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Editors

Writing Prompts to Identify At-Risk Students in Introductory Programming Courses

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Abstract

The identification of at-risk students early in introductory programming courses is critical to their success. Timely intervention requires assessment before substantial code has been written, and good and bad habits are formed. This study asserts that the use of natural language writing prompts can be used as a diagnostic tool, based on the SOLO taxonomy of cognitive development. The relationship between natural language metrics (Flesch Reading Ease, Flesch-Kincaid Grade Level, Gunning FOG Index) and code maintainability (McCabe's Essential Complexity) by 29 novice student programmers completing a Java assignment was evaluated. Statistical results show significant differences in all three natural language metrics between students who produced maintainable and unmaintainable code, with the strongest predictability demonstrated by the FOG Index (FOG Index: $p=.086$, $CI_{90}= [-3.4, -.20]$). These results were interpreted through the SOLO taxonomy, suggesting that students performing at the Multistructural level produce both disconnected writing (high complexity scores) and unstructured code (high essential complexity), while students performing at the Relational level produce coherent structures in both domains. Further, this study provides implementation guidelines for instructors to manage writing prompts, interpret results, and design impactful interventions, resulting in a low-cost, scalable approach for early student assessment.

Keywords: SOLO Taxonomy, Natural Language Metrics, Software Metrics, Halstead, McCabe, Programming Education

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Writing Prompts to Identify At-Risk Students in Introductory Programming Courses

Jon D. Clark and Seth J. Kinnett

1.INTRODUCTION

Improving student outcomes in computer programming courses is a priority for Information Systems instructors. Although remedial approaches can be implemented upon identification of particular student struggles, such approaches rely on some critical mass of assignments to be completed, so instructors can determine topics of concern for particular students. This challenge is compounded by the reality that introductory programming courses may not cover a substantive number of topics until several weeks into a given term, not to mention resource and bandwidth limitations could impact instructors' abilities to engage in remedial techniques. One ideal intervention centers upon the potential to identify at the very beginning of the course those students that might be expected to struggle. Implementing a programming assessment would be ineffective since all students are presumed to be beginners, resulting in the need for some form of non-programming assessment.

This paper provides insights into the possible relationship between one's complexity and level of written natural language expression and the corresponding complexity and level of expression in a programming language. This work extends what was done by Kinnett and Clark (2024) and presented at the ISCAP Conference that year. That research was directed at the relationship between software metrics (Halstead, 1977 and McCabe, 1976, 2024) and student learning. Findings included nuances about grading rubrics as well as general mutual support between Halstead and McCabe metrics. This was of interest since the two sets of metrics are based on quite different bases: information theory and program control paths. Due to a comment provided by an attendee at the presentation and a short conversation we decided to explore whether there is a relationship between natural language expression and that of computer programming. If such a relationship exists, then there is a possible shared cognitive process that is used and possible related outcomes that are quite important and possibly useful.

There are 29 Java programs used in this study, all of which satisfy a single in-class assignment in CIS 240, Application Design and Development. This is the first programming course that Computer Information Systems majors take. The 16-week course introduces students to object-oriented programming fundamentals using Java, spanning the concepts outlined in Table 1. In addition, an assignment in CIS360, Systems Analysis and Design, involved English text, and was used to derive several linguistic metrics. These metrics were used as a predictor of program complexity in the McCabe groups of Unmaintainable and Maintainable obtained in the CIS240 programming course. It is important to note that CIS360 concentrates on the Universal Modeling Language (UML) and not on computer programming.

Module Number	Topics
1	Course Overview & History of Programming Languages
2	Java Fundamentals (data typing, variables, constants)
3	Selection Statements (if/else/else if/switch)
4	Loops (while, do-while, for)
5	Methods & Method Overloading
6	Arrays (one and two-dimensional)
7	Classes & Objects (data encapsulation, constructors)
8	String Manipulation & File I/O

Table 1: Course Topic Summary

Natural Language Metrics

Language complexity can be captured by a number of characteristics relative to structure. With approximately 6,000 natural languages in existence, there are many variations in syntax and complexity. According to Rescher (1988) and Sinnemaki (2011) the general categories of complexity can be decomposed into the following:

> Syntagmatic complexity: number of parts, such as word length in terms of phonemes, syllables etc.
> Paradigmatic complexity: variety of parts, such as phoneme inventory size, number of distinctions in a grammatical category or aspect.

Organizational complexity: ways of arranging components, phonotactic restrictions, and variety of word orders.
Hierarchic complexity: such as recursion, and lexical-semantic hierarchies.

Three useful and easily obtainable Natural Language (NL) metrics were chosen for this research. Fortunately, beginning in the 1930's following the Great Depression, a number of readability formulas were developed. These focus on readability relative to the level of education. Rudolf Flesch (1955) produced the Flesch Reading Ease formula as a tool to enhance marketing of print matter. By 1975, the Flesch-Kincaid (Kincaid, 1988) partnership with the US Navy was formed. This metric became known as the Flesch-Kincaid Grade Level index based on the US educational system. In addition, Robert Gunning produced a formula which became known as the Gunning Fog index around 1952, with some changes in the formula that took place over the next several decades. The purpose of the index was to measure the degree of understandability of text in the newspaper and textbook publishing domain.

The metrics chosen for this study are commonly accepted, used, and serve as the independent variable: 1) Flesch Reading Ease; 2) Flesch-Kincaid Grade Level; and 3) Gunning Fog Index. These metrics address the readability of text based on measurable characteristics of a sample text for the purpose of assessing the ease with which a reader can consume and understand the passage. The Flesch Reading Ease metric is based on a similar formula with different weights and an index that begins at 0.0 through 100.0 and is a reciprocal of the Gunning Fog Index. A score of 100.0 is associated with 5th grade and 0.0 with college educated professionals. The formula is as follows:

Flesch Reading Ease = 206.835 – 1.015(total words/total sentences) – 84.6 (total syllables/total words)

This index applied to a sample of *Reader's Digest* has an index of 65 (between 8th and 9th grade), *Harvard Law Review* in the low 30s. Florida insurance policies have an index of 45 or greater (some college).

The Flesch-Kincaid Grade Level metric is based on the following formula:

Flesch-Kincaid Grade Level = 0.39 (Total Words/Total Sentences) + 11.8 (Total Syllables/Total Words) – 15.59

In the case of the Gunning Fog Index, the formula is as follows:

Fog Index = 0.4 (words/sentences) + 100 (complex words/words)

Where complex words consist of three or more syllables do not include proper nouns, familiar jargon, or compound words. Neither are common suffixes such as -es, -ed, and -ing counted as syllables.

It's well recognized that this index has its limitations, was intended for English, and may not be appropriate for other languages. The range of values produced range typically from 4 (fourth grade), through 17 (college graduate).

According to Gunning (p. 4-5,1969):

> "In 1944 I setup Robert Gunning Associates to help staffs of publications and corporations improve their writing. The Gunning Fog Index resulted from our efforts to produce a measure that would be sufficiently reliable and still easy to use. Apparently, this effort has been helpful to a great many people. The Army, Navy and Air Force chose this formula for their writing manuals, and we have given them permission to use it."

Not incidentally, the Gunning Fog Index is generally available and can be used on text produced in MS Word.

McCabe Control Flow Metrics

McCabe's complexity measures were based on graphs of control flow, where nodes represent program statements and edges (arcs) represent the flow. Statements that determine decisions produce branches in the graphs and the count of various paths are an important determinant of complexity. These metrics are far more domain specific to procedural programming than Halstead's approach but are not predictive of effort across the stages of systems development.

A graph of control flow produces the following metrics:

E = number edges of the graph
N = number of nodes of the graph
P = number of connected components (program exit points)

The derived metrics are as follows:

v(G) (Cyclomatic Complexity) = E-N+2: number of edges less the number of nodes plus the number of connected components
ev(G) (Essential Complexity) = 1<= ev(G) <= v(G): based on reduced control flow graph

Interpretation of v(G) thresholds by McCabe:

1. 1-10: simple procedure, little risk
2. 11-20: more complex, moderate risk
3. 21-50: complex, high risk
4. >50: untestable code, very high risk

Essential Complexity, ev(G) is produced by removing all the structured programming primitives. These include 1) sequence; 2) selection statements, including *if* and *case* statements; 3) iteration constructs, including *while, do,* and *for*.

2. SOLO TAXONOMY OF COGNITIVE DEVELOPMENT

The Structure of Observed Learning Outcomes (SOLO) taxonomy (Biggs and Collis, 1982) identifies five hierarchical levels of cognitive complexity evidenced in learning: Structural, Unistructural, Multistructural, Relational, and Extended Abstract. Learning complexity, and arguably effectiveness increases in the hierarchy. This framework has demonstrated usefulness relative to assessing learning outcomes (Burnett, P.C., 1999) and in the assessment of student code comprehension, algorithm design, and problem solving (Lister, et.al., 2006). Additionally, this taxonomy has been evaluated in empirical studies of Boulton-Lewis, G.M. (1995) and Chan et.al. (2002). It's noteworthy that this taxonomy aligns well with the extension of Bloom's taxonomy (Krathwohl, 2002) with a more insightful approach to how learners integrate knowledge.

The five levels of SOLO identify increasing levels of sophistication and ability. The Prestructural level is one in which one misses the point entirely and may not know where to begin. The result is that to proceed one must choose a focus whether or not it turns out to be useful in the end. The second level is called Unistructural due to the fact that a focal point is chosen in order to reduce the level of chaos. Development beyond a single focus is a critical transition point relative to learning in which multiple focal points and their relationships are identified. This level predictably is referred to as Multistructural. With greater mastery of the number of factors involved and the influence of relationships the Relational level is achieved. With this level of understanding much of the original chaos has been replaced with predictability. The final level is achieved when students can generalize and reorganize their understanding in other contexts. This level is called Extended Abstract.

We suggest that natural language complexity and code complexity are indicators of a learner's SOLO level.

Let's consider three students at different SOLO levels of complexity and the impact of their approach to an assignment. The Prestructural student who is facing an assignment involving Java, has to identify which statements are appropriate for a possible solution, and in addition, may not understand the problem. Maximum chaos exists and the only way to proceed is to focus on something. One might choose to understand the problem rather than the solution.

The Multistructural student on the other hand likely has developed an understanding of the problem, likely in a context without the programming language and all of its complexity. With this domain knowledge the student can greatly simplify the choices that have to be made to construct a solution and the language constructs that are useful for this purpose.

The Relational student will demonstrate a predictable approach that occurs in natural language expression, and the development of code. Likely, we will find that the learner will follow these steps:

1. Decompose a complex goal into manageable subgoals (outline in natural language equivalent to functions in an algorithm).
2. Organize elements into a logical sequence (paragraph flow equivalent to program control flow).
3. Establish clear relationship between parts (transitions of ideas versus function call sequences).

3. RESEARCH DESIGN & QUESTIONS

The dataset to be used in this research consists of a sample of 29 successful attempts at producing a solution to Java programming assignment for the Rock, Paper, and Scissors game. This assignment is one of many,

approximately halfway through a 16-week semester and is denoted as ICE04 (In Class Exercise 04) and features concepts related to loops. These exercises are carefully controlled in a classroom setting for a period of 75 minutes of individual programming effort. See Figure 1: **ICE04 Assignment** and **Table 2: ICE04 Grading Rubric**.

Write a Java program that plays the game Rock, Paper, Scissors. The rules are as follows: •Rock (0) beats scissors (2) •Scissors (2) beats paper (1) •Paper (1) beats rock (0) At the start of the program, the program must ask the user for their name. The program should then ask how many rounds the player wants to play. The program will then prompt the user to choose rock, paper, or scissors and randomly choose a value for the computer player. It will determine the winner of that hand, display the results, and keep track of the number of hands won by the player, the number won by the computer, and the number of tie games. Use JOptionPane for all inputs and outputs.

Figure 1: ICE04 Assignment

Proper coding habits including indentation & comments (1)
Proper compilation (no errors) (2)
Either *for* or *while* loop implemented properly to loop for the number of rounds specified by the user (2)
Correct use of if/else-if or switch to process user's choice each time (1)
Correct use of nested if/else-if to evaluate computer's choice (1)
Correctly implements counter variables to track computer wins, player wins, ties (1)
Correct computation of winner using if/else-if/else to evaluate the counters (1)
Correct generation of output using string concatenation (1)

Table 2: ICE04 Grading Rubric

Each program submitted and evaluated as successful according to the rubric was analyzed by *BattleMap IQ*, a tool that produces McCabe metrics from source code, in this case from Java. Appendix I has a table of values obtained in this manner. In addition, each student represented in this table was also evaluated in terms of a writing exercise from a class assignment in which English text was required and each such sample of writing was analyzed using the document evaluation tool contained in MS Word and an external application for the Gunning FOG Index. The dataset consists of McCabe's Cyclomatic measure v(G) and Essential Complexity ev(G), as well as Flesch Reading Ease, Flesch-Kincaid Grade Level, and Gunning Fog index.

It should be noted that the table contained in the Appendix I has been partitioned into the McCabe categories of Maintainable and Unmaintainable. These are highly significant and based on a threshold of 4 for Essential Complexity where if ev(G) > 4 the code is Unmaintainable for ev(G) =< 4 is Maintainable. This threshold has been determined by McCabe based on experience. Additionally, a threshold of 10 has been used by McCabe with regard to Cyclomatic Complexity where v(G) =< 10 is Reliable and v(G) > 10 is Unreliable. Surprisingly, all the student programs fell into the category of Unreliable in either Maintainable or Unmaintainable! See Figure 2 for the scatterplot of unmaintainable and maintainable complete working programs.

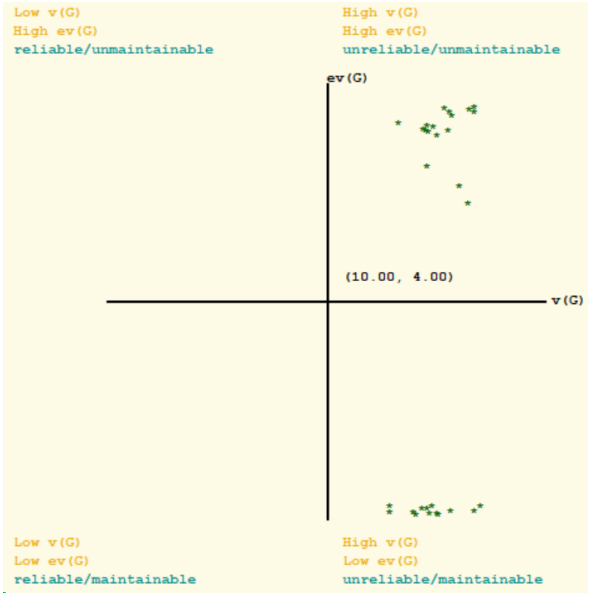

Figure 2: v(G) & ev(G) Scatterplot of Student Submissions

The distinction between Reliability and Maintainability may appear to be confusing. According to McCabe, the two subcategories of Reliability and Unreliability are based on v(G), a measure of decision structure complexity. If v(G) is greater than 10 then the module would be difficult to test. In a similar fashion, the subcategories of Maintainable and Unmaintainable are based on ev(G), a measure of unstructuredness. If ev(G) is greater than 4 then the module makes use of unstructured programming constructs resulting in maintenance

issues. A paper by Riabov (2007) provides an applied demonstration and explanation of these constructs.

The purpose of this research is to explore the correspondence between Natural Language and Program Complexity in an educational project setting. To carry out this evaluation, the dataset having fully functional programs that met the goals of the rubric, have been partitioned into Unmaintainable (UM) and Maintainable (M) categories. The following Research Questions (RQ) will be addressed:

RQ1: What is the relationship between Flesch Reading Ease mean scores and UM and M categories determined by McCabe's ev(G)?

> ($H_0$1) There is no difference in mean Flesch Reading Ease scores between the UM and M categories determined by McCabe's ev(G)
>
> ($H_1$1) There is a difference in mean Flesch Reading Ease between the UM and M categories.

RQ2: What is the relationship between Flesh-Kincaid Grade Level mean scores across the UM and M categories determined by McCabe's ev(G)?

> ($H_0$2) There is no difference in mean Flesch-Kincaid Grade Level scores across the UM and M categories determined by McCabe's ev(G)
>
> ($H_1$2) There is a difference in mean Flesch-Kincaid Grade Level scores between the UM and M categories determined by McCabe's ev(G)

RQ3: What is the relationship between mean Gunning Fog Index scores across the UM and M categories determined by McCabe's ev(G)?

> ($H_0$3) There is no difference in mean Gunning Fog Index scores between the UM and M categories determined by McCabe's ev(G)
>
> ($H_1$3) There is a difference between mean Gunning Fog Index scores between the UM and M categories determined by McCabe's ev(G)

A bootstrapped independent samples t-test will be used to determine whether there is a relationship between English Natural Language Complexity and the Program Complexity produced. If there is a relationship, one might use this to better manage the programming process and produce better, perhaps more reliable and maintainable results.

One of the paper's authors administered the writing sample, while the other author administered the programming assignment. Both data collection exercises occurred through the natural administration of respective courses. Students included had completed both courses within one year of each other. The sample of programming exercises was drawn from a prior study, which sought to identify patterns in the McCabe metrics in introductory programming courses.

This population was identified first, then the writing samples collected as part of a different exercise were matched by name and the relevant scores were computed. The McCabe metrics used to segment programming samples into Maintainable and Unmaintainble categories were generated using the BattleMap IQ software. The readability metrics were generated using a combination of tools. The Flesh index and Grade Level index were computed using native tools in Microsoft Word (Review->Editor->Insights->Document Stats) while the FOG index was obtained via the public website http://gunning-fog-index.com.

Once these scores were all obtained, we created a spreadsheet containing two group indicators (Maintainable/Unmaintainable) and included columns for each of the three readability metrics. This data was loaded into SPSS Statistics v. 30.

An independent samples t-test evaluating mean differences across samples is an appropriate approach in this circumstance. As the gold standard for sample size in parametric statistical tests is a minimum of 30 observations per group in order to satisfy the Central Limit Theorem, we opted to employ bootstrapping upon our samples ($N_{maintainable}$ = 11, $N_{unmaintainable}$ = 18). Bootstrapping is a well-established and reliable technique to increase the reliability of findings when small sample sizes are present. Accordingly, we performed the difference of means independent samples t-test using 1000 simulated bootstrapped samples using SPSS to determine the degree of independence between the Maintainable and Unmaintainable categories of the samples. We utilized SPSS defaults for the technique, designating a simple (vs. stratified) sampling scheme and 90% confidence intervals. In order to assess the magnitude of any practical effect commensurate with statistical differences, we also generated Hedges' g, which applies a correction factor to the pooled standard deviation to reduce bias in the estimation of population

effect sizes (Hedges, 1981). This measure was selected for its widespread use in meta-analytic research, facilitating cross-study comparability.

4. RESULTS

Interpreting the results required us to evaluate the results of Levene's test for equality of variance. In all three calculations, Levene's test indicated variance between groups was equal. Table 3 shows that both the Flesch-Kincaid Grade Level and the Gunning Fog Index are significant at the 0.09 level. In accordance with best practices surrounding the use of bootstrapping, we evaluate our decisions regarding rejection or failure to reject null hypotheses based on the bootstrapped confidence intervals. Intervals spanning zero indicate that one possible result is no mean difference, which would cause us to fail to reject null hypotheses. Table 3 shows the summary findings from our bootstrapped independent samples t-test. Hedge's *g* indicates a medium to large practical effect size when comparing groups across all three metrics, with the highest being in Flesch-Kincaid Grade Level and FOG Index.

Metric	MD	σ_M	CI_{90}	*g*
Flesh Index	9.97	5.95	[.04, 19.5]	.65
Grade Level	-1.7	.97	[-3.2, -.10]	-.72
FOG Index	-1.8	.98	[-3.4, -.20]	-.72

Table 3: Bootstrap Independent Samples Test

RQ1 asks *What is the relationship between the Flesch Reading Ease and McCabe metrics determining the* UM and M categories*?* The 90% confidence intervals do not span zero (CI_{90} = [.039, 19.52]), leading us to reject $H_0$1. The Flesch Reading Ease index is based on the number of words per sentence and the number of syllables per word. Programming constructs and control flow appear to be predictable based on natural language constructs.

RQ2 asks *What is the relationship between Flesch-Kincaid Grade Level and McCabe metrics determining the UM and M categories?* In this case, the CI_{90} = [-3.26, -.10]. Once again, these confidence intervals do not span zero, leading us to reject $H_0$2. The Flesch-Kincaid Grade Level, though based on the same variables, uses quite different weights and is the reciprocal of the Flesch Reading Ease Index. One might conclude that the grade level has a better fit as far as prediction of M and UM categories.

RQ3 asks *What is the relationship between the Gunning Fog index and McCabe metrics determining the UM and M categories?* This case has CI_{90} = [-3.4, -.20]. Similarly to the prior metrics, we are empowered by the findings to reject $H3_0$ and conclude there is a significant difference in the FOG index mean scores across the groups. Further, we observe that among the three readability metrics, the FOG Index demonstrated the most robust group difference, with its 90% bootstrap confidence interval [−3.4, −0.20] excluding zero by the widest margin. This was further supported by a medium-to-large effect size (g = −.72). Again, the FOG index is based on weighted words per sentence and complex words of three or more syllables compared to the total number of words used.

