework.

III. Research Design

This section discusses the research design used for the study.

A. Philosophical Assumptions

This study adopts a pragmatic philosophical approach (Creswell & Poth, 2013), allowing for flexible and innovative exploration of the research problem (Morgan, 2014). Pragmatism emphasizes practical application and problem-solving over abstract theories, selecting research methods based on desired, actionable outcomes and addressing real-world challenges. It supports the researcher in making operational decisions that align with the study's focus and conceptual framework (James, 1975). Each philosophical assumption considers epistemology, axiology, ontology, and methodology. Here, reality is viewed as multiple, capturing students' experiences from the researcher's perspective. Knowledge (epistemology) is constructed with the researcher as an insider, interpreting subjective evidence from participants. Each student's unique experiences form the basis of ontology, while the axiological beliefs, including limitations and biases, are acknowledged by participants and researchers alike. The methodology combines qualitative and quantitative methods, utilizing a mixed-methods approach.

B. Theoretical Framework: Activity Theory

The study uses Activity Theory as its theoretical framework. The theory examines the interaction via the tools and artifacts. Influenced by social, cultural and historic contexts, it helps researcher to view activities from a holistic perspectives (Vygotsky, 2018). The theory was developed by Lev Vygotsky and further expanded by Alexei Leontiev and Yrjö Engeström. The key components of the theory include subjects, objects, tools, rules, community and division of labor (Burner & Svendsen, 2020). Activity Theory provides a framework to analyze the complex real world scenarios by focusing on interconnections between individuals, tools and social connections. Researcher can understand the deeper dynamics in each case meeting the needs of learning outcomes. Activity theory has been used as basis for the study of work (Bedny & Karwowski, 2004).

The work also uses constructivism. The theory says that learners construct knowledge while being active based on the experiences and interactions with the world (Cobern, 1993). Constructivism emphasizes the importance of creating learning environments that encourage problem-solving and critical thinking. The components of active learning, prior knowledge, social interaction and reflections make it suitable to be used along with the activity theory (Pouliot, 2004). The Vygotsky's zone of proximal development also plays a crucial role in the design of case studies (Chaiklin, 2003).

C. Research Question

By connecting the principles of problem solving, case studies, reflections and learning outcomes, the research question is formulated for this study. The abstraction and structured-ness in the case study design plays a major role in the effectiveness (Jonassen, 1997).

The research question designed for this study is: 'What are the effective ways to design case studies and write reflections points for a problem based learning case study?'

D. Context

The context of the study is second year students of Computer Science and Engineering from KLE Technological University. The course for which the study was made was algorithmic in nature. The course had PBL mode of delivery and case studies and reflections were evaluated for ten marks. The course had emphasis on problem solving, design techniques, computational thinking, case studies, analysis, self-directed learning and project work.

E. Data Collection and Sampling

The data was collected from the second year students of Computer Science and Engineering from KLE Technological University, Hubli. There were a total of 129 students and not all students participated in all the studies. An informed consent was taken from the students for each study and data was used for research work accordingly. The data collection involved survey forms and case study sheet analysis. The study used total population sampling and self-selection as sampling methods in the various data collection methods. In total population sampling, which is a type of purposive sampling, the entire population is examined. In self-selection sampling an announcement is made and all the interested ones who respond in the given time frame become part of the study (Sharma, 2017).

The study used statistical measures and coding methods for data analysis. As the study was driven by theoretical framework, purposive and in-vivo coding was used as a qualitative data analysis technique. In this method codes are assigned based on specific research objectives and from researcher's pre-existing knowledge or theoretical framework. Along with purposive, in-vivo coding was also used. In in-vivo participants exact words and phrases are used for coding (Saldana, 2021).

IV. Model

This section discusses model and its respective methodologies. In order to design the case studies, the instructor first needs to identify all the threshold concepts in the course. Threshold concepts are core ideas within a subject which once understood change the way by which the student perceives the course. They open up the new way of thinking (Cousin, 2006). These ideas are like doors that open up a

deeper understanding for the students. They can be difficult to learn at first, but once students grasp them, they can understand the subject much better. For example, in computer science, understanding pointers is a threshold concept. It helps students move from simple memory management to more complex topics like dynamic memory allocation in data structures. Grasping such concepts can lead to clearer and deeper thinking in the domain. This idea is presented in Figure 1 below.