As we can see, we found statistically significant differences across all three natural language metrics when comparing the two groups of maintainable vs. unmaintainable code based on McCabe's ev(G). Even though the practical effect sizes are notable based on Hedges' *g*, the statistical findings retain validity at 90% confidence but not 95%. A significance level of α = .10 (i.e., 90% confidence intervals) was adopted consistent with the exploratory nature of the study (Hair et al., 2009). The FOG index mean scores had the highest differences across the two groups which, along with a medium to high practical effect size via Hedges' *g* reveals FOG score to be our preferred mechanism to recommend to instructors interested in performing these assessments.

5. DISCUSSION AND LIMITATIONS

These findings lead to a number of interpretations and pedagogical implications. First, the idea that one aspect of code quality can essentially be predicted by an English language writing sample is – to our knowledge – a novel finding. We suggest that instructors could administer a writing prompt at the start of the term for students enrolled in a programming course to get a sense of which students might need more assistance in writing quality code.

Focusing on the FOG index, given its higher apparent predictive power, we suspect the findings explain the idea that succinct English sentence construction correlates with fewer control flow paths (measured by ev(G)), suggesting higher cognitive organization, whereas higher FOG scores correspond with

higher ev(G) values, suggesting a more meandering style of coding and writing English that both demonstrate less forethought.

We suggest that students are essentially less focused in their production of both English sentences and Java code. Such students need to plan their approach more in both arenas and are likely jumping right into both exercises with a *think as you go* approach, which leads to a decrease in both code structuredness and the more complicated sentence constructions.

These findings are consistent with the known understanding of the SOLO taxonomy. Namely, students with high FOG scores, which could be seen as representing essentially a Multistructural level of understanding, generate natural language that is cumbersome to consume, despite generally following the norms of English language. Namely, a solution can be generated, but natural language written at this level is analogous to the *stream of consciousness* approach, where syntactic succinctness or cognition surrounding sentence structure is largely absent. Our findings demonstrate the relationship between this reality and high ev(G) scores on an introductory programming assignment. Since ev(G) represents the maintainability of a program, characterized by a control flow graph that excludes structured programming primitives – techniques one would expect to see extensively in an introductory programming assignment artifact – it is evident that higher levels of ev(G) represent programs that use convoluted techniques rather than focused deployment of collections of fundamental programming techniques (n.b., with programming primitives entailing sequences, selection statements, and iteration constructs). The resultant code is thus aptly characterized as Multistructural and absent the type of cohesion and reflection necessary to create code that could be justly assessed at the Relational level. Pedagogically, all students received the same instruction, yet some students wrote maintainable code "naturally" while others didn't.

The key tactical pedagogical implication of this research is the potential early identification of students more likely to operate the Multistructural level in a programming course compared to the Relational level. We suggest instructors implement the following practices. First, at the beginning of the term, students are asked to write a 250-500 word response to a brief prompt. In our study, the prompt involved three answers in English text (see Appendix II, CIS360 Reflection Paper 1: IT Professionals). It is critical that students write this without the use of generative AI tools, so embedding the response inside of a tool like Lockdown Browser may be advisable. Next, instructors generate FOG index scores using http://gunning-fog-index.com/.

Based on the data we evaluated, we suggest that FOG scores above 15 correspond with Multistructural English language performance and accordingly suggest that this collection of students are candidates for early intervention. The score of 15 is provisional and we recommend instructors look for division in scores in their own samples should they choose to pursue this path. We also note that this is only one possible dimension through which an instructor could define an at-risk student. Accordingly, we suggest instructors would benefit from evaluating a variety of mechanisms to identify students, who could benefit from some intervention.

Since we did not specifically test different intervention strategies, we defer to instructors for their preferred courses of action, though some options include reinforcing available resource options such as tutors, help centers, and selected online resources.

We further note that student language ability may even be critical to successful use of generative AI tools for code assistance. Student access to AI has increased reliance on the use of available partial solutions as a development starting point. Vibe coding (Karpathy, 2025), a new type of process in which NL requests are made to a Large Language Model (LLM), has begun to receive attention. This process allows iterative refinement of a problem statement in which code is progressively refined as well. As an example, when a block of code is returned from a request, either functional extensions may be added or corrections to compile and runtime errors. Vibe coding has become an accepted practice by novice programmers in both academic and applied settings for simple application development. Andrew Ng (2025) is offering course material and training in this new process. Certainly, there are critics, but as AI develops, the effectiveness of the approach may well change. Given the relationship found in this paper, there is a possibility of further research between the NL component of the requests provided to the LLM and the degree of precision of the coded outcome. The research convergence of NL and coding deserves greater attention as shown in this research.

6. CONCLUSIONS

Computer programming entails a mastery of language. In this paper, we have demonstrated a relationship between characteristics of an English language writing assignment with characteristics of Java program code. This relationship enables instructors to forecast aspects of student Java programming fluency – namely, performance at the Multistructural vs. Relational levels of the SOLO taxonomy – vis a vis English language characteristics of student writing samples.

The recent advent of vibe coding also suggests that English language mastery has both indirect benefits to direct program code but also via vibe prompts, where better writers are presumably generating better responses from LLMs.

In addition, further research may be needed to determine the pedagogical impact of coding practice. The UM category contains a great deal of unstructured code that deserves further study including:

Does a time constraint affect structure?
Does coding environment play a role?
What role does application complexity play in the structure of the solution?
Will vibe coding mitigate the impact of NL understandability?

The connection between NL and code understandability encourages us to further study the development processes used and the pedagogical impact of teaching methods.

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Appendix I. Java Program Submissions with Metrics

ID	Group	v(G)	ev(G)	FlshRead	FlshKinGrade	SFOG
1	Maintainable	18	1	40.9	13.6	16.76
2	Maintainable	17	1	15.1	16.9	19.23
3	Maintainable	16	1	47.9	12.7	16.69
4	Maintainable	13	1	55.5	9.5	13.32
5	Maintainable	13	1	56.8	9.5	13.3
6	Maintainable	28	1	61	9.2	12.24
7	Maintainable	21	1	57.3	10.9	13.8
8	Maintainable	18	1	66	9.3	11.75
9	Maintainable	29	1	52.9	10.4	13.98
10	Maintainable	15	1	41.7	12.7	16.68
11	Maintainable	16	1	18.3	15.9	19.79
12	Unmaintainable	21	18	53.6	11.6	15.45
13	Unmaintainable	17	14	41.4	12.9	16.45
14	Unmaintainable	22	7	32.4	14.8	17.52
15	Unmaintainable	18	14	32.3	14.2	17.64
16	Unmaintainable	20	13	35.8	12.7	16.49
17	Unmaintainable	24	6	17.5	16.4	19.39
18	Unmaintainable	14	13	63.3	9.5	13.03
19	Unmaintainable	17	13	42.8	13.7	16.62
20	Unmaintainable	17	13	59.5	10.9	13.42
21	Unmaintainable	26	18	25.2	15.3	20
22	Unmaintainable	18	11	39.7	14.3	17.44
23	Unmaintainable	28	20	23.7	15.2	19.39
24	Unmaintainable	22	18	53.1	9.5	12.74
25	Unmaintainable	26	18	23.1	15.3	19.22
26	Unmaintainable	27	21	18.7	16	19.35
27	Unmaintainable	31	21	35.6	15	17.7
28	Unmaintainable	17	9	24.4	14.9	18.4
29	Unmaintainable	23	7	38.6	12.9	16.5

Appendix II. CIS360 Reflection Paper 1: IT Professionals

Name: _____

Requirements: Read articles on "Role of the Systems Analyst" and watch the IT & Strategy video posted on the Module 1 Canvas page and answer the questions below. Submit a word-processed document on Canvas by the deadline.

Evaluation Criteria: Overall quality of your writing (including using your words rather than quotes from the articles); the correctness, thoughtfulness, and clarity of your responses.

1. IT-business alignment has been one of the top three concerns of IT managers for the last ten years (or more), according to a series of studies on the "IT Issues and Trends." Watch the IT & Strategy video posted on the Module 1 Canvas page.

    a) Describe an example (from the readings, your experience, or the news) of an organization with strong IT-business alignment and an example of an organization with weak IT-business alignment and explain your rationale.[i] *(1 paragraph)*

    b) IT-business misalignment is often attributed to the "troubled relationship" between IT and the rest of the organization. What is the cause of this troubled relationship, according to the video? Reflect on your own experiences, either as part of "IT" or as part of "the rest of the business" (e.g., as an employee in your current or previous job, as a customer who has had to deal with IT professionals for tech support). Do you agree or disagree with the authors, and why? Why do you think the IT-business relationship is often problematic? *(1 paragraph)*

2. A systems analyst is an IT professional, and, as such, is often perceived as a "geek." However, I would argue that if the rest of the organization perceives the systems analyst as a one-dimensional technology expert, then the analyst should consider a different career (or should develop additional skills). After reading the description of systems analysts from the Bureau of Labor Statistics' Occupational Outlook Handbook and the IS Job Index 2019, how would you describe a systems analyst? What skills do you think an analyst needs, and why? *(1 paragraph)*

3. Think about your career goals (short- and long-term), and the knowledge/skill sets you will need to achieve those goals. What do you want to do (short-term, long-term, or both), and what kind of organization do you want to work for? Will you be on the IT side or the business side (or both)? What knowledge/skill sets will you need to be successful? What are your current strengths and weaknesses? How well prepared do you think you will be when you graduate, and if you do not think you are getting the preparation you need, what else can/will you do? Finally, are you looking forward to your post-graduation career? What about it excites or concerns you?

When One Account Exposes Millions: Design Debt, Relational Exposure, and the 23andMe Breach

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Abstract

This case examines the 2023 breach of 23andMe to illustrate how accumulated design debt in a relational genetic platform produced a condition of privacy fragility, enabling the compromise of 14,000 accounts to expose profile data from 6.9 million users. Rather than a traditional security failure, the incident reveals how architectural choices – visibility defaults, optional authentication safeguards, and weak consent mechanisms – can amplify harm across genetically linked networks. The case traces the breach's escalation, the company's delayed and defensive response, and the governance and legal challenges that culminated in 23andMe's 2025 bankruptcy and data transfer to a new corporate entity. Designed for one or two class sessions, the case offers a well-structured teaching case with conceptual scaffolding. It also offers instructors a foundation for discussing platform accountability in data-intensive systems. This case can be used in undergraduate courses in information systems, cybersecurity, or governance to anchor one or two class meetings on architectural trade-offs, privacy risk, digital platforms, and incident response.

Keywords: Privacy fragility, design debt, relational exposure, genetic data, cybersecurity breach, platform accountability

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When One Account Exposes Millions: Design Debt, Relational Exposure, and the 23andMe Breach

David J. Yates and Arthur Ream III

1. INTRODUCTION

This manuscript is structured as an analytical teaching case intended for classroom use. It integrates technical breach mechanics with organizational governance, regulatory context, and structural design considerations. Sections 2–4 support architectural analysis; Sections 5–7 support governance and policy discussion. Instructors may assign selected sections independently or teach the full case across two sessions.

Learning Objectives

After engaging with this case, students will be able to:

- Explain how architectural choices -- visibility defaults, authentication design, and consent mechanisms -- can produce conditions of privacy fragility in data-intensive platforms.
- Apply the concept of design debt to diagnose why 23andMe's post-incident remediation options were constrained.
- Distinguish relational privacy harms from individual privacy harms, and evaluate the adequacy of traditional consent frameworks in relational data systems.
- Analyze an organization's breach response against established frameworks such as NIST SP 800-61 Rev. 3 and Fair Information Practice Principles.
- Discuss the ethical, legal, and data stewardship implications of transferring biometric and genetic data during corporate bankruptcy.

Target Audience and Prerequisites

The case is suitable for upper-division undergraduate courses in information systems, cybersecurity, IT (or data) governance, or digital platforms. Familiarity with basic cybersecurity concepts and introductory data privacy law is helpful but not required; the necessary context is provided within the case.

Suggested Teaching Plan

Session 1 (Sections 2–4): Breach mechanics and architectural analysis. Open with discussion of the *DNA Relatives* feature and how network design shapes the attack surface. The discussion prompts (Section 8) help anchor this session.

Session 2 (Sections 5–7): Impact, governance, and policy. Focus on legal gaps, leadership accountability, design debt as a governance constraint, and data stewardship during bankruptcy. Discussion prompts also help anchor this session.

Suggested Student Deliverables (Optional)

- A policy memo recommending mandatory cybersecurity controls for direct-to-consumer genetic platforms.
- A redesign proposal for the DNA Relatives consent architecture that addresses second-order data subjects.
- A comparative analysis of 23andMe's breach response against a chosen incident response framework.

Instructors seeking sample discussion answers are encouraged to contact the corresponding author directly.

2. KEY CONCEPTS: RELATIONAL ARCHITECTURE, DESIGN DEBT, AND PRIVACY FRAGILITY

This paper uses three interlocking constructs -- relational architecture, design debt, and privacy fragility -- in specific ways. Because these terms are not used here in entirely standard fashion, brief definitions are provided before the case analysis.

Relational Architecture

In information systems research, *relational* most often refers to relational database management systems in which data is organized into tables linked by primary and foreign keys (Codd, 1970). That is not the meaning used here. In this paper, *relational* refers to a platform-level condition in which user accounts are structurally connected through shared data, inferred ties, or visibility mechanisms such that the exposure of one account can alter the privacy surface of others.

A relational architecture therefore creates persistent, traversable connections among users. DNA Relatives exemplified this condition. Each user who opted in became a node in a network, while the ties between nodes -- shared genetic segments, match scores, and related profile

information -- could be explored through the platform's interface. In a non-relational design, breaching Account A primarily exposes Account A's data. In a relational design, breaching Account A may also expose information about users reachable through the linkage structure. The extent of amplification depends on graph density, the granularity of visible attributes, and the presence or absence of containment mechanisms.

Design Debt

The concept of technical debt, introduced by Cunningham (1992), describes the future costs created when developers adopt expedient solutions instead of more robust ones. *Design debt* is a broader construct. It refers to the deferred costs associated with architectural, interaction-design, or policy-design decisions whose risks may remain latent until a system scales, threats evolve, or a failure occurs (Kruchten, Nord & Ozkaya, 2012; Avgeriou et al., 2016). Unlike narrow code-level debt, design debt concerns how a system is structured, how users encounter and manage risk, and how data flows are governed over time.

At 23andMe, the most consequential debt was architectural and policy-based rather than code-level. The company did not require MFA by default, allowed DNA Relatives to operate with broad visibility, and relied on consent mechanisms centered on direct participants rather than indirectly affected relatives. Each decision may have reduced friction and supported growth, but each also deferred risk. Over time, these choices increased authentication exposure, widened relational visibility, and limited the company's ability to respond effectively once the breach occurred.

Privacy Fragility

Privacy fragility describes a condition in which a limited failure produces privacy harm across a much larger population (Kotlan, Magoon & Yates, 2026). It emerges when three conditions coincide: A densely connected relational architecture, weak containment mechanisms, and a breach or misuse event. The 23andMe case illustrates this dynamic: Once accounts were linked through DNA Relatives, the compromise of a small set of credentials exposed far more than the directly accessed accounts. This concept parallels systemic fragility in other domains: Systems may appear manageable under normal conditions yet fail non-linearly once a threshold is crossed (Minsky, 1986; Woods, 2015).

Relational Privacy

Relational privacy builds on Nissenbaum's (2004) theory of contextual integrity and emphasizes that, in some environments, information about one person is also information about others. This is especially true in genetic systems, genealogical databases, and family health records. As Phillips (2016) argues, such contexts create involuntary data subjects: Individuals whose privacy may be affected not by their own choices, but by the participation of relatives. Traditional consent models, which assume that privacy decisions are individualized and self-contained, are poorly suited to these circumstances unless they are adapted to account for indirect and second-order exposure.

3. 23andMe AND THE DNA RELATIVES FEATURE

Founded in 2006, 23andMe became one of the leading direct-to-consumer (DTC) genetic testing platforms by offering ancestry and health-related insights derived from user-submitted saliva samples (Regalado, 2019). By 2022, the company had collected genetic data from more than twelve million customers and had expanded its revenue model through partnerships and data-driven drug discovery. That scale made the platform commercially significant, but it also increased the importance of security, privacy, and governance.

A defining feature of the platform was DNA Relatives, an opt-in service that enabled users to identify and connect with genetically similar individuals in the database. The feature supported genealogical discovery and user engagement, but it also created relational exposure. Because genomic data is inherently shared across biological networks, one person's participation could reveal identity cues or probabilistic traits about relatives who had never joined the platform or opted into the feature. DNA Relatives therefore did more than expose individual profile data; it transformed participation into a source of visibility for others linked through genetic similarity.

The platform's privacy posture compounded this dynamic. 23andMe's Privacy Statement permitted the collection of extensive genetic, demographic, and behavioral information and allowed the company to revise its policies over time. Although aggregate or research datasets were often described as anonymized, prior research has shown that genomic data can sometimes be re-identified when combined with auxiliary information (Bampoulidis & Lupu, 2019). These technical and policy choices meant that 23andMe was not simply storing isolated customer records.

It was building an expanding graph of linked identities, profiles, and inferences.

That architecture became especially consequential in late 2023, when attackers used credentials recycled from breaches elsewhere to access approximately 14,000 23andMe accounts. Because many of those accounts were enrolled in DNA Relatives, the attackers were able to view profile information associated with roughly 6.9 million additional users. What began as credential-based account compromise expanded through the platform's relational design. A feature intended to facilitate discovery and connection thus amplified the consequences of a relatively limited authentication failure by allowing exposure to propagate across a much larger visibility network.

23andMe initially emphasized password reuse as the primary cause of the incident, but that explanation was incomplete. By focusing on user behavior, the company downplayed the role of optional two-factor authentication, limited automated login monitoring, and visibility settings that enabled secondary exposure within DNA Relatives. Privacy scholars and cybersecurity analysts argued that the platform's relational architecture, combined with weak containment safeguards, materially magnified the scale of harm (Holthouse, Owens & Bhunia, 2025; 23andMe, 2024).

The case is therefore more than an example of credential stuffing. It demonstrates how platform design and governance choices shaped both the attack surface and the downstream consequences of failure. DNA Relatives enhanced engagement and personalized discovery, yet it also externalized privacy risk to relatives, weakened the adequacy of individualized consent, and amplified the effects of authentication compromise. In this sense, the breach was not simply the result of reused passwords. It was also the product of accumulated design debt embedded in a relational architecture that made systemic exposure possible. Once a relatively small number of accounts were compromised, privacy harm propagated across a densely connected visibility graph, affecting many individuals who had never meaningfully chosen to participate in that exposure.

4. CREDENTIAL STUFFING ATTACK AND SCOPE OF EXPOSURE

In October 2023, 23andMe confirmed that the breach began with a credential-stuffing attack that compromised approximately 14,000 accounts. Credential stuffing uses previously leaked username-password combinations to gain access to accounts on unrelated platforms, and is particularly effective when multi-factor authentication (MFA) is optional and high-volume login attempts are not monitored -- both conditions present on 23andMe's platform at the time (Holthouse, Owens & Bhunia, 2025).

The breach rapidly expanded because compromised accounts acted as gateways into millions of additional profiles through the DNA Relatives feature. Many of the 14,000 directly breached users had opted into DNA Relatives, which displays genealogical matches and profile attributes from other users; as a result, the attacker could view data linked to about 6.9 million individuals (23andMe, 2024). This expansion occurred without any deeper intrusion into 23andMe's internal systems, illustrating how the platform's relational design magnified the consequences of weak authentication.

The attacker obtained access to highly identifiable genetic and demographic information, including ancestry results, haplogroups, inferred family relationships, names, photos, geographic indicators, and user-submitted traits. Although some data elements were nominally non-identifying, prior research shows that genetic data can often be re-identified when paired with auxiliary datasets or publicly available information (Gymrek et al., 2013; Erlich & Narayanan, 2014).

The company's initial public response centered on the narrative that the incident resulted from user password reuse rather than platform shortcomings. While 23andMe noted that its systems had not been hacked, this framing overlooked structural vulnerabilities -- such as optional MFA, insufficient rate-limiting, and absent anomaly detection -- even though predictable user behaviors like password reuse are well-documented in the security-usability literature (Florêncio & Herley, 2010).

The breach took on new dimensions when the attacker began selling ethnicity-specific datasets extracted from the compromised profiles. These included data on more than one million Ashkenazi Jewish users and over 100,000 users of Chinese descent (Carballo, Schmall & Tumin, 2024). The emergence of these curated datasets raised concerns about discrimination, stigmatization, and targeted surveillance, underscoring how genetic information can be exploited for harmful population-level inference.

At a technical and governance level, the incident revealed multiple systemic failures in 23andMe's security and privacy architecture. MFA was not mandated despite the sensitivity of the underlying data; rate-limiting and automated detection mechanisms did not prevent bulk login attempts; and users were not fully informed that their DNA Relatives participation could expose others. These weaknesses reflected a broader misalignment between the permanence and relational nature of genetic data and the comparatively modest safeguards applied to it.

Regulatory and legal responses accelerated because millions of individuals who had never opted into DNA Relatives were nonetheless exposed through relatives who had participated, raising novel questions about relational consent and platform accountability (Gerke, Jacoby & Cohen, 2025). State attorneys general opened investigations and affected users brought class-action lawsuits citing deceptive practices and inadequate cybersecurity protections (23andMe, 2024; Hernandez, 2025; Kirk, 2025).

5. IMMEDIATE RESPONSE: COMMUNICATIONS, REMEDIATION, AND GOVERNANCE BREAKDOWN

23andMe's initial reaction to the breach drew criticism because the company framed the incident as a matter of user misconduct rather than platform vulnerability. In its October 6, 2023, announcement, the firm emphasized that its systems had not been "hacked" and attributed the breach to users reusing passwords from prior incidents (23andMe, 2024). This framing deflected responsibility, even though predictable password reuse is well documented in the security-usability literature (Florêncio & Herley, 2010).

Public confidence eroded further because the company relied on staggered, delayed disclosures rather than timely, comprehensive notification. 23andMe did not file a breach notice with the California Attorney General until January 2024, months after signs of suspicious activity first emerged (23andMe, 2024). Although the company cited investigative complexity, the delay raised broader concerns about its preparedness to manage sensitive, large-scale genetic data (Hernandez, 2025).

When the company did implement remediation, 23andMe required password resets without mandating multi-factor authentication, undermining the utility of its primary security response. Optional 2FA had long been a structural vulnerability, and its continued optionality after the breach ignored the uniquely sensitive, immutable nature of the affected genetic and relational data. These response limitations reflect accumulated design debt rather than isolated implementation failures.

The incident also revealed that internal and external governance mechanisms failed across multiple layers of the response. Internally, there was no evidence of a formal incident response program aligned with frameworks such as NIST SP 800-61 Rev. 3 (Nelson et al., 2025). Externally, the company delayed communication not only with regulators but also with research partners and millions of indirectly affected users. By the time formal notices were issued in January 2024, compromised datasets were already circulating on dark web markets.

In communications to users, 23andMe adopted a minimization strategy that overlooked the platform's relational exposure architecture. The company emphasized that only users who reused passwords were directly compromised and that DNA Relatives participation was voluntary (23andMe, 2023). This narrative sidestepped the fact that many individuals exposed through DNA Relatives had not opted into the feature themselves, as later alleged in multiple lawsuits (Kirk, 2025). These second-order harms challenge traditional notions of consent (Nissenbaum, 2004) and demonstrate the limitations of identity-based legal definitions of personal data (Schwartz & Solove, 2011).

Remediation was further weakened because 23andMe did not individually notify users whose information was exposed indirectly through relatives, creating a gap between the affected population and those who received assistance. Although the company offered credit monitoring to a subset of users, it did not extend support to the millions of relatives affected indirectly – a stance inconsistent with modern Fair Information Practices (Gellman, 2025) and regulatory expectations under frameworks such as the GDPR (Greenleaf, 2011; Shabani & Borry, 2018).

Public trust deteriorated even further because the company's leadership remained largely silent throughout the crisis, despite its branding as an ethics-conscious, science-forward organization (Carballo, Schmall & Tumin, 2024; Rutherford, 2025). CEO Anne Wojcicki did not make a substantive public statement until months after the breach and ultimately did not testify before Congress until June 2025.

The company's crisis management also revealed that regulatory gaps and permissive platform policies enabled weak accountability during the response. This regulatory ambiguity became more problematic as 23andMe approached bankruptcy and asset transfer, where contractual consent superseded meaningful user control (Gerke, Jacoby & Cohen, 2025).

Under growing public and legal pressure, 23andMe eventually issued an action plan promising stronger authentication, expanded auditing, and more granular consent controls, but these commitments were voluntary, limited, and widely viewed as oriented toward litigation and public-relations management rather than deeper institutional reform (23andMe, 2023).

In the months that followed, the company faced mounting litigation, multi-state investigations, and regulatory attention across the U.S., U.K., and EU, yet it remained largely shielded by its Terms of Service – highlighting how contractual consent can displace substantive privacy protections when statutory safeguards are weak.

In short, 23andMe's response was delayed, defensive, and structurally incomplete, obscuring architectural contributors to the breach and failing to meet expectations of transparency, preparedness, and ethical stewardship (Barocas & Nissenbaum, 2009). This phase of the incident illustrates how minimization rhetoric and insufficient crisis governance can amplify reputational, legal, and operational damage long after the initial compromise.

6. IMPACT ASSESSMENT: DATA BREACH SCALE, SENSITIVE DATA AT RISK, AND LEGAL/FINANCIAL FALLOUT

The breach revealed that a small number of compromised accounts created an outsized privacy disaster because platform design amplified the scale of exposure. Although the attacker directly accessed roughly 14,000 accounts through credential stuffing, the structure of DNA Relatives allowed the scraping of data from approximately 6.9 million users (23andMe, 2024; Lanzing, 2016; Holthouse, Owens & Bhunia, 2025). This was not the result of malware or database intrusion, but of architectural choices that failed to contain relational visibility, dramatically expanding the breach's long-term consequences.

The compromised dataset demonstrated that the breach exposed highly sensitive, uniquely permanent biometric and familial information. Names, ancestry results, haplogroups, inferred relationships, photographs, locations, and shared DNA segments were all accessible – attributes that cannot be revoked or changed (Erlich & Narayanan, 2014; 23andMe, 2023, 2024, n.d.). Genomic data also gains value over time because of its predictive, inferential, and relational characteristics, meaning harms can extend to relatives and descendants (Narayan, Kohli & Martin, 2025).

The incident escalated into a legal and regulatory crisis because millions of individuals who never opted into DNA Relatives were exposed through those who did, revealing deep flaws in traditional consent models. Class-action lawsuits filed in early 2024 argued deceptive practices and negligent protection of sensitive data, emphasizing the exposure of individuals who had made no affirmative disclosure decisions (Kirk, 2025). This highlighted the inadequacy of consent centered solely on individual users in contexts where data is inherently shared.

Across jurisdictions, regulators responded because the breach violated emerging expectations for safeguarding special-category data and transparency in high-risk systems. The U.K. ICO imposed a £2.31 million GDPR fine for inadequate organizational and technical protections, and investigations by U.S. and Canadian regulators soon followed. The FTC raised concerns under Section 5, particularly regarding privacy promises and the downstream transfer of genetic data during bankruptcy (Lee, 2025).

Legal remedies remained limited because U.S. privacy law does not yet recognize relational privacy or second-order data subjects, leaving large categories of affected individuals without formal recourse. A $30 million preliminary settlement in 2024 covered only directly compromised users, excluding relatives whose data became exposed through DNA Relatives (Hernandez, 2025). Privacy scholars have noted that such omissions reflect structural gaps in the U.S. regulatory landscape (Nissenbaum, 2004; Schwartz & Solove, 2011).

Financially, the breach accelerated 23andMe's decline and contributed to the company's eventual bankruptcy. Once valued at roughly $3.5B at IPO, 23andMe's stock fell below $1 by 2023 and the firm entered Chapter 11 in March 2025 (Greely, 2020; Hernandez, 2025); see Appendix B. At the time of filing, market capitalization had fallen to under $50 million -- approximately 1.4% of its IPO valuation --

reflecting the combined reputational, legal, and operational damage wrought by the breach and its aftermath. By then, the company held genetic data from over 15 million users and had accumulated over $300 million in losses.

The bankruptcy process intensified concerns because genetic data held by distressed firms can become a commercial asset with limited statutory protections. Although 23andMe's privacy statement claimed that user data would not be sold without consent, it also reserved the right to transfer information during corporate restructuring, creating a contradiction that surfaced during bankruptcy auctions (23andMe, n.d.; Bradshaw, Millard & Walden, 2011). As Gerke, Jacoby, and Cohen (2025) note, U.S. bankruptcy law offers only weak safeguards for sensitive personal data.

These tensions came to a head when Anne Wojcicki repurchased the company's assets – including its genetic database – through the TTAM Research Institute, outbidding firms such as Regeneron (Saey, 2025; Kirk, 2025). Privacy advocates questioned whether legacy user consent extended to post-bankruptcy transfers, especially given the company's history of privacy policy revisions without explicit re-consent (Gellman, 2025).

The fallout extended beyond legal and financial impacts because the breach triggered a significant erosion of public trust in direct-to-consumer genetic testing. Media reports documented rising numbers of users deleting profiles, downloading data, or abandoning the platform altogether (Saey, 2025; Rutherford, 2025). Many found that withdrawal was constrained by retention policies and longstanding research agreements.

The 23andMe journey unfolded to produce a state of privacy fragility in which the compromise of one account could expose entire familial networks (Boyd & Crawford, 2012; Phillips, 2016).

The aftermath of the 23andMe breach has already prompted calls for:

- stronger breach notification rules that include indirect victims;
- clearer restrictions on genetic data transfers during bankruptcy; and
- greater platform accountability for relational exposure risks.

7. POST-INCIDENT GOVERNANCE: ACCOUNTABILITY, ACQUISITION, AND DATA STEWARDSHIP

The post-incident phase made clear that 23andMe's governance breakdown was not simply a matter of weak crisis communication or isolated managerial error. It reflected constraints created by years of design choices that prioritized growth, visibility, and engagement over containment, user control, and accountability. By the time the company was responding to the breach, its relational architecture linked profiles through DNA Relatives, relied on weak consent structures, and offered limited mechanisms for retroactive protection. As litigation mounted and bankruptcy approached, these constraints interacted with leadership silence and regulatory gaps, turning a security incident into a broader failure of stewardship.

Throughout 2024, 23andMe's board and senior leadership did not provide a full public accounting of the breach or the factors that amplified it. CEO Anne Wojcicki made only limited public comments, and no senior executive testified before Congress or major regulators about incident handling until June 2025 (Rutherford, 2025). The company also did not publish a detailed independent breach report or commission a third-party audit. This lack of transparency drew criticism from privacy advocates and investors, who argued that the company treated genetic data governance as a matter of proprietary control rather than public trust. In a platform built on sensitive and enduring user data, the absence of visible internal reform weakened confidence that the company understood the harm or its stewardship obligations.

Weak accountability was reinforced by the legal environment in which 23andMe operated. Consumer genetic data in the United States remained subject to a patchwork of protections, and the company's Terms of Service explicitly permitted transfers of user data during mergers, acquisitions, or bankruptcy. That clause became central once 23andMe entered financial distress and its assets, including its genomic database, were put up for sale. In June 2025, TTAM Research Institute, a new entity created by Wojcicki, won the auction for 23andMe's assets in a $305 million deal, outbidding firms including Regeneron Pharmaceuticals (Saey, 2025; Kirk, 2025; Herper, 2025). Although the transaction promised continuity for users and research partnerships, it also raised difficult questions about whether earlier consent agreements, often

accepted under prior privacy policies and narrower expectations, could authorize the transfer of sensitive biometric and relational data to a new entity.

Those concerns were intensified by the lack of any broad-based re-consent process before or after the sale. Privacy scholars have long argued that consent in high-risk data environments cannot be treated as a one-time contractual event divorced from context, organizational change, and downstream use. Yet 23andMe's governance posture largely assumed that legacy terms were sufficient. The result was a weak form of accountability in which continuity promises substituted for renewed user authorization, even though the company's ownership structure, financial condition, and trust posture had changed dramatically.

The breach also demonstrated how accumulated design debt narrowed the range of post-incident responses. DNA Relatives created value for users, but it did so by making relational linkages broadly visible and by offering limited safeguards against secondary exposure. Broad profile sharing, insufficiently granular privacy controls, and the lack of conservative default settings made it difficult to stop cascading exposure or restore privacy expectations after the breach. Even after the incident, 23andMe did not introduce mechanisms that would allow users to control how their information appeared in others' match results or to retract already shared relational data. Instead, optional and relatively hidden settings continued to reflect a design philosophy that externalized familial risk. Once millions of users had been connected through the platform's visibility structure, those relationships could not be easily unwound.

The bankruptcy and transfer to TTAM therefore raised a question: Who should be trusted to steward one of the world's largest consumer genetic databases after a governance failure? Although 23andMe's privacy policy stated that personal information would not be sold without consent, it also treated data as transferable during restructuring, effectively allowing sensitive genetic information to move as part of an asset sale. With TTAM, led by the company's former CEO, assuming custodianship, users were left to rely largely on assurances of continuity rather than enforceable, updated permissions. Because 23andMe had revised its privacy policies multiple times without requiring explicit re-consent from legacy users, many individuals now face the prospect that their genetic information is governed by terms they may never have reviewed or accepted.

Taken together, these post-incident dynamics show that the 23andMe breach evolved into more than a case of poor cybersecurity. It became a test of whether institutions that collect persistent, relational, and sensitive data can remain accountable when technical failure, legal ambiguity, and organizational distress occur at the same time. Years of accumulated design debt left 23andMe with little room to maneuver after the breach, while contractual consent and bankruptcy law allowed its data assets to remain transferable despite questions about legitimacy, user expectation, and long-term stewardship. The case therefore illustrates how leadership silence, technical lock-in, and weak legal safeguards can converge to limit meaningful accountability after a major platform failure.

8. DISCUSSION, LIMITATIONS, AND CONCLUDING REMARKS

Discussion

The 23andMe breach shows that failures in data-intensive platforms are often structural as well as technical. Reused passwords opened the door, but the scale of harm was shaped by platform design: DNA Relatives converted individual accounts into points of access for genetically linked others, while weak authentication, limited containment, and permissive data-governance terms magnified downstream exposure. The result was not simply a breach of 14,000 accounts, but a broader failure of stewardship over persistent, biometric, and relational data.

The case reinforces three broader implications. First, platforms handling relational data cannot rely on user choice alone, because one person's participation may expose others who never meaningfully consented. Second, privacy harms in these environments are networked rather than isolated: A small failure can cascade across many profiles when visibility and linkage are built into the system. Third, design debt matters because architectural and policy choices made for growth, usability, or engagement can later limit response options when a crisis occurs. In 23andMe's case, the company could not easily unwind relational visibility, restore prior privacy expectations, or separate routine product functionality from systemic exposure once the breach occurred.

Several governance lessons follow. Accountability cannot be outsourced to users. Blaming password reuse overlooks predictable behaviors and understates the platform's responsibility to require stronger authentication, detect

anomalous access, and constrain unnecessary visibility (Florêncio & Herley, 2010; Holthouse, Owens & Bhunia, 2025). Relational data also requires relational governance. Where system outputs affect people beyond the direct user, governance must account for second-order data subjects, indirect exposure pathways, and collective harm (Narayan, Kohli & Martin, 2025). In addition, contractual permission is not the same as ethical legitimacy. Terms allowing transfer during merger or bankruptcy may satisfy formal notice requirements while still violating user expectations for sensitive genetic and biometric data (Bradshaw, Millard & Walden, 2011). Finally, leadership transparency remains central to trust. Delayed acknowledgment, defensive framing, and limited executive visibility can deepen institutional damage long after the initial compromise (Rutherford, 2025).

Suggested Discussion Prompts

These prompts are designed for use in undergraduate information systems, cybersecurity, IS security, and IT (or data) governance courses.

- How could 23andMe have redesigned DNA Relatives to reduce relational exposure without sacrificing functionality?
- What mandatory cybersecurity controls make sense for biometric/relational data (e.g., MFA-by-default, rate-limiting, anomaly detection); how would you evaluate their effectiveness?
- How does design debt shape the feasibility of post-incident reforms?
- Under what conditions should platforms be permitted to transfer biometric data during bankruptcy, and what constraints should apply?

These lessons should be understood alongside the incentives 23andMe faced. Features such as DNA Relatives supported engagement, differentiation, and network effects in a competitive market, while stricter authentication and narrower visibility likely would have introduced friction. Those trade-offs help explain the platform's trajectory, but they do not diminish responsibility for failing to anticipate how relational exposure, once embedded, could scale harm so rapidly.

Limitations

This analysis has several limitations. First, individuals exposed indirectly through genetic linkages received limited recognition in litigation and regulation, leaving an incomplete empirical record of second-order harm (Calo, 2011; Schwartz & Solove, 2011; Carballo, Schmall & Tumin, 2024). Second, although 23andMe announced new security and consent measures, those changes do not appear to provide retroactive visibility controls or meaningful ways to reclaim already-shared data (23andMe, 2023). Third, TTAM Research Institute has signaled a public-interest orientation, but its long-term governance model remains uncertain, and no broad re-consent process has been launched (Herper, 2025). Future research should examine whether these commitments produce enforceable protections in practice.

Concluding Remarks

The 23andMe breach illustrates how design debt in relational systems can harden into privacy fragility. Once broad visibility, weak consent structures, and permissive transfer terms become embedded in a platform, a relatively small compromise can expose far larger populations, while remediation choices narrow sharply (Erlich & Narayanan, 2014; Hernandez, 2025; Kotlan, Magoon & Yates, 2026). For that reason, this breach should be understood not as an anomaly, but as an early warning about the behavior of biometric and inferential data systems under stress.

For scholars, practitioners, and students, the central lesson is that protecting relational and biometric data requires more than better passwords, stronger MFA, or improved incident response. It also requires governance models that treat consent as ongoing and contextual, recognize second-order data subjects, and impose substantive limits on data reuse and transfer, especially during restructuring and bankruptcy. As more platforms collect genetic, biometric, and behavioral traces, the 23andMe case offers a clear warning: Systems built for connection and growth can also concentrate long-term, distributed harms when their governance fails.

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APPENDIX A

Sample Output of DNA Relatives Tool

Below are two important paragraphs about the DNA Relatives tool. These were taken directly (verbatim) from the 23andMe website in June 2025:

> "The *DNA Relatives* feature is an interactive 23andMe feature, allowing you to find and connect with your genetic relatives and learn more about your family story. Genetic relatives (also known as DNA Relatives matches) are identified by comparing your DNA with the DNA of other 23andMe customers who are participating in the DNA Relatives feature. When two people are found to have an identical DNA segment, they very likely share a recent common ancestor. The DNA Relatives feature uses the length and number of these identical segments to predict the relationship between genetic relatives.
>
> …
>
> To see your shared relatives, click on a match in your DNA Relatives list and scroll down to the *Relatives in Common* section. In this section, you can see the list of relatives that you have in common, the predicted relationship between each pair, and in some cases, if you share DNA in the same region of your genome. Keep in mind that only matches with whom you have a sharing connection or those showing ancestry results will display whether or not you share DNA in the same region of your genome."

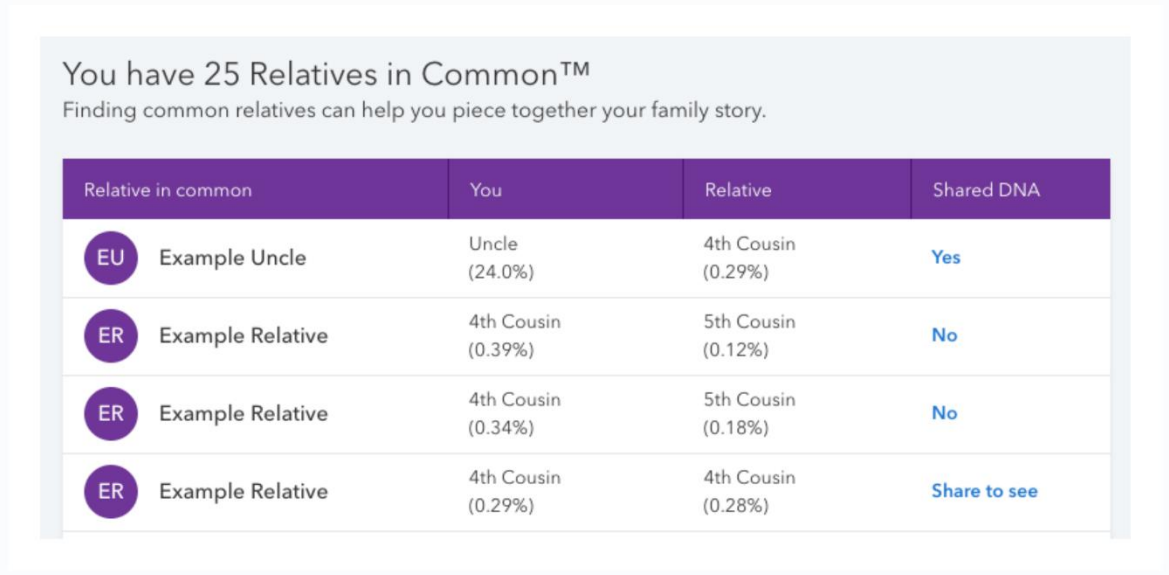


Figure 1: Sample Output from DNA Relatives Tool (Source: https://customercare.23andme.com/hc/en-us/articles/221689668-DNA-Relatives-In-Common-Report-Feature)

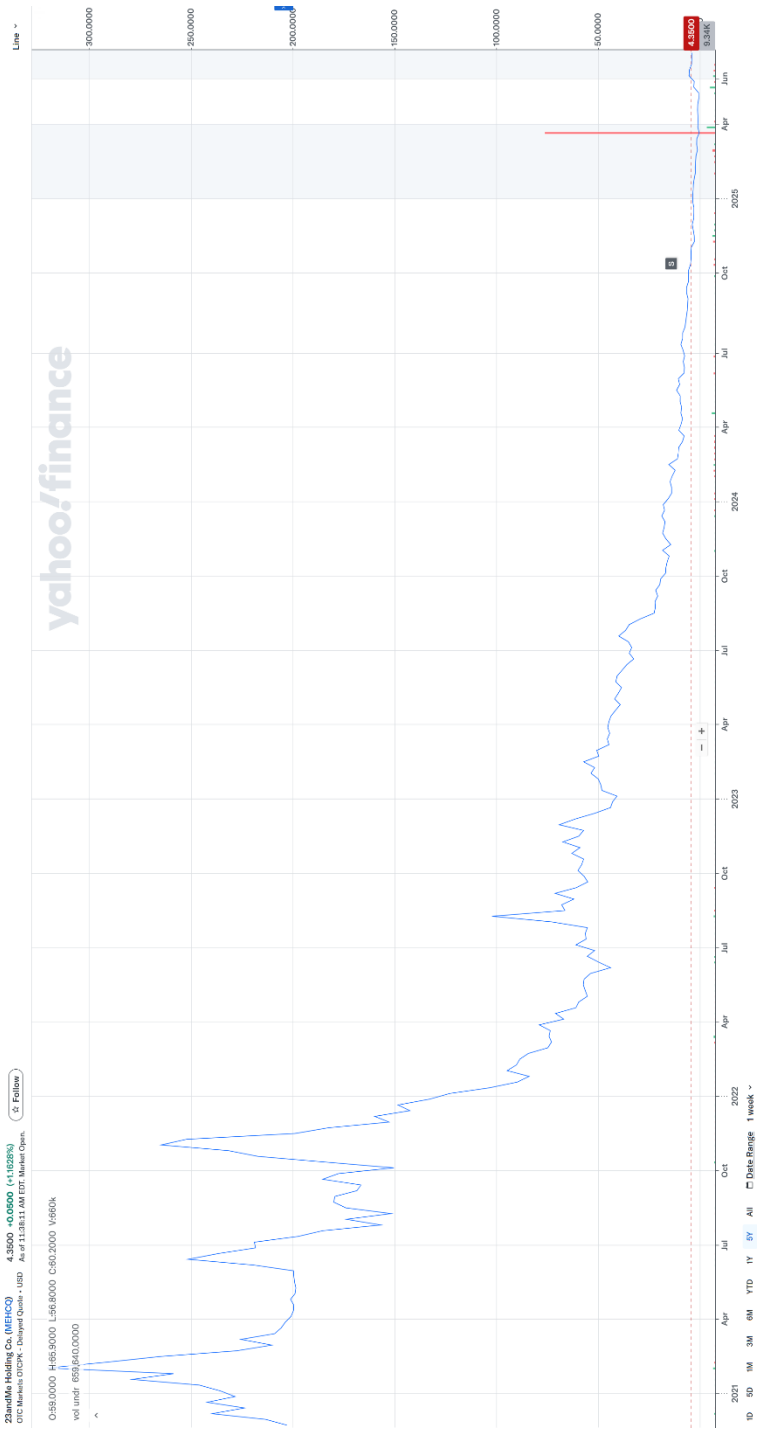
As of September 2025, this tool includes the following disclosure:

> "We have temporarily disabled some features within the DNA Relatives tool as an additional precaution to protect your privacy. Read more here."