The faculty first selects the concepts from the course and then identifies the threshold concepts from them. Threshold concepts are usually challenging, associated with principles, integrate several concepts from course and most importantly, once learned; it's difficult to unlearn them. They are also challenging for faculty to bring them into classroom sessions.

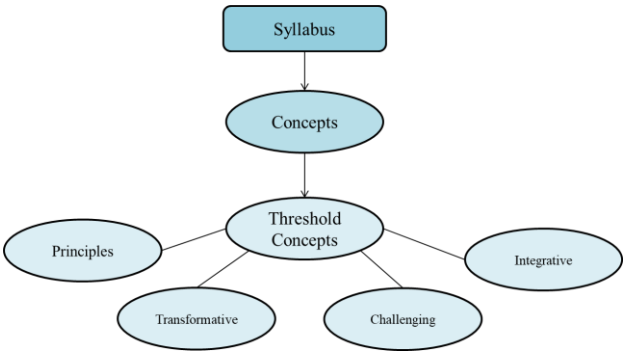

Fig. 1. Threshold Concepts

Once the threshold concepts are identified, based on the class bandwidth, the number of case studies is decided for the case study formulation. The further process is explained in Figure 2.

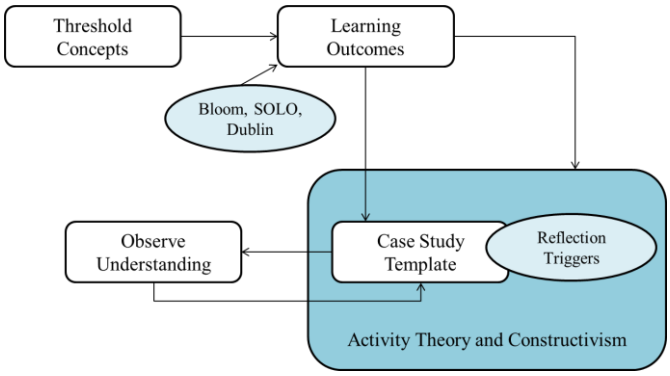

Fig. 2. Overall model of the case study design

First the learning outcomes are formulated based on what is intended to be learned from the concepts. These can be realized using Blooms (Krathwohl, 2002), SOLO (Biggs & Collis, 2014) or using Dublin Descriptors (Masaev et al., 2020). With that the case study is formulated based on the template provided. The template uses the constructs form activity theory and constructivism. Based on the student performance from each study, the case studies are revised for the future concepts and case study designs. Instructor understands the mud points and scaffoldings are created for next case studies or for other assignments. The trigger points created are based on the intended learning outcomes.

The case study formulation template along with description is presented in the Table 1 below.

TABLE I
CASE STUDY TEMPLATE

Attribute	Description
Concept Name	Name of Threshold Concept
Concept Domain	What domain does the concept belong to
What Students Already Know	The knowledge that students already have on the concept
Principles Involved	What principles does the concept involve
What will Students Learn	What new algorithms will students learn from the case study
Applications	List some of the real time applications
Trigger	What is the direction of this case study? Does it deal with properties? Applications? How must students connect with principles? Can students get a direction to solve this case study?

The case study is further designed with one of the application as a center piece and building on the knowledge of what students already know.

V. RESULTS AND DATA ANALYSIS

A. *Case Study Design*

For the algorithms course, the threshold concepts identified are presented below in Table 2. The table presents some of the samples only.

TABLE II
THRESHOLD CONCEPTS

Concepts	Applications
Problem Type	Recursion, Iteration and Backtracking
Nature Patterns	Nature patterns as a computational thinking activity
Sorting and Searching	The organization of the data to arrange them in ascending or descending order
Range Query	All kinds of range query algorithms
Graph Traversals	For depth and breadth first search
Spanning Trees	For graph algorithms

As the intention was to theorize using the case studies, learning outcome was written using SOLO taxonomy and is listed below:

- Theorize and reflect on the properties, operations and applications of data structures and algorithms using application case studies.

Using the threshold concepts and learning outcome, four major case studies were designed. The case studies are presented below in Table 3.