APPENDIX B

Timeline of 23andMe Milestones

23andMe Share Price Versus Time



23andMe Timeline (2006 – September 2025)

- **2006 –** 23andMe is founded by Anne Wojcicki, Linda Avey, and Paul Cusenza with the aim of democratizing access to genetic testing for health and ancestry (McGuire, Caulfield & Cho, 2008).
- **2008 –** The company gains major public attention; its testing kit is named Time magazine's *Invention of the Year* (Hamilton, 2008).
- **2013 –** The U.S. FDA orders 23andMe to halt health-related genetic reporting, citing concerns over unvalidated medical risk interpretations (Holpuch, 2013). The company temporarily suspends parts of its product.
- **2015–2018 –** 23andMe relaunches health reports and enters into a $300 million partnership with GlaxoSmithKline (GSK) to leverage aggregated genetic data for drug discovery (23andMe, 2018). By February 2018, there are ~3 million customers.
- **2018 –** 23andMe solidifies its position as a leader in the direct-to-consumer genetics market (Regalado, 2019).
- **June 2021 –** The company goes public via SPAC at ~$3.5B valuation; ~12M customers at close (23andMe, 2021).
- **2022 –** 23andMe faces increased scrutiny over privacy practices and monetization strategies. Growth slows even though the company surpasses 12 million genotyped customers (23andMe, 2022).
- **May 2023 –** The company reported >14 million genotyped customers (Holthouse, Owens & Bhunia, 2025); lawmakers later referred to more than 15 million during 2025 oversight and bankruptcy proceedings. https://oversight.house.gov/release/wrap-up-congress-taking-action-to-ensure-the-safety-of-americans-personal-dna-data/
- **October 2023 –** 23andMe suffers a credential-stuffing attack affecting ~14,000 accounts and indirectly exposing profile data from 6.9 million users through the DNA Relatives feature. The company does not issue full disclosures until months later (23andMe, 2024; Hernandez, 2025).
- **January 2024 –** California AG breach notice filed (23andMe, 2024). Reported ~14,000 accounts accessed via credential-stuffing; noted forced password resets and MFA expansion.
- **Late 2024 –** Trust in the platform declines, and user engagement drops. Still, estimates suggest ~15 million cumulative users remain in the database (Hernandez, 2025).
- **October 2024 –** 23andMe executed a 1-for-20 reverse stock split to raise its share price above the NASDAQ minimum listing requirement after its stock had fallen below $1 for an extended period. https://www.nasdaqtrader.com/TraderNews.aspx?id=ECA2024-495
- **March 2025 –** The company files for Chapter 11 bankruptcy, citing falling revenue, reputational damage, and unresolved legal claims. CEO Anne Wojcicki steps down from leadership (Hernandez, 2025; Herper, 2025).
- **June 2025 –** 23andMe had accumulated class-action lawsuits and faced regulatory action in the U.S., U.K., and Canada. The UK ICO fined the company £2.31 million following a joint investigation with Canada's OPC (Kawaguchi & Lee, 2025; Kirk, 2025).
- **July 2025 –** Wojcicki's new non-profit venture, TTAM Research Institute, successfully purchases 23andMe's assets – including its genetic data – for $305 million in a bankruptcy auction, outbidding firms like Regeneron. This sale raises unprecedented concerns over data transfer ethics, user consent, and platform accountability in the DTC-GT industry (Herper, 2025; Kawaguchi & Lee, 2025).
- **September 2025 –** 23andMe seeks approval for a $50 million class-action settlement; this reflects an increase from the $30 million preliminarily approved in December 2024. https://www.reuters.com/legal/government/23andme-seeks-approval-larger-50-million-data-breach-settlement-2025-09-05/

APPENDIX C

Technical Vulnerabilities and Security Failures that Contributed to the 23andMe Breach

Category	Failure or Weakness	Implication
Authentication	No mandatory multi-factor authentication (MFA)	Allowed attackers to access accounts using stolen passwords alone
Access Control	Inadequate rate limiting and anomaly detection on DNA Relatives queries	Enabled lateral exposure of millions of profiles from a small number of compromised accounts
Credential Management	Susceptible to credential stuffing due to weak password reuse protection	Exploited passwords reused across platforms; lacked protections against bulk login attempts
Logging and Monitoring	Insufficient real-time monitoring of unusual query behavior	Delayed detection and containment of attacker activity
Data Minimization	Broad data exposure via the DNA Relatives feature	Enabled visibility of names, ancestry, and relationships beyond the originally compromised account
Incident Response	Absence of a formal incident response plan aligned with NIST SP 800-61 Rev. 3	Delayed disclosure and inconsistent regulatory communication
User Consent Architecture	No granular or retroactive consent options for shared data	Users had no ability to limit relational data exposure post-breach
Third-Party / Data Governance	Lack of vendor risk assessment and unclear data-sharing boundaries during research partnerships	Elevated risk of secondary exposure and uncertainty during bankruptcy or data transfer

Implementing Personalized Learning Pathways as Informed by the 5E Model: Digital Tools to the Rescue!

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Abstract

The growing diversity of students entering higher education presents challenges for instructors seeking to meet varied individual learning needs. A promising approach to addressing this issue is the implementation of personalized learning paths that are tailored to students' specific needs, learning styles, and levels of self-regulated learning. This study examined how using optional digital learning support tools (H5P technology in conjunction with Discussion forums) for building personalized learning paths affects the learning experience of postgraduate students in a Database Systems subject. Using LMS and Ed Discussion analytics from 543 postgraduate students across two cohorts studying Database systems in in 2025, this study found that completing more optional H5P activities was associated with higher final grades, with a stronger H5P-grade association in Semester 2 than Semester 1. Discussion board engagement, including active posting and passive viewing each independently predicted final grades alongside H5P engagement, with passive viewing showing a stronger standardized association with final grades than active posting. Follow-up analyses suggested these supports were additive, such that H5P engagement was unrelated to active discussion posting but positively related to passive discussion viewing, and these H5P-discussion forum associations did not vary by cohort. Overall, the findings indicate that H5P completion and discussion forum engagement are distinct, additive forms of learning engagement associated with higher academic performance, and that the strength of the H5P-performance association varies across cohorts. These findings imply that multiple optional digital tools, including scaffolded H5P activities and discussion forums can provide personalized learning pathways for students with diverse learning needs, and that the benefits of H5P engagement may depend on cohort context.

Keywords: H5P, Discussion forum, personalized learning pathways, scaffolding, self-regulated learning, Database Systems, Higher Education

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Implementing Personalized Learning Pathways as Informed by the 5E Model: Digital Tools to the Rescue!

Celeste Tipple and Tanya Linden

1. INTRODUCTION

The contemporary higher education landscape is marked by increasing diversity in students' academic preparedness, cultural backgrounds, digital literacy, and study skills. The growing diversity among students calls for integration of technology into pedagogical strategies that foster flexible, inclusive and engaging learning environments, ensuring equitable access to learning opportunities (Mendoza & Venables, 2023).

Many institutions have shifted towards student-centered learning approaches which emphasize learner autonomy, personalized engagement, and differentiated support (O'Neill & McMahon, 2005). Within this context, blended learning has significant potential to support students with diverse learning needs and preferences (e.g., flexibility, pacing, access to resources), and can be especially nourishing for self-regulated learners (Zhao et al., 2025). Self-regulated learners understand their learning needs, seek help sources to meet these needs, and overcome obstacles that impede their learning (Zimmerman, 1990). Self-regulated learning skills are crucial in both online and blended learning environments because students are expected to manage their time and task completion by themselves through self-discipline, motivation, and responsible behavior (Pintrich, 2000).

Instructors can provide support to self-regulated learners and foster their self-regulation skills by guiding them through the process of developing autonomy, learning strategies, and self-reflection skills (Nicol & Macfarlane-Dick, 2006; Vovides et al., 2007). One of the successful pedagogical approaches in supporting and strengthening self-regulated learning skills is the 5E model (Bybee et al., 2006). The model is built on constructivist learning theory, which posits that students construct knowledge from their own experiences making them active participants in discovering information and developing understanding. The model encourages students to ask questions, form hypotheses, and investigate problems.

Digital technology provides a range of tools which educators can utilize to implement the stages of the 5E model while providing personalized learning paths based on learners' individual needs (Warren et al., 2014). One of such tools is H5P (https://h5p.org/), short for "HTML5 Package", - a free, open-source tool that offers a range of activity types and can be integrated into learning management systems (LMS). H5P offers a range of digital activity types which can be adopted to build a learning path by offering a series of tasks with gradually increased difficulty while reducing provided support for building a solution. Students can follow the offered learning path, or if they find it too slow for their abilities, they can skip easier tasks and attempt more challenging ones. To keep learning effective, the important part of the process is for the educator to ensure that they provide formative feedback on every attempt. This can be implemented using asynchronous online Discussion forums which are available via LMS or through complementary technologies (e.g. Ed Discussions or Forum Channels in Discord).

Although H5P holds promise for enabling personalized learning paths that are tailored to individual student needs (Jacob & Centofanti, 2024), there has been a limited number of studies examining the effectiveness of H5P in higher education. A recent systematic literature review identified only 30 studies focusing on H5P in higher education, highlighting both the potential of H5P and the current gap in the literature (Ping, 2025). Among the studies that have examined whether H5P can improve student learning in grades, while some have reported positive effect (Clune et al., 2022; Sharmin et al., 2025), the findings are not consistent. For instance, Jacob and Centofanti (2024) and Unsworth and Posner (2022) found no significant difference in student performance outcomes when implementing H5P activities. Notably, despite the lack of measurable improvement in academic performance, students in Jacob and Centofanti's (2024) study reported positive experiences and high levels of engagement when using H5P activities, indicating that H5P has positive benefits for students' learning experiences. However, these limited and mixed findings in the literature point to the need for further research to clarify whether H5P contributes to measurable improvements in

student performance and learning outcomes in higher education contexts.

To address this research gap, this study explores how students engage with H5P-based personalized learning activities supported by help-seeking via discussion forums, and how these engagement patterns relate to academic performance. Drawing on the 5E model of learning as a primary framework, optional H5P activities provide weekly practice opportunities with increasing difficulty across key concepts in the subject, supporting students' learning through repeated application and feedback. In parallel, the asynchronous online discussion forum provided an additional means for students to seek clarification, feedback, and peer/instructor interaction, as students work through concepts and tasks. Since these digital learning tools support learning in different ways, engagement may not be uniform across learning processes: some students may preferentially invest in structured practice (H5P), whereas others may rely more heavily on forum-based support and explanation. Importantly, we recognize that discussion forum engagement is not a single behavior: students can engage passively by viewing and reading existing threads (exposure to explanations and solutions), or actively by posting questions, comments, and answers (articulating reasoning and help-seeking). Both active and passive engagement with online discussion posts are useful for learning (Smith & Smith, 2014; Wilton, 2018) despite the widely accepted, evidence-based postulate that active learning is more productive. Accordingly, this study differentiates discussion engagement into passive and active indicators to better capture how students access learning support outside of class and to examine whether these distinct forms of engagement show different relationships with H5P completion and final grades.

Using learning management system (LMS) analytics (H5P completion), discussion forum analytics (active posting and passive viewing), and final subject grades, the study examines whether H5P engagement predicts academic performance, and whether this association differs by semester cohort. The study also evaluates whether discussion forum engagement explains additional variance in grades beyond H5P engagement, and whether patterns of engagement across H5P and forums suggest co-occurring engagement versus selective engagement in one tool over the other.

2. LEARNING-CENTERED PEDAGOGY

Multiple theories and models on how students learn and how to best support their learning have been proposed and tested over decades. Modern theories advocate student-centered learning where the focus is shifted from teaching activities to learning processes that engage students in active problem-solving where individual needs, interests, and abilities guide the learning process (Cross, 2005). Many educational and learning theories are built on constructivism as a foundation which promotes active building of new knowledge based on the foundations of prior knowledge through meaningful participation in interactive processes (Elliott et al., 2000; Ertmer & Newby, 2013). One model strongly grounded in constructivist learning theory is the 5E model proposed by Bybee et al. (2006). Although the 5E model was originally developed for planning biology teaching including development of materials and teaching texts, it has since been widely adopted in other STEM subject areas, e.g. physics (Ergin, 2012), mathematics (Magsalay et al., 2019), and biology (Tanner, 2010), with a recent meta-analysis documenting positive effects on learning in STEM (Polanin et al., 2024).

The stages of the 5E model - Engage, Explore, Explain, Elaborate, Evaluate - support learning through the implementation of a structured, inquiry-based learning cycle through active engagement. The goal of the *Engage* stage is to ignite interest and connect to students' prior knowledge. This stage is critical because it inspires students to study the topic and provides instructors with insight into students' prior knowledge of the phenomenon, enabling instructors to design explanations of the concepts that align with students' learning needs. In the *Explore* stage, students investigate the topic through hands-on activities that help to identify misconceptions about the topic and develop their initial ideas while building on their prior knowledge. The *Explain* stage aims at deepening students' engagement with concepts. During this phase, the instructor introduces formal vocabulary, clarifies misunderstandings, and introduces key concepts while facilitating students' active participation and articulation of their understanding through solving problems of adequate difficulty. The *Elaborate* stage involves active problem-solving, where students apply their new understanding to new contexts while seeking clarifications on the "muddy" points of the topic. This is a stage where students, as self-regulated learners, reflect on their understanding and decide how much practice and what type of practice they need (e.g. whether they need to

repeat easier exercises again or to move to more complex ones). Finally, the *Evaluate* stage is when students' understanding and ability to solve problems is assessed. The Evaluate stage includes both formal assessment by instructors and student self-assessment, with self-regulated learners using feedback to decide whether to revisit easier tasks to consolidate concepts or to move to more challenging tasks. The key advantage of the 5E model is its scalability: the 5E model can be implemented within a single lesson, or span multiple lessons (e.g., when more complex topics require gradual scaffolding).

3. METHODS

Applying the 5E model in the educational context of Database Systems

We implemented phases of the 5E learning cycle using H5P interactive activities combined with the discussion forum in teaching a Database Systems subject in the Master degree of a university in Australia. Students enrolling in this subject come from a range of backgrounds, i.e. some of them completed IT-related Bachelor degrees whereas others come from non-IT backgrounds. Therefore it is necessary to provide individualized learning pathways that address variations in students' background knowledge.

Altogether 10 weeks of the 12-week semester offered at least two H5P activities incorporated in the learning materials supporting phases of the 5E cycles. Since the main goal of the H5P tasks was learning support, they were not part of the formal assessment and it was the students decision whether to attempt all, some or none of the tasks. These tasks were offered as supplementary optional tasks for students who needed or wanted to practice skills development. Within this context, students with self-regulated learning skills could identify their needs in additional practice themselves, whereas other students needed instructor recommendation to attempt additional tasks after classes to improve their knowledge and skills.

To support students outside of class time, they were encouraged to seek clarification of concepts and feedback on their solutions (especially if different from sample solutions) by posting on the subject Discussion forum (Ed Discussion https://edstem.org/).

In applying the 5E model within our subject Database systems (Figure 1), the first stage - *Engage* - takes the form of a face-to-face (in the lecture and tutorials) discussion of people's everyday activities, data they generate and data from database systems that everyday activities depend on. Through these discussions, students discover why IT professionals need sound understanding of database systems while teaching staff get insights into students' familiarity with database foundations and identify students from non-IT backgrounds who may need additional support and longer time to grasp the foundational concepts.

In the *Explore* phase, students are given simple hands-on activities. In addition to lecture explanation and tutorial exercises, a series of tasks was implemented as H5P activities which were based on a certain topic that needed to be mastered over 2-3 weeks. Students who wanted additional practice could complete these optional activities in their own time and seek feedback via Discussion forum or in in-person consultations as needed. Initial problem-solving tasks were illustrated through the H5P activity type "agamotto", a slide show that can be used to explain the step-by-step solution development from one slide to the next. Before presenting the slides, a simple case study was published on the LMS page (Figure 2). Then an explanation of how to create a data model was designed as "agamotto" slides with each slide showing a statement from the case study and how it should be modeled. Although this task is a one-way flow of instruction where students are passive learners, it is necessary to provide examples on how to split a case study into bits that can be easily modeled, as well as demonstrate the modeling notation.

The next step in the *Explore* phase would be another simple case study, but this time instead of the solution demonstration, an indirect approach was used. Students were given a H5P activity containing multiple-choice questions (MCQ) to help them make initial decisions on starting the solution (Figure 3). The important aspect of these activities is for the educator to embed feedback into every option of each MCQ. This formative feedback ensures that students learn from selecting incorrect answers as it is often important to understand why a particular decision may be problematic (especially in the long run) during database modeling. This use of simple tasks on concepts application aligned with the core purpose of the *Explore* stage - to facilitate understanding of foundational concepts through hands-on activities.

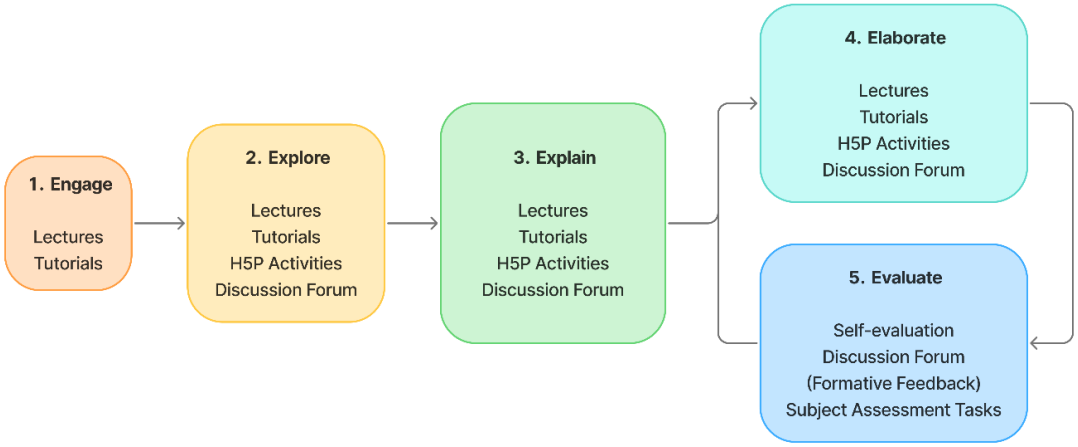

Figure 1: Implementation of the 5E model in Database Systems

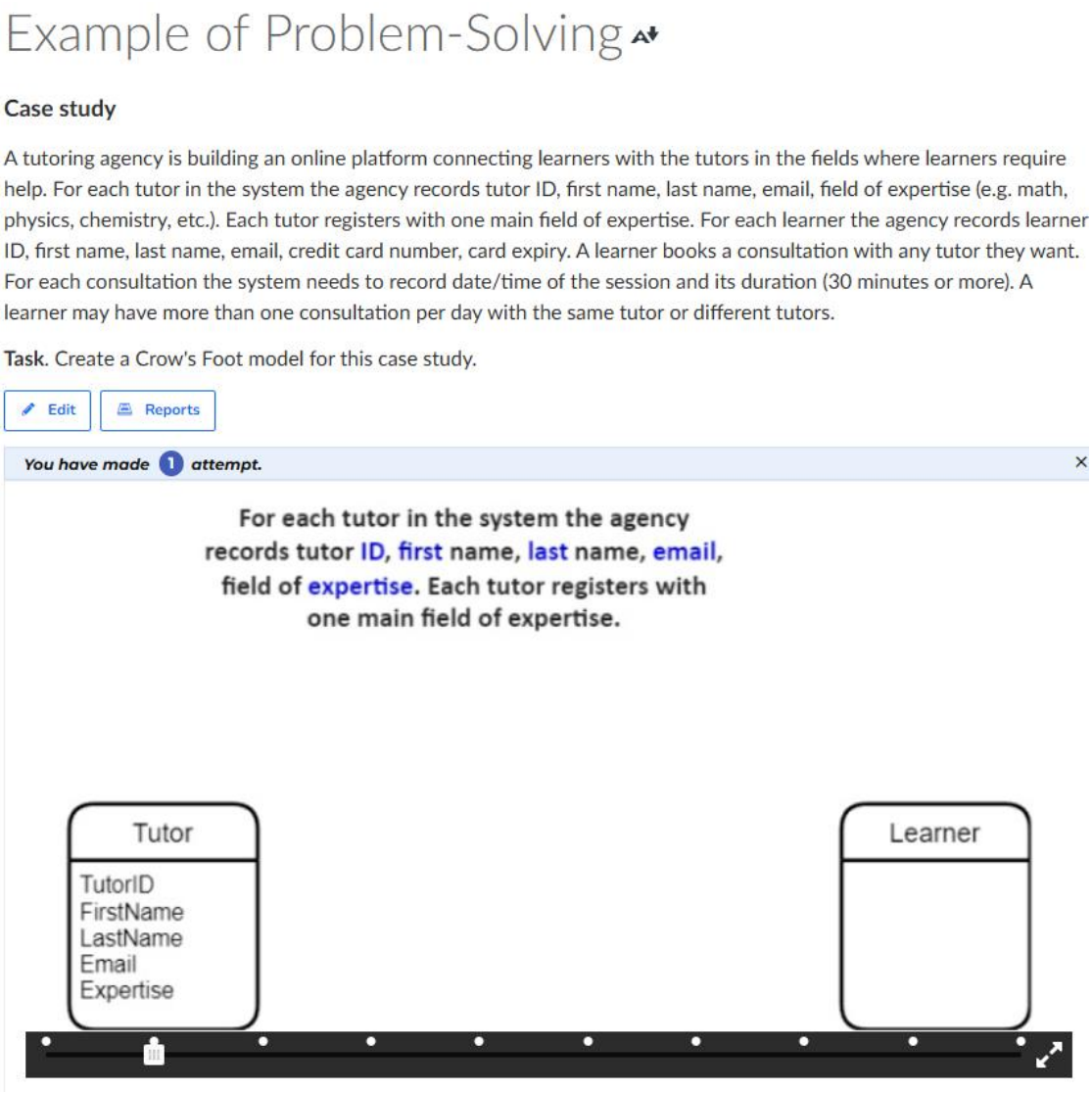

Figure 2: Step-by-step solution development using 11 slides. Currently selected is slide 2 corresponding to step 2 in the solution development

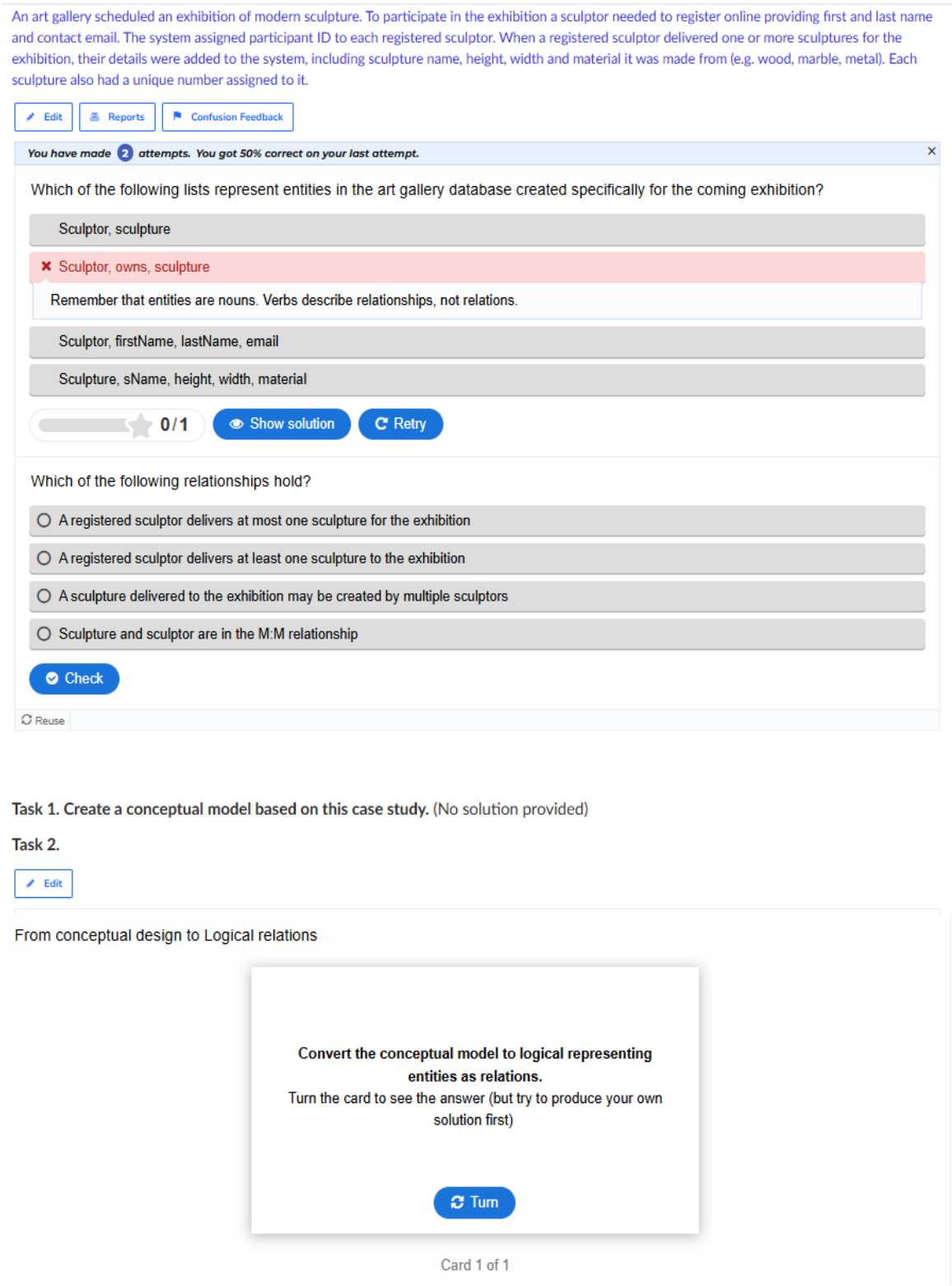

Figure 3: Practice task in week 2. The page shows a case study and questions based on that case study. Incorrect answer in MCQ1 results in feedback.

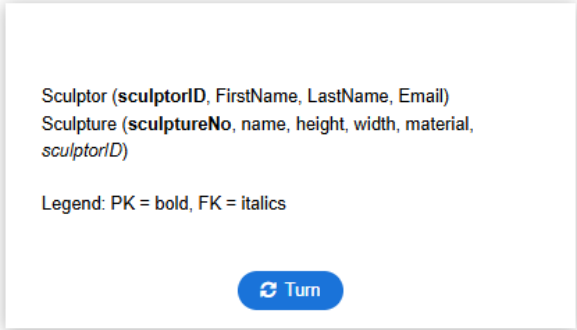

Figure 4: The other side of the dialogue card with the answer (for illustration of how the activity works)

Since in the Explore stage foundational concepts are explored by students, regular support in building correct understanding is crucial. To facilitate this process, students were encouraged to seek clarifications via the discussion forum. In our experience with database design topics students often experience difficulty in modeling weak entities, identifying cardinality (optional or mandatory participation of entities) and placing foreign keys. So after watching the "agamotto" slides, students may need additional explanation of reasoning behind modeling relationships between entities, i.e. how to interpret the case study statements and why a particular requirement in the case study is modeled in a certain way. Teaching staff answer students' questions on Ed Discussion which provides personalized help "on demand", without the need to wait for a class session or for a formal consultation time.

Then the instruction continued into the *Explain* stage, where open-ended questions on creating a logical relations model were first discussed in class sessions and also offered as additional H5P activities in the form of a turn-around dialogue card (Figure 4). The other side of the card contained a solution to the task so that students could compare their model with the expected solution. In this stage, students articulate their understanding of concepts at a more difficult level. Again, if a student's solution is different from the sample solution on the back of the Dialogue card, it is beneficial for the student to seek feedback on their solution, i.e. whether it is a good alternative solution or whether they made mistakes. Such Discussion threads became valuable for the student who made the initial post, as they sometimes turn into a several-step conversation, but also for other students who may improve their problem-solving by reading other students' posts, questions and comments.

Next, the *Elaborate* stage, aims to deepen learning by applying concepts to new situations. In this stage for the Database Design topic, we developed several open-ended modeling questions which were presented to students as H5P dialogue cards with a question on one side and the solution on the other side. This design gives students an opportunity to check their answer against the correct solution immediately. As continuous support to the learning process, students were encouraged to post questions on the Discussion forum to seek further clarification. Since at this stage the tasks become more challenging, some students can benefit from in person consultations.

Students' self-regulation within this subject manifested itself in their decision-making regarding their learning, as they tailored their engagement in H5P activities and discussion forums based on their learning needs. Students could choose either to complete all scaffolding exercises, or to skip tasks with detailed steps and move to more challenging ones which provide little to no guidance. Also, self-regulation was evident through students' decision-making on how to seek help, whether to post on Discussion forum, read existing posts, or seek in-person consultation.

Finally, the *Evaluate* stage was implemented through ongoing informal assessment where students judged their skills and decided on whether they were ready to progress to the next topic, alongside formal assessment in the form of assignments and tests. This is where *Evaluate*/*Elaborate* stages may overlap and create an internal cycle between the two stages, as students use feedback and self-assessment to decide whether to revisit earlier tasks, or attempt more challenging tasks. Help-seeking behavior also emerged from students' evaluation of their own learning progress in deciding between in-person consultation and posting questions on Ed Discussion.

The subject has formal assessment tasks that contribute to the final grade, however, since there are no resubmission options, it is hard to judge whether students acted on feedback from assignments and tests, except the cases where self-regulated learners attempted the assessments informally and sought feedback by posting on Ed Discussion.

Data Collection

The data was collected using learning management system (LMS) analytics and Discussion forum Ed analytics. LMS analytics has

been used effectively by educators to evaluate students' engagement which in turn could guide educators on which aspects of student learning need attention (Wang, 2017). We used LMS reports on students' access to pages containing H5P activities along with Ed Discussion analytics which capture students' discussion activity (posts, comments and views).

The sample in this study was comprised of postgraduate students with the majority of whom are international, i.e. English is their second language. In a sample like this, many students might find it challenging to understand in-class instruction. Although the subject has no pre-requisites, students come from different backgrounds, i.e. some of them have never studied any IT subjects, whereas others have significant exposure to IT knowledge through previous studies or work. Importantly, at postgraduate level, students are usually motivated and committed to their studies (Bergann et al., 2025). This study used the cohorts from two teaching semesters in the 2025 academic year, with a total of 543 students used in the analysis. Ethics approval was obtained before downloading LMS analytics reports (HREC approval 2025-33684-69852-2).

Study Design

This study employed an observational, correlational quantitative methodology to explore whether students' engagement in H5P activities can impact student performance in a Database Systems subject, and if this association differed by cohort across the 2025 academic year (consisting of two semesters). Primary analyses were conducted using moderated linear regression which tests whether an interaction exists between H5P engagement and Cohort (engagement × cohort) in predicting final grades. To further contextualize these associations, additional statistical models examined whether discussion forum engagement (active participation [ActiveDB] and passive viewing [PassiveDB]) explained unique variance in grades beyond H5P engagement, and whether H5P engagement was associated with discussion engagement across cohorts. All analyses were conducted using IBM SPSS Statistics Version 29 and Hayes PROCESS Macro for SPSS Version 4.2 (Hayes, 2017). The participants included in the analysis were students who completed all assessments in each respective semester, resulting in a final sample of N = 543 (Semester 1 n = 345, Semester 2 n = 198) which exceeded the minimum sample size of N = 107 with a medium effect size (α = .05, power = .80, m = 3) for a moderated linear regression by Tabachnick and Fidell (2013).

4. RESULTS

Data preparation and analytic approach

Analyses were conducted at the student level (one row per student). Semester was treated as a binary cohort indicator (0 = Semester 1; 1 = Semester 2). H5P engagement was operationalized as the number of H5P activities completed (ENACT). Discussion forum engagement was operationalized as (a) ActiveDB (questions/posts/comments/answers) and (b) PassiveDB (views). Final grades were operationalized as students' overall subject mark (percentage out of 100) awarded at the end of the semester. Final subject scores were calculated from the combination of two assignments, short mid-semester test (MCQ + short answer questions), short end of semester quiz (MCQ only) and a 2-hour end of semester exam (short and long answer questions). Descriptive statistics indicated that discussion engagement variables were strongly right-skewed with many low/zero values and a small number of very high-engagement cases (see Table 1).

Given the highly right-skewed engagement variables (ActiveDB and PassiveDB) and the presence of many zero/low-engagement cases alongside a small number of very high-engagement cases, the assumption of homoscedastic (constant) residual variance was unlikely to hold. Accordingly, moderation models were estimated using heteroscedasticity-consistent (HC3) robust standard errors, which provide more reliable inference when residual variance differs across levels of predictors and when influential observations may be present. In addition, PROCESS generated 5,000-sample percentile bootstrap confidence intervals, and these were found to be broadly consistent with the HC3-based intervals reported in Tables 2-6, providing convergent support for the robustness of the calculated parameter estimates.

Primary analysis: Does engagement with H5P activities predict final grades, and does this differ by semester (cohort)?

A moderation model tested whether ENACT predicted final grade (FINGRA) and whether this association differed by cohort/semester (ENACT × Cohort). The model indicated that H5P completion was positively associated with final grades, and this relationship differed by semester (Table 2). Probing the interaction further showed that the ENACT-grade association was positive in

both cohorts, but stronger in Semester 2 than Semester 1 (see conditional effects in Table 3). This pattern suggests that completing additional H5P activities was associated with higher grades across both semesters, with a steeper "gain per activity" observed in Semester 2.

Secondary analysis: Does the H5P – grade relationship remain significant after accounting for discussion engagement?

This model was specified a priori as an adjustment/robustness check to evaluate whether the ENACT × Cohort effect was independent of concurrent engagement in any other learning supports available in the subject (in this case, discussion forums). Thus, to evaluate whether the cohort-specific association between H5P activities completion and grades could be statistically accounted for by engagement in posts and comments on Ed Discussions, ActiveDB and PassiveDB were added as covariates into the regression model. The covariate-adjusted moderation model remained significant (Table 4). Importantly, the ENACT × Cohort interaction also remained significant after adjusting for active posting (ActiveDB) and passive viewing (PassiveDB), indicating that (a) H5P completion explained variance in grades above and beyond discussion forum engagement, and (b) the stronger H5P-grade association in Semester 2 could not be explained by cohort differences in discussion forum engagement alone.

In addition, both forms of discussion engagement showed unique positive associations with grades when entered alongside H5P completion and cohort (Table 4). The relative strength of predictors (ActiveDB and PassiveDB) was compared in order to determine which type of discussion forum engagement was a stronger predictor of subject performance, so we re-estimated the covariate-adjusted model using z-standardized variables (i.e., FINGRA, ENACT, PassiveDB, and ActiveDB were converted to z-scores) and reported the resulting standardized coefficients (β). This standardized re-estimation does not replace the PROCESS results in Table 4 (which are reported in raw units) - it is included solely to support magnitude comparison between PassiveDB and ActiveDB. Thus, in this standardized model, passive discussion engagement (PassiveDB; β = .256) showed a stronger association with grades than active posting (ActiveDB; β = .159), although both effects were statistically significant.

Variable	Cohort 0 (Sem 1)	Cohort 1 (Sem 2)
Final grade (FINGRA)	*M* = 70.41, *SD* = 11.79	*M* = 70.42, *SD* = 11.70
H5P completed (ENACT; 0-35 activities)	*M* = 8.81, *SD* = 11.33	*M* = 17.05, *SD* = 12.11
Active discussion activity (ActiveDB)	*M* = 3.89, *SD* = 9.23	*M* = 2.94, *SD* = 5.92
Passive discussion (PassiveDB views) activity	*M* = 257.41, *SD* = 295.20	*M* = 186.04, *SD* = 195.79

Table 1: Descriptive statistics by cohort (semester)
Note. Cohort 0 = Semester 1; Cohort 1 = Semester 2.

Predictor	b	SE (HC3)	t	p	95% CI
Intercept	71.01	0.61	117.18	< .001	[69.82, 72.20]
ENACT (centered)	0.199	0.050	4.01	< .001	[0.102, 0.296]
Cohort	-2.66	1.091	-2.44	.015	[-4.801, -0.520]
ENACT × Cohort	0.196	0.080	2.46	.014	[0.040, 0.352]

Table 2: Moderation model predicting final grade from H5P completion and cohort (N = 543)
Note. Model fit. R^2 = .084, F(3, 539) = 19.00, p < .001. Interaction increment. ΔR^2 = .009, F(1, 539) = 6.07, p = .014. HC3 robust SEs were used. ENACT was mean-centered by PROCESS.

Semester	Simple slope (b)	SE (HC3)	t	p	95% CI
Semester 1	0.20	0.05	3.98	< .001	[0.10, 0.30]
Semester 2	0.40	0.06	6.36	< .001	[0.27, 0.52]

Table 3: Simple slopes of H5P completion predicting final grade by semester

Predictor	b	SE (HC3)	t	p	95% CI
Intercept	67.04	0.81	82.58	< .001	[65.45, 68.64]
ENACT (centered)	0.143	0.049	2.93	.004	[0.047, 0.239]
Cohort	-1.176	1.019	-1.15	.249	[-3.178, 0.826]
ENACT × Cohort	0.196	0.076	2.59	.010	[0.047, 0.345]
ActiveDB	0.228	0.086	2.66	.008	[0.060, 0.396]
PassiveDB	**0.011**	**0.003**	**4.13**	**< .001**	**[0.006, 0.017]**

Table 4: Moderation model predicting final grade from H5P completion and cohort, with discussion engagement as covariates (N = 543)
Note. Model fit. R^2 = .199, F(5, 537) = 19.25, p < .001.
Interaction increment. ΔR^2 = .009, F(1, 537) = 6.71, p = .010.
HC3 robust SEs and 5,000 bootstrap samples were used. ENACT was mean-centered.

Predictor	b	SE (HC3)	t	p	95% CI
ENACT (centered)	0.028	0.033	0.86	0.392	[-0.036, 0.092]
Cohort	-1.238	0.679	-1.82	0.069	[-2.572, 0.096]
ENACT × Cohort	**0.012**	**0.051**	**0.24**	**0.810**	**[-0.088, 0.113]**

Table 5: H5P completion predicting discussion engagement with ActiveDB as outcome (N = 543)
Note. Model fit. R^2 = .005, F(3, 539) = 1.43, p = .233.

Predictor	b	SE (HC3)	t	p	95% CI
ENACT (centered)	4.410	1.700	2.59	.010	[1.071, 7.750]
Cohort	-106.435	22.373	-4.76	< .001	[-150.383, -62.486]
ENACT × Cohort	-0.241	1.976	-0.12	.903	[-4.122, 3.640]

Table 6: H5P completion predicting discussion engagement with PassiveDB as outcome (N = 543)
Note. Model fit. R^2 = .053, F(3, 539) = 12.23, p < .001. HC3 robust SEs; ENACT mean-centered; Cohort coded 0 = Sem 1, 1 = Sem 2.

Exploratory follow-up: Does engagement in discussion boards complement or replace H5P engagement?

Since the covariate-adjusted model (Table 4) showed that both H5P completion and discussion forum engagement contributed unique variance in subject performance (FINGRA), we conducted exploratory follow-up analyses to clarify how these two forms of engagement (ENACT and discussion forum use) were related to each other. Therefore, to examine whether patterns of engagement differed across H5P and Discussion, we ran two separate additional moderation models with discussion engagement as the outcome (ActiveDB and PassiveDB) and H5P completion (ENACT) as the focal predictor, with Cohort as the moderator. For ActiveDB, neither ENACT, nor the ENACT × Cohort interaction was significant (Table 5), indicating no evidence that H5P completion was associated with active posting in either Cohort (semester). For PassiveDB, ENACT showed a positive association with discussion forum views, whereas the ENACT × Cohort interaction was not supported (Table 6). Overall, these results suggest that H5P completion (ENACT) was not meaningfully associated with active discussion forum engagement (ActiveDB), but was instead positively associated with passive forum engagement (PassiveDB; viewing). The ENACT-PassiveDB association did not vary by cohort (ENACT × Cohort, ns). However, cohorts differed in overall passive viewing, with Semester 2 students exhibiting substantially fewer PassiveDB engagement than Semester 1 students. Active posting did not differ significantly by cohort (Cohort p = .069), although the direction of the effect was consistent with lower ActiveDB in Semester 2.