TABLE III
CASE STUDIES

ID	Concept	Description
CS1	Problem Types and Patterns	Two photographs were given one of millipede with recursive repeating type of similar legs
CS2	Graph Traversals	Wikipedia hyperlink strategy was used as case study
CS3	Spanning Tree	Jal Jeevan mission was explained to lay the pipe system for a hypothetical city.
CS4	Array Query Comparison	Different kinds of queries were used to observe for optimization and design of algorithms

All the case studies were analyzed qualitatively using purposive and in-vivo coding to understand and comprehend the student understanding. The gaps were covered in the class sessions and loops were closed in written assessments. Or each case study, reflection points were designed based on principles involved and what students are supposed to learn from it. The coding sample is presenting in Table 4 below. The phrases are the direct sample codes taken from the student answer sheets. The Table 4 is only a sample from 129 case study sheets. A total of 113 codes were generated and was stopped when data saturation was reached.

TABLE IV
CASE STUDY CODES – PATTERNS

Phrase	Code
Nature has pattern forming mechanism	FORMATION
are not coincidences	INHERENT
Laws of nature favor these formations	NATUIRE LAW
small as DNA to large as galaxy	SMALL TO LARGE
seeing the pattern allows brains to see order	PREDICTION
repeated patterns formation	ITERATE
observed patterns in day to day life	OBSERVATION, REPEAT
patterns involves shapes, colors and repetition at equal intervals	VISUALLY PLEASING
Scientifically they do that to maximize the use of sunlight	REASONING
We can observe the patterns on animals like snake, where the scales on skin are repeated	REPEAT
finding inspiration and balance	MOTIVATION
all the things in universe are connected	INTERCONNECT
they have repeated step moment and not random	PATTERN
stunning visualization	COSMETICS
Operations are described	OPERATIONS
play a crucial role in ecosystem	NATURAL ORDER
a periodic tiling of repetitive pattern	PATTERN
Which i think is efficiency	EFFICIENCY
patterns help to make it efficient	EFFICIENCY/PURPOSE
mother nature's behavior	INHERENT
Millipede is example of repetition in nature	REPEATATION
nature follows steps, procedures and rules for the functioning of all basic creatures	PATTERN
Understanding patterns helps us to make predictions about future occurring events.	PREDICTION

The idea of the case study was to make students realize the importance of patterns and then explain the computational thinking building block of 'pattern recognition'. The case study was successful in achieving the objective.

B. Case Study Scores

The scores of four case studies along with mean, standard deviation, variance and other descriptive statistics are presented below in Table V. The number of student scores used for study was 129.

TABLE V
CASE STUDY SCORES

Measures	CS1	CS2	CS3	CS4
N	129	129	129	1209
Mean	5.45	7.02	4.51	6.72
Median	5.00	7	4	6.50
Standard Deviation	0.696	1.39	1.01	0.755
Variance	0.484	1.94	1.02	0.570
Minimum	4	4	4	6
Maximum	8	10	9	8
Skewness	1.42	-0.275	2.40	1.00
Std. error skewness	0.213	0.213	0.213	0.213
Kurtosis	2.38	-0.424	6.22	0.291
Std. error kurtosis	0.423	0.423	0.423	0.423
Shapiro-Wilk W	0.773	0.941	0.577	0.845
Shapiro-Wilk p	< 0.001	< 0.001	< 0.001	< 0.001

The total score for each case study was 10 marks. The levels of case studies designed were hard. Lower standard deviation and variance indicate that the data points are clustered closer to the mean, implying less variability or more consistency. This also indicates more consistent level of performance within the class. A value of error skewness 0.213 means that the skewness could vary by about 0.213 units from its calculated value due to sampling variability.

A skewness of 1.42 indicates a right-skewed distribution with more low values and a few high outliers. A skewness of -0.275 suggests a slightly left-skewed distribution, with a near-symmetric shape and mild lower outliers. Positive skewness leans right, while negative skewness leans left in data distribution.

Kurtosis measures the tailed-ness of a distribution. For the four case studies, kurtosis values of 2.38 and 0.21 suggest distributions with moderate to near-normal tails, while -0.424 indicates a flatter, less-tailed distribution. The value of 6.22 reflects a distribution with significantly heavy tails, or more extreme values. The standard error of 0.423 helps assess the significance of these kurtosis values. Dividing the kurtosis by the standard error, 6.22 and 2.38 are significant, indicating pronounced tails, while -0.424 and 0.21 are not, suggesting distributions closer to normal. Thus, two distributions have significant kurtosis, with one heavy-tailed and the other moderately-tailed.