5. DISCUSSION

The aim of this study was to examine whether engagement with H5P activities in a 5E-informed, scaffolded learning pathway that allowed students to self-select optional practice was associated with academic performance, and whether this association differed across two semester cohorts in 2025. As an exploratory extension to this primary aim, we examined whether LMS-tracked discussion forum

engagement (active posting in the form of posting and commenting, and passive viewing of posts, comments and answers by others) showed independent associations with grades and how it was associated with H5P engagement. The H5P activities were designed as optional scaffolded practice opportunities aligned with core database concepts, and discussion forums were available for clarification, feedback, and peer/instructor interaction. With the implementation informed by the 5E model as a framework, H5P completion can be viewed as one pathway supporting *Explore, Explain* and *Elaborate* stages as guided practice and application, whereas discussion forum engagement may support learning through both active contributions (e.g., asking/answering questions that help clarify reasoning; *Explore* and *Explain*) and passive viewing (e.g., reading explanations and worked solutions in subject materials and on Ed Dicussion). Notably, in this subject, the *Engage* phase was primarily implemented through in-class lecture/tutorial discussions that connected everyday activities to database-generated data - this component is pedagogically central but is not directly captured by LMS analytics.

To address the primary aim of the study, we examined whether engagement in H5P activities predicted final grades and whether this association varied by semester. Consistent with prior work (Abusalim et al., 2024; Linden & Tipple, 2025), this study found that students who completed more H5P activities tended to achieve higher final grades. However, this finding differed by semester (Cohort). The association was stronger in Semester 2 (b = .40) than in Semester 1 (b = .20), indicating that each additional completed H5P activity corresponded to a larger increase in grades for Semester 2 students. In the unadjusted model, Semester 2 students were estimated to have slightly lower grades than Semester 1 students at the overall mean of H5P engagement (i.e., at mean-centered ENACT = 0). However, after adjusting for discussion engagement, this difference became smaller and was no longer statistically significant (Table 4), suggesting that any semester-related difference in performance at average H5P engagement was small once forum engagement considered. This helps explain why the observed average grades were similar across semesters, even though Semester 2 students completed more H5P activities. Consistent with this pattern, model estimates suggest that at high engagement (approximately 14 activities above the mean; ~26/35 completed), Semester 2 performance would be expected to converge with, and slightly exceed, Semester 1. To illustrate the size of H5P engagement, completing 10 additional H5P activities corresponded to an estimated ~2-point increase in final grade (FINGRA) in Semester 1 and ~4 points in Semester 2, suggesting that structured practice through H5P activities was particularly beneficial for the second cohort compared to the first.

Importantly, the difference between semesters in the ENACT-grade slope remained when ActiveDB and PassiveDB were added as covariates into the model (Table 4). That is, the ENACT × Cohort term remained significant, indicating that: (a) H5P engagement explained variance in subject performance above and beyond discussion forum engagement (both active and passive), and (b) the stronger association between H5P completion and grades in Semester 2 was not explained by differences in discussion forum engagement. Furthermore, in the covariate-adjusted model, both ActiveDB and PassiveDB showed independent positive associations with grades alongside H5P completion, suggesting that H5P engagement and discussion forum engagement captured distinct aspects of learning rather than functioning as simple proxies for one another. When coefficients were standardized to compare magnitudes, passive forum viewing (PassiveDB; β = .256) was more strongly associated with final grades than active posting (ActiveDB; β = .159), although both were significant. This pattern of results is consistent with the possibility that accessing other students' explanations/solutions through passive discussion forum viewing supports subject performance, and that discussion forum viewing is a meaningful learning behavior, consistent with previous studies (Chiu & Hew, 2018; Smith & Smith, 2014; Wilton, 2018). Finally, follow-up models which further investigated whether there was a relationship between H5P activity attempts and discussion forum engagement provided little evidence of a trade-off between learning support options: lower H5P completion was not associated with higher active discussion forum posting, and passive discussion forum viewing tended to co-occur with H5P completion rather than substitute for it (Tables 5-6). This pattern of results suggests lower H5P engagement did not reflect a compensatory shift toward active forum participation, instead, it was more consistent with lower uptake of optional supports overall (particularly passive viewing), rather than a preference for the discussion forum as an alternative learning strategy.

In this subject context, H5P completion may reflect structured opportunities spanning Explore-Explain-Elaborate, including guided worked

examples (e.g., step-by-step demonstrations), formative concept-checking with feedback-rich MCQs, and more open-ended modelling practice (e.g., dialogue cards that prompt articulation and checking of solutions). Accordingly, H5P completion is not only an Explore indicator - it also captures students' engagement with scaffolded explanation and extension opportunities embedded in the pathway. Consistent with this interpretation, engagement with H5P differed substantially across the 2025 academic year, with 64.9% of students in Semester 1 completing at least one H5P activity compared to the 95% of students in Semester 2. This pattern suggests that the two cohorts may have differed in how they chose to engage with learning. In particular, Semester 2 students showed substantially higher uptake of the optional H5P pathway, whereas a sizeable proportion of Semester 1 students did not engage with H5P at all. Because the H5P activities were identical across semesters, this difference is unlikely to reflect changes in the resources themselves and instead points to cohort-level differences in engagement patterns, and the extent to which students opted into the optional H5P activities.

When considered alongside the engagement trends for the discussion forum and H5P, the data indicated that Semester 2 students showed lower passive discussion engagement (views) alongside much higher uptake of H5P activities. In contrast, active discussion posting did not show strong evidence of cohort differences, suggesting that cohort variation was more pronounced for H5P completion and passive viewing than for active posting. Interpreted through the 5E model, this pattern is consistent with Semester 2 students making greater use of H5P as a structured pathway for practice and feedback (i.e., Explore/Explain/Elaborate-aligned learning opportunities embedded in the activities), while Semester 1 students' relatively higher forum viewing may reflect greater reliance on asynchronous exposure to explanations and worked solutions outside class. Importantly, because the Engage phase was primarily implemented in class and was not captured by LMS analytics, these interpretations should be treated as indicative rather than direct measures of 5E phases. This pattern is also consistent with the follow-up analyses of active and passive discussion forum activities, which did not support the idea that lower H5P completion was offset by increased active discussion forum posting, and instead, suggested limited evidence of substitution or preference between learning support options. Possible explanations for this pattern of engagement include differences between cohorts in educational background, learning preferences, and self-regulated learning behaviors that influence which learning support options students use most often. Other explanations for cohort effects include some students deeming core materials (e.g., lecture slides/recordings, tutorial solutions, practice exam tasks) sufficient for their learning needs. More broadly, this suggests that some students may have perceived the additional optional learning opportunities as unnecessary given their existing strategies or prior knowledge, rather than making an explicit decision to follow a self-directed learning pathway.

The lack of engagement with H5P activities suggests that some students may be less likely to make effective use of optional learning supports, whether due to self-regulated learning challenges, competing demands, or uncertainty about how to integrate activities effectively, rather than a lack of capability per se. The issue of students frequently not engaging with provided resources for the benefit of their learning has been identified in the past research (Clarebout & Elen, 2006). However, lack of engagement with the additional materials could also be explained by poor self-regulated learning skills or poor time management. For example, students who struggle to plan, prioritize, or monitor their study progress may be less likely to take advantage of additional, non-mandatory learning activities offered, such as H5P. Importantly, low engagement with H5P activities is not unique to this study. Other studies such as Jacob and Centofanti (2024) and Rahmi et al. (2024) report low and declining engagement in H5P activities, citing reasons such as poor perceived value, visibility and accessibility, technological barriers, reduced novelty, and repetitiveness in activity formats can reduce motivation for students to engage in H5P activities. To address concerns with engagement, educators could consider embedding H5P activities more explicitly into the curriculum and emphasize their relevance, aligning or signposting H5P activities as being closely relevant to assessment tasks, or providing guidance on how and when to use them. From a 5E-aligned design perspective, this could include signposting which activities support Explore for particular concepts, and using the online asynchronous discussions forum strategically to answer questions and prompt Explain and Elaborate (e.g., "show your reasoning" prompts, troubleshooting threads) to provide individualized support to everyone, regardless of their self-regulation skills.

When comparing the two forms of forum engagement, passive viewing showed a stronger association with grades (PassiveDB; β = .256) than active posting (ActiveDB; β = .159), although both were positively related to performance. Interpreted through the 5E model, this pattern is consistent with the idea that the discussion forum may function as an ongoing Explain resource that students repeatedly return to as they Elaborate their understanding through practice and prepare for assessment. In other words, revisiting explanations, worked solutions, and peer/instructor clarifications may support the Elaborate–Evaluate cycle by helping students check their reasoning, identify gaps, and refine their approach while preparing for assessments. Active posting may still be important for targeted help-seeking and articulating reasoning (for example, allowing students to engage in multiple cycles of solution resubmission for the purpose of getting feedback and learning), but the present findings suggest that exposure to explanations via discussion forum viewing is particularly salient in this subject context. In this way, active posting on the discussion forum may reflect a different type of engagement that is used by fewer students, but is more targeted (e.g., help-seeking, checking reasoning, and clarifying misunderstandings). This would fit with the finding that ActiveDB predicted final grades despite showing little association with H5P completion.

Additionally, since H5P activities were identical across semesters, the stronger engagement–grade association in Semester 2 cannot be explained by the activities themselves. Instead, it suggests that cohort or semester conditions influenced how effectively engagement translated into student performance. One possibility is that Semester 2 students were more likely to use H5P activities in a way that supported the Elaborate–Evaluate loop (e.g., returning to activities after feedback, selecting tasks strategically, or integrating activity feedback into assessment preparation), whereas in Semester 1, engagement may have been more intermittent or less tightly coupled to assessment demands. These interpretations remain tentative because the current observational design does not directly measure how students used feedback or made learning decisions across the 5E stages. More broadly, because engagement was self-selected and the design is observational, the reported associations may also reflect unmeasured differences between students (e.g., prior knowledge, motivation, time availability, or assessment-related study strategies), rather than causal effects of H5P or forum engagement. In practical terms, the results highlight that the benefits of H5P depend not only on the activities provided, but also on student uptake, their self-regulated learning skills, and the learning context that supports their use.

The results of this study showed that the 5E model provided a pedagogically sound way for students to follow a customized learning path. However, decision-making on how to construct this path through selection of optional H5P tasks, and how to seek learning support was up to individual students and depended on their self-regulated learning skills. The 5E model also offers a useful interpretive lens for understanding how different forms of engagement may relate to learning within this scaffolded, student-choice pathway, while recognizing that the present study does not directly measure all phases of the 5E stages. Taken together, these findings suggest that H5P engagement combined with the Discussion forum support is a meaningful but modest contributor to subject performance within this sample, and that H5P activities may function most effectively as a scaffold that supports learning alongside other factors. Interpreted through the 5E model, the H5P pathway may have supported students cycling between *Elaborate* (applying concepts to new problems and extending understanding through increasingly complex practice tasks) and *Evaluate* (checking understanding via embedded feedback, comparing solutions, and using feedback from staff via Discussion forum to decide whether further practice or help-seeking is needed). In this sense, H5P completion may function as a reflection of students' participation in the 5E iterative learning cycle, which would be expected to relate to stronger performance outcomes. Consistent with this interpretation, discussion forum engagement showed unique positive associations with grades when included alongside H5P completion, suggesting that multiple learning opportunities across the cycle (e.g., H5P practice and forum-based clarification) can contribute additively rather than acting as substitutes in improving overall subject performance. Overall, the findings point to two related but distinct patterns of engagement with optional subject learning supports. One pattern involves H5P completion alongside passive forum viewing, which may reflect a "practice and feedback" learning mode by accessing available explanations and worked solutions. The other involves active posting on Ed Discussion to seek additional feedback, which appears to capture a more participatory form of engagement (e.g., articulating reasoning and help-seeking) that is not simply an extension of H5P activities

engagement.

5. CONCLUSIONS

This study examined the combined use of two digital tools - H5P and asynchronous online discussion forum – to implement personalized learning paths in the context of teaching a Master level subject Database Systems. Guided by the 5E framework, the subject materials incorporated multiple H5P activities combined with options to seek clarifications and feedback on solution attempts via Ed Discussion tool. Unlike past studies which relied on self-reported data (e.g. Gil-García et al., 2023; Jacob & Centofanti, 2024), our study offered greater opportunities for addressing individual learning needs and a stronger basis for evaluating how combining these tools impacts student learning and performance.

In line with many previous studies, our research confirms that H5P, if used in a pedagogically sound way, has significant potential in supporting students learning, especially for students who mastered self-regulated learning skills. Unlike previous studies, these research findings indicate that H5P activities yield greater learning value when integrated with opportunities of seeking additional help (e.g. in this study mainly via online asynchronous discussion forum). Also similar to previous studies, it was determined that passive viewing of discussion forums is a valuable learning opportunity which should be encouraged. Although considered passive, students' viewing of posts and comments by others that clarify concepts and provide alternative solutions and explanations, supports learning in a meaningful way.

Although the data was collected from one postgraduate subject only, the alignment of findings with the previous studies enhances their contribution and supports the potential for broader generalizations to similar higher education contexts. Future research could consider implementing H5P in conjunction with asynchronous online support in multiple subjects and comparing engagement data across longer periods.

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How 21st Century Skills Have Evolved in the 21st Century and How AI Is Shaping Their Next Evolution

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Abstract

In the years leading up to the 21st century, technology began transforming almost every aspect of how we live, learn, and work. From the rise of the Internet to the emergence of artificial intelligence, these changes have reshaped the skills that students need to succeed in today's digital and interconnected world. This paper explores how the Four Cs of 21st Century Skills (collaboration, communication, critical thinking, creativity) have been incorporated in computing fundamentals courses over the past 25 years. By analyzing national student engagement surveys, evolving standard ACM/AIS/AITP computing curricula, and a widely used introductory computing textbook, this study provides a longitudinal perspective on how computing education has adapted to meet the demands of today's ever-changing workforce. This paper addresses a gap in literature by providing a longitudinal comparison using these different sources across 25 years, offering insights into how computing education has integrated, and in some cases, overlooked essential 21st Century Skills. It also highlights growing attention to skills such as ethical reasoning, adaptability, empathy, and entrepreneurial thinking, which are increasingly relevant to how students learn, solve problems, and take initiative in technology-assisted learning environments. An analysis of the impact of generative AI on the evolution of 21st Century Skills suggests that the Four Cs remain relevant in the AI era.

Keywords: 21st Century Skills, Model Curriculum, Fundamentals of Computing course, Generative AI

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How 21st Century Skills Have Evolved in the 21st Century and How AI Is Shaping Their Next Evolution

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1. INTRODUCTION

While 21st Century Skills have been a central part of the discussion on effective learning outcomes for more than two decades, few studies have compared how these skills have evolved with national student engagement data, formal computing curricula, and foundational textbooks during the past quarter-century. This paper fills that gap by providing a longitudinal analysis, from engagement metrics to model curricula to instructional materials, to gain a better understanding of how 21st Century Skills have been incorporated into computing education. Recent trends show that CIS curricula have increased focus on critical thinking and problem-solving skills as students analyze problems and create original solutions (Lyytinen et al., 2021). Project-based learning is on the rise, especially in the current era of artificial intelligence (Abulibdeh et al., 2025), and that requires students to develop collaboration and communication skills and demonstrate proficiency in basic technology tools and platforms. The rapid pace of digital transformation and the widespread use of data-driven technologies have fundamentally reshaped necessary technology skills (Cummings et al., 2025).

While the early 2000s focused on basic computer literacy and productivity tool usage, the emphasis has now shifted to digital fluency, or the ability to critically evaluate, learn, and apply new technological tools for effective problem-solving (Fleming et al., 2021). The artificial intelligence (AI) era has also required students to consider how to use the latest tools effectively, ethically, and responsibly, requiring technological proficiency (Frydenberg et al., 2025; Zhang et al., 2025).

Examining how curricula, employers, and textbooks prepare Information Systems (IS) students to enter a technology-driven workforce will demonstrate the ongoing need to evolve relevant 21st Century Skills.

This research aims to address these questions:

RQ 1. How are 21st Century Skills relevant to IS education?

RQ 2. How have model IS curricula and textbooks responded to technological change while promoting 21st Century Skills?

RQ 3. Are 21st Century Skills still relevant 25 years later? What additional skills need to be included?

RQ 4. What implications do these changes have for education and workforce development?

2. LITERATURE REVIEW

Twenty-first-century skills include a set of competencies and knowledge areas considered necessary for success in a world where the impact of, and reliance on, technology is critical. The Partnership for 21st Century Learning ("P21 Resources | 21st Century Learning Resources," n.d.) developed a set of measurable skills and outcomes necessary for digital students to succeed as global knowledge workers. These four C's (critical thinking, communication, collaboration, and creativity) augment the three R's (reading, writing, and 'rithmetic) of the 20th century.

The Four Cs remain relevant at the beginning of the second quarter of the 21st Century, yet recent literature suggests that 21st Century Skills in a business context extend to integrate digital aspects (Van Laar et al., 2020) and interpersonal skills, to navigate the impact of technology successfully. Technology-enabled project-based learning develops communication, collaboration, and problem-solving skills, which employers highly value over basic content knowledge (St. Louis et al., 2021). Students need to acquire data literacy, problem-solving, programming, and creative thinking to remain competitive in the workforce (Birru, 2024).

Along with information literacy as an essential 21st Century Skill (Khan et al., 2022; Zhang et al., 2025), emphasis on innovation and entrepreneurship is increasingly present. Research shows the importance of integrating entrepreneurship in the IS curriculum, focusing on essential skills of tech startups (Jones & Liu, 2017; Lang & Babb, 2015) for preparing graduates for the ever changing job market.

Researchers have also emphasized the importance of digital ethics (Young et al., 2018) and the responsible use of technology, including the Internet, mobile devices, and artificial intelligence (Paltiel et al., 2023) and data practices (Hand, 2018) as essential 21st Century Skills. As technology evolves, students must consider the ethical dilemmas and implications of using AI, data privacy, and other advancements from multiple disciplinary perspectives (C Yallop & Aliasghar, 2020; Sharples, 2023). This includes the ability to evaluate the credibility, quality, and accuracy of digital or AI-generated information to make justifiable decisions (Federiakin et al., 2024; Remmik et al., 2024).

The challenges of the modern workplace, often called the "new normal", also demand resilience as an essential skill for 21st Century workers (Foteini & Angela, 2022) who need to adapt to changing work environments. Finally, Dondi et al. (2021) identify empathy as a crucial skill, with an emphasis on digital citizenship, interdisciplinary learning, and the impact of social media. Learners must "appreciate the world through the eyes of others (Dondi et al., 2021)" in contexts such as user interface design, addressing bias, and developing leadership skills.

3. METHODOLOGY

This study utilizes a mixed-methods approach combining literature review, comparative analysis, and historical evaluation of curricula to examine how 21st Century Skills have been integrated into IS education during the past 25 years. The narrative will progress from a macro perspective down to the micro perspective. The intent of moving from the macro to micro levels is to tease out whether 21st Century Skills are being addressed at the entire student body versus those skills that the information Systems field felt were needed for their discipline majors.

A five-point scale (see Table 1) was used to evaluate the presence of 21st Century Skills: Critical Thinking, Communication, Collaboration, Creativity, and Digital Literacy, in each data source. Each author independently analyzed one of the three sources; the NSSE surveys, Information Systems model curricula, or editions of *Discovering Computers,* based on their subject-matter expertise. Ratings were informed by both explicit mentions and implied presence of each skill. While inter-rater reliability measures were not employed, the division of labor allowed for a focused, contextually informed evaluation of each domain. To ensure consistency, the authors reviewed and discussed each other's rating rationales and summary tables to ensure alignment in interpretation and scale usage. The authors acknowledge this as a limitation and recommend future work include formal inter-rater reliability procedures across sources.

Ranking	Interpretation
0	Barely present / Non-existent
1 ■	Somewhat present
2 ■■	Moderately present
3 ■■■	Strongly present
4 ■■■■	Very strongly present

Table 1: Ranking Presence of 21st Century Skills

At the macro level, the National Survey of Student Engagement (NSSE), an instrument which "provides educators with an estimate of how undergraduates spend their time and what they gain from attending college" (*National Survey of Student Engagement*, 2021), informs this discussion. At the intermediary level, the evolution of the IS Model Curriculum (Davis et al., 1996; Gorgone et al., 2003; Leidig & Salmela, 2020) provides insights since the model curriculum addresses technology at both the MIS major/minor and technology skills needed for the whole student body. Finally at the micro level, examining several editions of *Discovering Computers* (Shelly et al., 1999), a popular textbook for teaching introductory computing concepts shows when new technologies were taught (relative to when they were introduced) and different skills required to assess student learning.

Across each area, the authors employed a scale ranging from 0 (Barely Present/Non-Existent) to 4 (Very Strongly Present), as shown in Table 1. Qualitative coding is used to evaluate how NSSE, model curricula, and a popular computing fundamentals textbook reflect the evolving definitions of 21st Century Skills.

4. EVOLUTION OF STUDENT ENGAGEMENT SURVEY RESULTS

The National Survey of Student Engagement (NSSE 2025 U.S. English Version, 2025; *The NSSE 2000 Report: National Benchmarks of Effective Educational Practice*, 2000) provides insights into relevant technology skills for undergraduate students. This analysis focuses on the perceived skills that students need, not on the actual skills that students possess, by examining

the survey instrument itself. Each question from the 2000 and 2025 NSSE surveys was coded according to each of the Four Cs (critical thinking, communication, collaboration, and creativity) plus digital literacy, often defined as the ability to use information and communication technologies to find, evaluate, create, and share information (Khan et al., 2022; Riel et al., 2012), to determine the level of emphasis each of these had in the survey, applying a 5-point scale for each category.

Based on an evaluation of the NSSE surveys from 2000 and 2025t, Tables 2 and 3 present a side-by-side comparison of how 21st Century Skills have evolved in undergraduate education during the past 25 years.

NSSE 2000	
Critical Thinking ■■■	Clearly present, but mostly through mastery of discipline content. Focused on academic rigor in specific courses
Collaboration ■■■	Clearly present in in-person, course-based interactions to support academic success
Communication ■■	Moderately present, through class discussions or presentations
Creativity	Not present; little or no assessment of originality, innovation, or problem solving
Digital Literacy ■	Barely present; mentioned only in use of electronic communications or email

Table 2: Presence of 21st Century Skills in NSSE 2000

While the NSSE 2000 survey reflected traditional educational environments focused on content mastery and in-person learning, the 2025 version captures a broader, dynamic skill set aligned with contemporary educational methods. This evolution represents a shift from assessing students mastery of content to evaluating their performance of technology-enabled competencies across a variety of learning environments. Many of the dimensions noted in the 2025 survey, including ethical reflections, adaptability, and entrepreneurial thinking and perspective taking, point to a growing recognition of skills beyond the Four Cs. Table 3 shows the presence of 21st Century skills in the NSSE 2025 survey, which are more fully integrated, reflecting the needs of today's digital and collaborative world.

NSSE 2025	
Critical Thinking ■■■■	Very strongly embedded, including integrative, and cross-disciplinary thinking and making connections between ideas in different course
Collaboration ■■■■	Very strongly present; expands to working effectively in technology-enhanced and globally diverse teams
Communication ■■■■	Emphasized across written, oral, and interpersonal communication; across, diverse and digital contexts
Creativity ■■	Moderately present through high-impact projects, research, or integrative assignments
Digital Literacy ■■■■	Fully integrated across course and assignments, supports research, collaboration, and using technology to communicate, create, and reflect on one's learning

Table 3: Presence of 21st Century Skills in NSSE 2025

Figure 1 summarizes these findings, showing that each skill increased in emphasis from 2000 to 2025. By 2025 all skills except creativity scored highest as *Very Strongly Present* indicating that these skills were considered essential for student success. The NSSE's has aligned with evolving educational practices and employer expectations. While 2000 captured the novelty of digital tools, 2025 reflects a reality where digital literacy is not optional, it is foundational to how students learn, collaborate, and demonstrate competence.

In addition to the Four Cs, entrepreneurship was indirectly addressed through experiential learning in 2000, but 2025 NSSE highlights innovation and ownership of learning, key aspects of entrepreneurship.

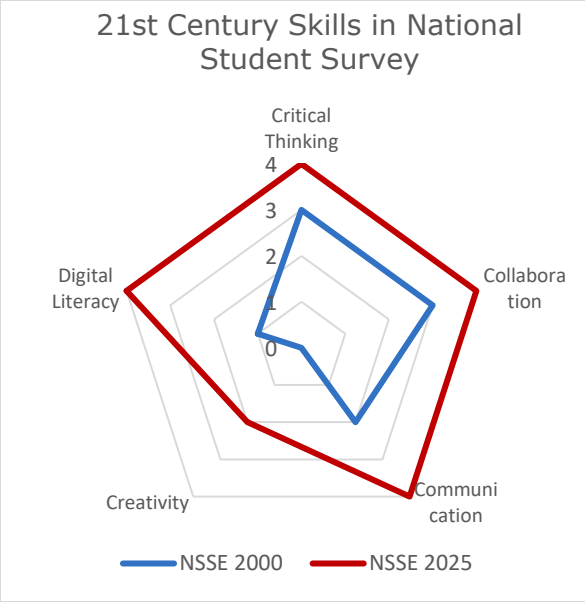

Figure 1: 21st Century Skills in NSSE

5. EVOLUTION OF INFORMATION SYSTEMS MODEL CURRICULA AND 21st CENTURY SKILLS

The Association for Information Systems (AIS) and Association for Computing Machinery (ACM) with other partner organizations offered four major curriculum revisions in 1997, 2002, 2010, and 2020. The linkages between IS and business in IS 2002 represent the relevance of the Four Cs and digital literacy combined with business fundamentals, as interpreted by the authors, illustrated in Figure 2.

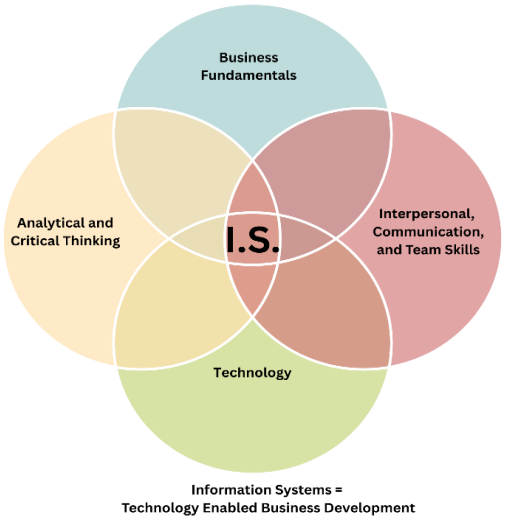

Figure 2: Components of Information Systems.

For each curriculum revision, the authors subjectively evaluated each 21st Century skill based on the scales as shown in Table 1.

IS '97 Model Curriculum

The IS '97 model curriculum (Davis et al., 1996) developed by AIS and ACM laid the foundation for undergraduate Information Systems (IS) education, and supported but predated the formal recognition of 21st Century Skills. IS '97 introduced. Students to essential technology topics such as hardware, software, databases, and networking, it also emphasized systems knowledge over soft skills. Critical thinking appears in the context of a systems analysis course and in the digital literacy course. Creativity, communication, and collaboration were either assumed or minimally mentioned, with few learning outcomes targeting these competencies.

Tables 4 and following present the authors' averaged independent assessment score of the presence of critical thinking, collaboration, communication, creativity, and digital literacy in each curriculum's Fundamentals of Information Systems course description.

IS '97 Model Curriculum	
Critical Thinking ■■	Systems analysis required problem solving and structured thinking
Collaboration ■	Mentioned in team projects, but not a focus
Communication ■	Expected, but not taught or assessed
Creativity ■■	Implied in system design, and home computer use, but not formally developed.
Digital Literacy ■■	Focus on hardware, software, and early Internet tools

Table 4: Presence of 21st Century Skills in IS '97 Model Curriculum.

Although not designed with 21st Century Skills in mind, IS '97 provided technical foundations upon which later curricula would build skill development in collaboration, communication, and creativity.

IS 2002 Model Curriculum. The IS 2002 Model curriculum (Gorgone et al., 2003) introduced coding as a way to build critical thinking. Group projects promoted teamwork and creativity were encouraged through developing solutions to business problems. Table 5 summarizes how the

IS 2002 foundations course aligns with the Four Cs and digital literacy.

IS 2002 Model Curriculum	
Critical Thinking ■■■	Required for IS professionals, especially problem solving
Collaboration ■■	Emphasizes teamwork and interpersonal skills
Communication ■■	Listed as a skill, but not a focus area
Creativity ■■	Encouraged through prototyping and developing solutions
Digital Literacy ■■■	Focused on core technology concepts in hardware, software, networks

Table 5: Presence of 21st Century Skills in IS 2002 Model Curriculum.

IS 2010 Model Curriculum. IS 2010 (Topi et al., 2010) marked a major pedagogical shift by integrating leadership, ethics, and interdisciplinary knowledge along with technical competencies in foundation courses. It expanded IS applications across industries and emphasized soft skills alongside technical expertise. Creativity and digital literacy became essential in understanding and using IS tools.

Table 6 summarizes the presence of 21st Century Skills in the computing fundamentals course of the IS 2010 curriculum.

IS 2010 Model Curriculum	
Critical Thinking ■■■■	Framed as a central skill, along with ethical reasoning
Collaboration ■■■■	Emphasizes teamwork, leadership and interpersonal skills
Communication ■■■■	Recognizes written and oral communication as necessary skills for effective IS professionals
Creativity ■■■■	Developed through prototyping solutions and creatively using IS tools to solve business problems
Digital Literacy ■■■■	Focuses on productivity tools (spreadsheets, word processing, browsers) to support business decision-making

Table 6: Presence of 21st Century Skills in IS 2010 Model Curriculum.

The importance of working on diverse teams, developing leadership skills, and understanding user requirements all provide opportunities for students to appreciate the perspectives of others, essential when developing empathy as an additional 21st Century Skill.

In addition, the IS 2010 undergraduate model curriculum identifies ethical analysis as "one of the foundational knowledge and skills categories (Topi, 2014)." "Two notable content areas missing from the curriculum include the tools for analysis of ethical issues and incorporating ethics in the design process. (2014, p. 32)" Graduates need strong models and frameworks to analyze the implications and potential ethical and moral consequences of emerging technologies like AI and blockchain, due to the complex ethical issues they present. (Lyytinen et al., 2021)

IS 2020 Model Curriculum. A move toward competency-based thinking and the rapid growth and changing roles of digital technologies throughout society were prime motivators for the IS 2020 Model Curriculum (Leidig & Salmela, 2020).

Table 7 summarizes the presence of 21st Century Skills in the computing fundamentals course of the IS 2020 curriculum.

IS 2020 Model Curriculum	
Critical Thinking ■■■■	Applied to data and systems analysis, business decision making
Collaboration ■■■■	Required for work on cross-functional teams
Communication ■■■■	Emphasizes importance of explaining processes and findings and interacting with stakeholders
Creativity ■■■■	Integrated into use of emerging technologies, and data visualization
Digital Literacy ■■■■	Distributed across the use of productivity tools and incorporating them in decision making

Table 7: Presence of 21st Century Skills in IS 2020 Model Curriculum.

The project-based focus of the IS 2020 curriculum (Leidig & Salmela, 2020) also recognizes application development as a core competency, reflecting an entrepreneurial mindset. Its competency-based model promotes adaptability, applying skills across contexts, iterative design and responding to feedback, key elements of

flexible learners. Its focus on "people, processes, and organizational users" shows the need for empathy in understanding stakeholders' needs.

Together, these curricula show an evolution from technical literacy (IS '97) to integrating teamwork and creativity (IS 2010) to a full competency alignment (IS 2020). Figure 3 illustrates these trends by charting the values for each skill in each curriculum revision as shown by the ■ above. a strong, balanced focus across all skills.

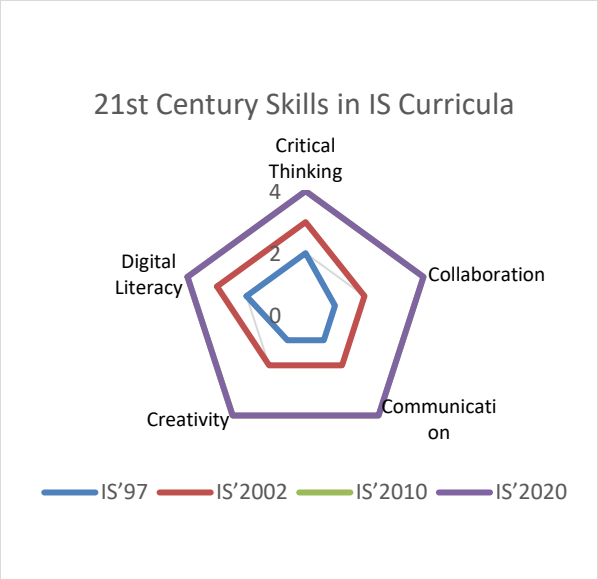

Figure 3: 21st Century Skills in IS Curricula.

Comparing how the Foundations of Information Systems course in each of the IS Curricula from 1997 to 2020 emphasize 21st Century Skills, the small shape of IS 97 shows minimal emphasis on 21st Century Skills. The shape of IS 2002 increases somewhat to have moderate focus across all skills, especially critical thinking and digital literacy. IS 2010 and 2020 form complete (overlapping) pentagons, showing a significant effort in integrating the Four Cs as core educational goals.

6. EVOLUTION OF DISCOVERING COMPUTERS AND 21st CENTURY SKILLS

Discovering Computers (Shelly et al., 1999) is the title of a series of introductory computing textbooks that originated in the 1980's when Gary Shelly authored its first edition, published by the former Course Technology, now part of Cengage Learning. It has been updated regularly (see Figure 4) and used by millions of students in computer concepts courses.

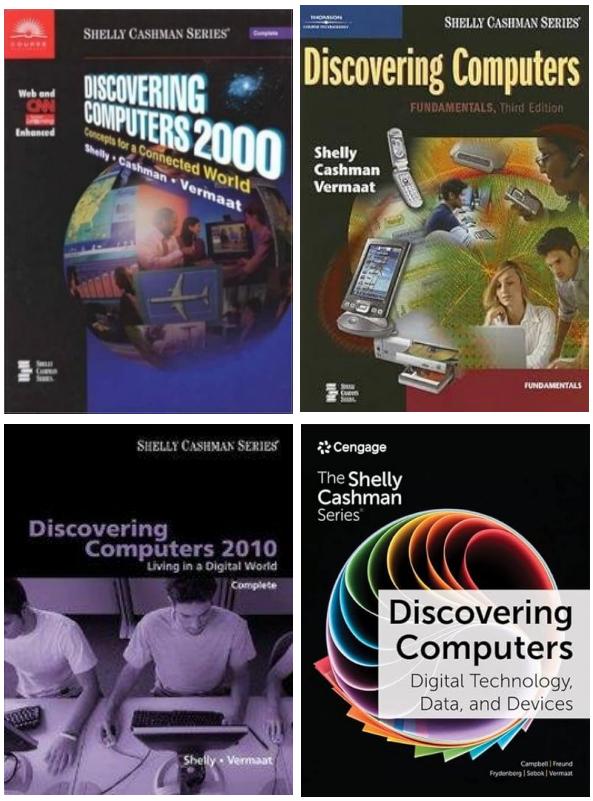

Figure 4: *Discovering Computers* covers from 2000, 2007, 2010, and 2023 illustrate the influence of technology in the digital world, and the shift from a focus on the Internet and devices to collaboration and data visualization.

Table 8 maps each exercise type to its related 21st Century Skill and corresponding levels of Bloom's Taxonomy (Bloom, 1956) and shows the evolution from emphasis on memorization to applying technology concepts.

Symbols used are:

- 🧠 (Critical Thinking).
- 💬 (Communication),
- 🤝 (Collaboration), and
- 🎨 (Creativity).

Exercise Type	Description	Four Cs	Bloom's
Chapter Review	Recap of key concepts via summaries, T/F, multiple-choice, matching questions.		Remember
Key Terms	Glossary reinforcement via definitions and term identification exercises.		Remember
Checkpoint	Concept-check T/F, matching, brief answer items.		Apply
Learn It Online	Interactive, web-based activities to reinforce chapter concepts		Analyze
Learn How To	Step-by-step instructions to complete a common task		Apply
Web Research	Guided online research tasks		Analyze
Case Studies	Practical examples of ethics and issues, technology at work, or technology innovator profiles		Evaluate
Problem Solving	Practical scenario-based or computational exercises.		Evaluate
Critical Thinking	Prompts for evaluating, defending, or critiquing information		Evaluate
Collaboration	Group-based or peer collaboration activities.		Create

Table 8: *Discovering Computers* Exercises, 21st Century Skills, and Bloom's Taxonomy

Figure 5 shows how the types of exercises in *Discovering Computers* have evolved from 2000 to 2023. Over time, editions have increased the number of Key Terms, Checkpoint, and Chapter Review exercises, with 2023 showing the highest levels. Newer editions also include more diverse activities like Collaboration, Critical Thinking, and Learn It Online, reflecting a broader pedagogical approach. Figure 6 maps exercise types by Bloom's Taxonomy level. Earlier editions focused mainly on Remember and Understand, while recent editions, especially 2023, show a rise in higher-order skills such as Apply, Analyze, and Evaluate. This shift demonstrates a modest alignment with select 21st Century Skills, particularly digital literacy and teamwork, as recent editions include more diverse exercises such as collaboration tasks and applied technology use. However, the emphasis on critical thinking and problem solving appears relatively stable across editions, suggesting room for further enhancement in future versions.

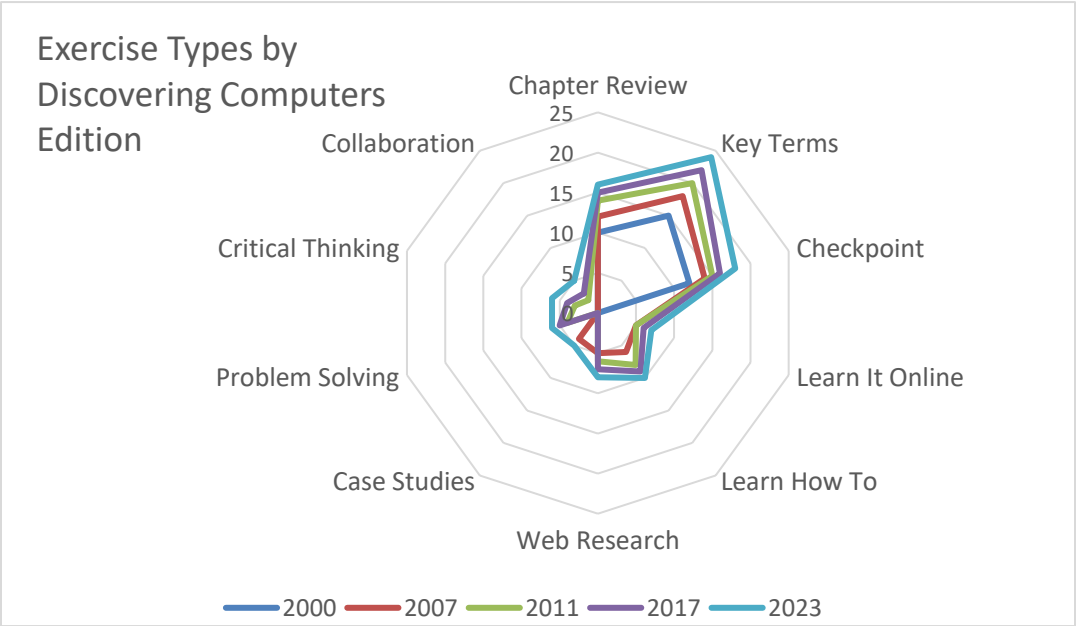

Figure 5: Exercise Types by *Discovering Computers* Edition

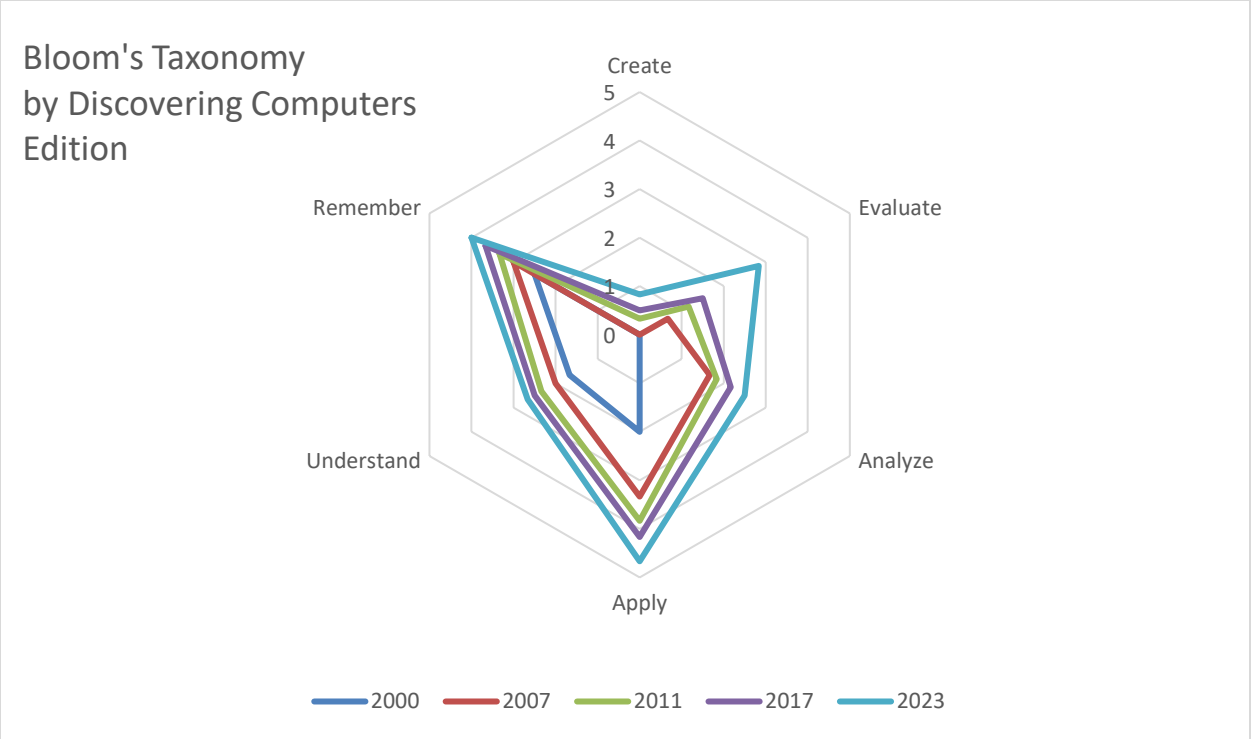

Figure 6: Bloom's Taxonomy by *Discovering Computers* Edition

The widespread availability of the Internet and web-based collaboration tools such as Google Docs in the mid- to late 2000s coincided with the introduction of new learning scenarios utilizing these technologies and encouraging educators to adapt teaching methods to better support 21st Century Skills.