The Shapiro-Wilk test results indicate that all four datasets significantly deviate from a normal distribution, as evidenced

by p-values < 0.001. The W-values of 0.941, 0.773, 0.577, and 0.845 suggest varying degrees of non-normality. The second dataset (W = 0.941) is the closest to normal, while the others, especially the third dataset (W = 0.577), show more substantial departures from normality. Overall, none of the datasets follow a normal distribution, and the deviations are statistically significant.

C. Student Feedback

A survey form was circulated to the students seeking for the effectiveness of the case study and reflections and was filled by 100 students out of 129. The results are presented in Figure 3 below. 48% students agreed they were highly effective in the learning process and 42% stated it was effective. A total of 90% acceptance is a positive remark towards the approach. As the number of students equals 100, the percentage also equals the number of students.

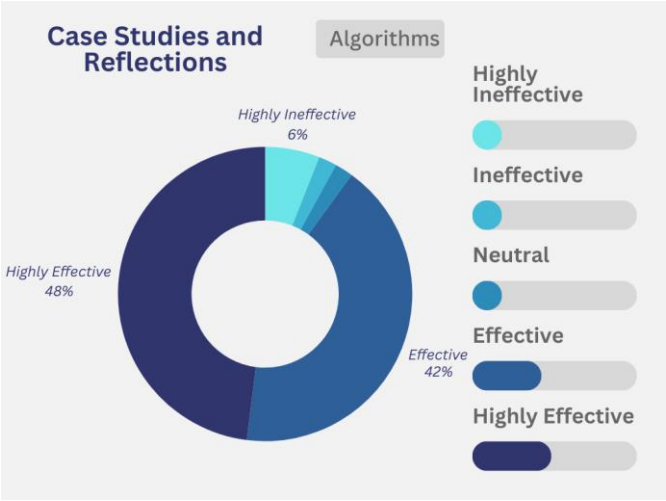

Fig. 3. Feedback of students measuring the effectiveness of the case studies and the reflections.

VI. DISCUSSION

While most of the times, the instructor designs a case study from their past experience or a relevant concept and it might not cover and meet the objectives of intended learning outcomes. It is necessary for an instructor to bridge the gaps between known and unknown. This was successfully achieved using the activity theory framework. The idea of the framework and constructivism is to bring the cultural and social contexts into the classrooms. When we define what students already know and the applications, we are connecting the classroom experiences with the real world case studies.

If we closely observe the mean of first case study, it is low for a total score of 10. Students were not aware of the process and how to write meaningful reflections. When the discussion session happened in the class, next case study score significantly improved. The complexity of further two case studies was increased as students were already aware of the system. The scores of Jal Jeevan Mission case study turned out to be low as most students failed to consider the real time constraints as they were supposed to build a proposal and estimate the cost. Designing such case studies can make students realize the real time intricate threads of the social world and dynamics.

After each case study, the answers were analyzed with qualitative coding. Using the codes, the next assessment questions were designed so as to cover the missing gaps. For a single case study students were looking from different perspectives as they were open-ended. For example, for the recursive pattern of leaves, as discussed in Table 4, some students explored the scientific reasoning behind it. Some felt they were visualizing appealing. Some felt it was inherent. Some talked about natural order. Each of them connected it with the past experiences they had. All these codes were further used in classroom discussion to close the loop of the case study.

Further, the table contents as populated in Table 1 can be used for prompt engineering for generative AI tools to design effective case studies. Rather than giving generic concept name, these details can help in case study design. Especially when the known concepts are elaborated, case studies description can be meaningful catering to the learning experiences of the students.

VII. CONCLUSION

The proposed study demonstrates the effectiveness of designing case studies with a focus on achieving specific learning objectives. Traditionally, case studies have been created primarily to teach or reinforce theoretical concepts. However, this study advocates for a more practical approach, where case studies are developed to connect academic content with real-world applications and constructs. While this shift may initially present challenges for instructors, particularly due to the significant time and effort needed to design and iteratively refine these case studies, has long-term. These case studies can enrich the learning. These case studies make learning more meaningful. They help students apply what they learn in class to real-world situations. Instead of just looking up information, students get to actively work through a problem, which makes the learning process more engaging. This hands-on experience is important for preparing them to face real-life challenges.

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