7. DISCUSSION

While each data source provides a unique lens on the integration of 21st Century Skills, the most powerful insight comes from comparing them side by side. (See Table 9.) This triangulated view reveals not just individual shifts but broader alignment across engagement metrics, curriculum design, and instructional materials.

After examining NSSE surveys, model IS curricula, and an information systems textbook, this study concludes that 21st Century Skills have become increasingly central to computing education, although the extent to which they are integrated varies. NSSE data shows that while critical thinking, communication, and collaboration were already present in the 2000 survey, they were framed largely within the context of traditional academic engagement. By 2025, these same skills are reframed as competencies that can be applied across disciplines. Digital literacy experienced the greatest change, reflecting the increasing role of technology in personal and professional lives.

Skill	NSSE 2000 → 2025	Curricula 1997 → 2020	Textbook 2000 → 2023
Critical Thinking	↑ strong shift	↑ consistent increase	→ stable
Collaboration	↑ sharp increase	↑ strong increase	↑ added in later editions
Communication	↑ expanded contexts	↑ integrated explicitly	↑ evident in case studies/tasks
Creativity	↑ modest growth	↑ notably in 2010/2020	→ limited emphasis
Digital Literacy	↑ dramatically increased	↑ major focus across all	↑ very strong and growing

Table 9: Summary of Evolution of Four Cs and Digital Literacy across Student Engagement Surveys, Curricula, and IS Textbook approaches

Creativity remained minimally represented, especially in areas of assessment. Keeping in mind that the NSSE applies to all students (macro-level), these changes highlight that skills originally developed to support information systems majors have now been adopted as skills necessary for all students.

The same pattern is noted in the model IS curricula. IS 1997 and 2002 provide solid framework in technical foundations and problem solving with technology while creativity and collaboration are implied but have a much smaller presence. IS 2010 was the beginning of a shift to explicitly integrate essential skills such as ethical reasoning, teamwork and leadership. Finally, the competency-based model of IS 2020 aligns well with 21st Century Skills, emphasizing creativity, applying IT across multiple domains, and emerging demands for flexibility, innovation, and interdisciplinary collaboration. This progression shows a broader shift, positioning IS majors to move beyond technological expertise to play a more collaborative, strategic role across the organization.

The textbooks examined in this study mirror some of these shifts, especially in digital literacy and communication, but lag behind curricular guidelines and engagement surveys in promoting creativity, ethical reasoning, and entrepreneurship. Exercises are mixed in how they support higher order thinking and real-world problems. The evolution from exercises focusing on memorizing and recalling information to higher order thinking and problem solving align with revisions of information systems curricula and contemporary pedagogical approaches such as flipped classroom (Bergmann & Sams, 2014; Frydenberg, 2013; Thi Lan Huong et al., 2018) to foster critical thinking, analysis, and creativity.

Together, these findings suggest that computing education continues to strengthen its focus 21st Century Skills that prepare students for their future careers, with essential life skills beyond the Four Cs increasingly reflected as themes within current assessment surveys, curricula, and educational resources., though to varying extents. Critical thinking, collaboration, and communication are consistently emphasized, while creativity, ethical reasoning, and adaptability remain areas to watch for continued growth in future years.

These overlaps are important because they suggest that the growing emphasis on digital literacy and teamwork is not isolated to a single domain but reflected across student surveys, curricular mandates, and textbook practices. At the same time, the relative stagnation of creativity and critical thinking in some sources (particularly the textbook) highlights areas where further curricular innovation is needed.

8. THE IMPACT OF GENERATIVE AI ON THE EVOLUTION OF 21st CENTURY SKILLS

The widespread use and integration of Generative Artificial Intelligence tools into students' daily lives, from using productivity apps to integrated development environments, and tools for research and multimedia generation, requires rethinking the role of 21st Century Skills in the AI era.

Critical thinking must expand beyond solving problems to evaluate the validity of AI-generated results. Students must learn to make sense of the results AI gives them, determining their accuracy and any implicit bias.

Creativity evolves from solely human creation to a co-creative process shared by humans and the AI tools they use, as students rely on AI tools for brainstorming ideas, writing essays, and generating images and videos(Frydenberg et al., 2025).

Communication requires effective prompt engineering as a new skill, as generative AI users interact with chatbots using natural language to obtain new knowledge.

Collaboration is shared between the "human in the loop" (Anderson & Fort, 2022) and the AI agent. AI becomes the student's thought partner in brainstorming new ideas and creating digital artifacts. Students must describe assumptions, risks, and limitations to AI as they would to stakeholders (Leidig & Salmela, 2020).

These shifts elevate the 4C's from digital literacy skills to AI literacy skills, (Zhang et al., 2025). Early evidence of rapid student adoption of generative AI suggests that instruction should move from prohibiting its use toward guided, ethical use with transparent expectations (Frydenberg et al., 2025). Students must understand the limitations of the language models they use and examine the data that trains them; they must learn to create effective prompts and select appropriate AI tools or prompt structures for their tasks. The AI era also requires students to understand the ethical use of AI (and technology, in general) as a core competency, not only how to use AI tools effectively, but also how to use them responsibly maintaining privacy of

personal information, when to disclose their use, and minimizing bias.

The rapid rise of AI does not diminish the 4C's; rather, it reframes them to include AI literacy, ethical reasoning, and human-AI partnerships as additional essential skills for graduates entering a workforce that is becoming increasingly reliant on the use of AI tools to boost employee productivity. The authors conclude that 21st Century Skills remain relevant in the AI era, when they must evolve to include learning with AI, not just learning about AI.

9. CONCLUSION

This study explored four guiding questions:

RQ 1. How are 21st Century Skills relevant to IS education?

Analysis shows that 21st Century Skills remain highly relevant to IS education. They provide a necessary framework for problem-solving, teamwork, adaptability, and digital competence in a rapidly evolving tech environment. These skills are increasingly reflected in standards and expectations for IS graduates.

RQ 2. How have model IS curricula and textbooks responded to technological change while promoting 21st Century Skills?

During the past quarter-century, model IS curricula have expanded their emphasis on 21st Century skills. Critical thinking, communication, and collaboration are consistently represented in foundational courses, while creativity and ethical reasoning are receiving growing attention. While textbooks have shifted from memorizing definitions toward more project-based learning, they have been slower to evolve, particularly in promoting creativity and critical thinking through assessment tasks.

RQ 3. Are 21st Century Skills still relevant 25 years later? What additional skills need to be included?

The relevance of 21st Century Skills is evident though their presence in assessments, technologies, and teaching methods. At the same time, ethical reasoning, empathy, and adaptability are emerging as *next-generation* competencies that expand on the original Four Cs. The rise in AI usage will require precise communication skills (for effective prompting), the ability to discern accuracy of AI-generated content, and the adaptable problem-solving skills to collaborate with a non-human partner in an iterative process

RQ 4. What implications do these changes have for education and workforce development?

Rapidly evolving digital skills and next-generation competencies require educators to reconsider what they teach, how they teach it, and how they assess learning. A shift toward emphasizing process over product can encourage creative problem solving, ethical judgment, and innovative thinking. For IS educators, this means aligning assignments, tools, and learning outcomes with skills required in the workplace.

At the same time, widespread availability of artificial intelligence capabilities in productivity tools and creative applications signal that the original 4Cs are no longer sufficient on their own. AI is transforming our understanding of what it means to think critically, create original work, collaborate effectively, and communicate with specificity. Students must now be prepared to evaluate AI-generated information, understand its limitations, and communicate how AI was used in the process of problem solving. This requires awareness of AI literacy, ethics, and the ability to collaborate wth an AI agent as extended 21st Century Skills.

Finally, to answer the question posed as the title of this paper, how have 21st Century Skills evolved, and how is AI shaping their next evolution?

21st Century Skills remain relevant in the 21st Century, but only when they continue to evolve to reflect contemporary technologies, learning environments, and workforce demands. This shift requires IS educators to realign curricula, assignments and assessment strategies to prepare students to use technology responsibly and creatively and make sense of their results. 21st Century Skills including the 4Cs now form the foundation for an expanded skill set in the AI era that supports learning, innovation, and responsible participation in an AI-enabled world.

10. ACKNOWLEDGMENTS

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Teaching Case – Student Materials

Paddles for Paws: Development of a Pickleball Tournament Event Management Database for a Cool Cause

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Hook

Whispering Hills' Animal Shelter staff are hot under the collar… literally. Their air conditioner has had electrical problems and needs significant repair and possible replacement so the animals and workers can chill out. Volunteers at the facility plan to host a pickleball tournament fundraiser in hopes of raising much needed funds. The shelter needs our help to develop an event management system that they can use to track tournament players and volunteers.

Abstract

The unprecedented increase in popularity of pickleball has driven Whispering Hills' Animal Shelter to consider offering a pickleball tournament to raise funds to repair the shelter's air conditioner. In this teaching case, students engage with a simulated client requirements' interview process to design and develop a database system for a pickleball tournament fundraiser. This immersive approach allows students to practice eliciting and documenting system needs and requirements for an event management system, focusing on players, teams, and volunteers. The case can be used in a systems analysis and design or database development course. Multiple assignment options are provided, allowing instructors to select an assignment based upon course material coverage. Suggested assignments include the development of process modeling diagrams such as data flow and swim lane diagrams, database design diagrams such as UML diagrams or ERDs, and database artifacts such as tables, queries, and reports.

Keywords: Teaching Case, Process Design, Swimlane Diagrams, Database Design, Tournament Event Management

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Paddles for Paws: Development of a Pickleball Tournament Event Management Database for a Cool Cause

Dana Schwieger

1. CASE STUDIES

Case studies provide faculty with the opportunity to incorporate simulated experiential learning opportunities into the classroom to allow students to practically apply course learning (Jenkins & Allen, 2017). Case studies engage students in the learning process and support higher order thinking as well as the development of several skills including creative problem-solving, analytical, interpersonal, communication, and teamwork (Cappel & Schwager, 2002; Freeman & Zhang, 2022).

Although working with community clients would be a more ideal approach to hands-on learning, identifying appropriate projects and working with willing clients can be challenging and adds to the complexity of content coverage. (Wharton & Parry, 2012). Written case studies, like this manuscript, provide instructors with the opportunity to provide realistic experiential learning opportunities to students without the additional concerns of managing external client expectations.

The pickleball tournament scenario was chosen due to the sport's rapidly growing popularity. The case and associated assignments were designed to give students the opportunity to apply course concepts to a simulated real-world setting. The author regularly incorporates case studies in her MBA MIS course and has written several similar cases focusing on business case writing and systems design and development concepts, all set within the fictional community of Whispering Hills.

2. INTRODUCTION

Nonprofit organizations, such as animal shelters, often operate on limited budgets. Many of these facilities serve communities where a significant portion of the residents earn below the median U.S. household income level (Alley Cat Allies, 2025). While annual budgets may be prepared to cover some unexpected expenses, discretionary dollars are typically limited. In this case, Whispering Hills' Animal Shelter faces the unexpected expense of a broken air conditioner and turns to a pickleball tournament to help generate some additional funds. Shelter administrators would like to develop a pickleball registration database that can be used to register participants, keep track of tournament play and volunteer assignments, and facilitate communication with players and volunteers before and after the event.

3. SETTING THE STAGE

Whispering Hills Animal Shelter is a donation-supported animal shelter. Like many facilities, they rely on local volunteers to help run and support operations.

Lisa and Mark Williams are strong community supporters with Lisa serving on the shelter's board as well as volunteering. As the case begins, Lisa is reviewing the shelter's budget in search of extra funds to allocate for the unexpected air conditioning problem. Her husband, Mark, is returning from playing pickleball at Pickleball Pete's Pickleball Complex. He is excited to share good news about a possible fund-raising pickleball tournament opportunity. Sandy, an MBA student who has previously assisted them with system development projects, will be brought onboard to interview Pete about the pickleball tournament process as well as the data and reports that would need to be collected and generated to make the event a success.

4. THE BROKEN AIR CONDITIONER

"Okay, Pete's is on board!" Mark excitedly exclaimed as he shut the front door and set his racket on the dining room table.

"What are you talking about?" his wife Lisa asked as she looked up from her spreadsheet.

"When I left the house this morning to play pickleball, weren't you combing the shelter's budget to find some line items you could trim to cover the costs of the broken air conditioner?"

"Yes," Lisa sighed, "that's what I am still doing. Summer will be here before you know and we need to get the air conditioner problem fixed before the heat sets in."

5. THE PICKLEBALL SOLUTION

Mark smiled, "I think I have a solution. As I was driving to Pickleball Pete's Pickleball Complex, I started thinking about how we could raise money to cover the costs of getting a new air conditioner or, at the very least, repair the old one. I ran into Pete, the complex owner, and told him about the shelter and its air conditioning problem. Pete offered to let us use the complex for a pickleball tournament. He thought it could provide some great exposure for the facility while supporting a good cause. What do you think?"

"Wow!" Lisa exclaimed. "With pickleball's popularity and the soft spot the shelter holds in our community, I think it's a great idea! However, I'll bet there's a lot of data that will need to be managed with the participant registrations, volunteers, and tournament play. I don't know anything about tournaments. Do you think that Pete would be willing to meet with Sandy, our MBA intern, to explain the pickleball tournament process and the data that we would need to collect?"

"I'll give Pete a call while you contact Sandy," Mark offered. "He said he would do whatever he could to help, so it's just a matter of finding a time to meet."

6. THE MEETING

"Thank you for finding time to meet so quickly," Sandy said to Pete as she took a seat in the snack bar of the pickleball complex the next day. "I don't know much about pickleball or hosting a pickleball tournament. Would you mind giving me an overview?"

Registration Form

"Of course," Pete began. "Before you start advertising the event, you'll need to create a tournament registration form for players. I have an old one that you can use as a template (Appendix A). You will also want to have the players fill out a liability release form so that neither the shelter nor the pickleball complex are held liable should someone get hurt. That is a standard form that we give out to anyone who plays at our facility; so, I will provide you with that. You will want to collect those and track whether each player submitted the form.

"I suggest that you have players submit their forms and registration fees to the shelter about five days before the event. This will give office staff time to enter player data, deposit fees, set up the brackets, and place last-minute t-shirt orders. Once you have the brackets set up, you can enter the data for the first round of tournament play into your database. Office staff can run a report for the first round that can be used to direct players to their assigned court at player check-in. I'll give you a copy of a bracket that you can use" (Appendix B).

"During the tournament," Pete continued, "your event administrators will need to maintain the brackets and update round progress in your database based upon the reports they receive from the runners. This information will be helpful throughout the event and for creating awards and certificates at the end."

Pickleball Games

Pete began by explaining how the tournaments were usually run. "Each game is typically played to 11 points with the winner needing a two-point lead," Pete said. "If a score is tied at 10-10, play is continued until one player gets a two-point lead. Matches are usually best-of-three games with the winner advancing after two victories. Tournaments are generally structured as double elimination play, meaning that the team is eliminated after losing two matches. This format ensures each team plays at least four games, making the cost of the tournament more economical to the players.

"Since this is your first pickleball tournament, I suggest only offering doubles tournaments, or games for teams of two players. You can offer beginner and advanced tournaments for men's doubles, women's doubles, and mixed teams doubles which consist of a male and a female. I can provide you with eight courts for your tournament; so, you will be limited to 16 teams playing simultaneously. Thus, you may want to use four courts for the men's tournament and four courts for the women's. The mixed doubles tournament will need to be offered separately since some of the players may participate in multiple tournaments.

"Although pickleball play is generally self-officiated, you will probably want to have one referee per game as a neutral set of eyes. Although this is supposed to be a casual tournament for fun and fundraising, some players take their game play seriously, so having a referee for each game would be a nice courtesy to provide."

7. EVENT MANAGEMENT

"As popular as pickleball is," Pete continued, "you might be able to find some cloud-based programs

that will meet your needs. I think you may want to investigate purchasing access to pickleball tournament software before designing and building a custom database?"

"That's a great suggestion," Sandy replied. "The shelter's budget is tight; so, I am not sure what they can afford… but, it's worth investigating to find out how much the software costs and what it looks like. Since we are here, could you continue and explain the types of data collected for pickleball tournaments, how it is used, and the reports that are needed to hold a successful event?"

"Of course," Pete said. "I'm not a database expert," Pete added, "but I did have a couple of programming classes when I was in college, so I will try to talk in terms of the data you will need to collect and use.

"Coding bracket management could get a little complicated, so you may want to focus your database on event and participant management rather than assigning teams to matches and courts. You can track brackets manually on paper this year. There is plenty of data you are going to have to collect and reports you will want to create regarding players, rounds, and volunteers without having to worry about brackets, too."

Timeline
Lisa looked thoughtful. "How should we begin?"

"Before the event starts," replied Pete, "you will want to record data about the event, tournaments, players, teams, volunteers, and volunteer job roles. After each round, you will want to record the round's match results for each team, or two records per court. I've participated in a pickleball tournament or two, so let me try to break down the event and roles for you a bit."

Event
"If this event is successful and you decide to host it again," Pete said, "we can include an event table that can help with future planning. The table would contain fields that could be completed before the event began such as an event ID, name, the start and end dates/times, and a description. You might also want to include the location name and address as well as a description of the event that you can use for future flyers and advertisements. The event manager's ID should be included, too, so you will know who is responsible for the event. You would also want to include some fields that would be completed after the event such as total costs, amount raised, and a notes field for any additional details that you would like to record. The notes field might be helpful to include for each entity on which you are collecting data."

Tournament
"Since you plan to have women's, men's, and mixed tournaments for intermediate and advanced players," Pete continued, "you will want to collect information on your tournaments as well. You will want to include a type field to distinguish the different types of tournaments: men's, women's, or mixed. However, in the future, you may want to add additional options to this field to include tournaments for youth and singles' tournaments. If the tournament is as popular as I anticipate, it may stretch across multiple days in the future, so you may also want to include a date field. Thus, the fields you might want to include for this entity are the event ID, tournament ID, type of tournament, date, skill level, and notes."

Players
Pete thought for a moment. "Data collected about the players will mostly come from the registration forms and include their first and last names, address, city, state, zip code, cell phone, email address, skill level, age class, gender, t-shirt size, emergency contact information, payment and form of payment, and liability form submission status. You will also want to include the event ID field and create a player ID field to uniquely identify each player."

Teams
"The role of the Teams table," Pete continued, "is to identify the teams and their members as well as the tournament of play and skill level. Thus, this table will include the event ID, a generated team ID, team member 1's ID, team member 2's ID, the skill level of the strongest player, and the tournament ID in which the team plans to participate. A player may be listed in two records if they participate in the men's or women's tournament as well as a mixed doubles tournament. You might also want to include a notes field to record any data that would be helpful to reference in the future."

Workers
"We also want to collect data about the volunteers who work the event," Lisa interjected.

"Sure," Pete responded. "The people who work the event will probably include shelter administration and staff as well as community volunteers. I have an example of a volunteer registration form that can give you an idea of the type of data that is collected. (Appendix C) The

volunteer registration form will contain the volunteers' data such as their first name, last name, address, city, state, zip code, cell phone, email address, age, role with the facility (such as an administrator, employee, or volunteer), job preference, work timeframe availability, guardian's name and cell phone (if applicable), t-shirt size, job preference, liability release form submission status, and notes. You will also want to include the event ID and create a worker ID number to uniquely identify each worker."

Worker Roles
Pete paused, thinking about what else might be needed. "Some of the roles that you may need for the tournament are setup, registration desk, snack table, referees, runner, administration, and clean-up. The runners will collect match results throughout the event and relay this information to administration. Administration will oversee maintaining the brackets and assigning teams to courts for each round. Some of the fields that you might collect to describe this entity would be role ID, role name, role description, and a notes field."

Worker Assignment
"You will want to use this table to match your workers to their roles, their tournament, and for some, their court. Thus," Pete continued, "you may want to include the event ID, tournament ID, worker ID, role ID, court ID, and notes. The notes field might be used to store reminders for the event, or it could be used after the event to record notes about role performance or concerns the volunteer voiced about the role."

Rounds
"For each round in the tournament," Pete said, "you will want to record the event ID, tournament ID, round ID, court ID, round date, and round time. You might also want to include a notes field to record anything that might be helpful to know about rounds for future events."

Match.
"Each round," Pete continued, "would have multiple matches playing simultaneously on multiple courts. The match table would consist of the event ID, round ID, match ID, court ID, winning team ID, and, again, a notes field to record anything you might need to know for the future."

Games
"There are at least two, and possibly three, games," Pete noted, in each match since a team must win two games to win the match. This table will identify the teams, scores, and winners of each game. The fields that you might want to include in this table are Event ID, round ID, match ID, game ID, team 1 ID, team 2 ID, team 1 score, team 2 score, the winning team's ID, and any notes you would like to remember."

"From the game play perspective," Pete said, "since you will handle tournament court and team assignments using a bracket, there will not be a lot of reports. While you finish writing your notes, I'll sketch out my thoughts for the reports."

8. REPORTS

Based upon Pete's work with pickleball tournaments, he thought the following reports would be beneficial to the tournament's success.

Team Rosters
Pete thought that a roster of teams and their members would be needed before, during, and after the event. The roster would include the team ID number, the team member names, their skill level, and the tournament in which they were playing.

Round Results
He also thought that Round Results reports would be helpful to keep track of round performance during and at the end of the event. He suggested that the report include the tournament ID, round ID, court ID, team IDs, team member last names, scores, and result. (Appendix D)

Volunteer Assignment Lists
Since volunteers are integral to the success of the event, he also thought that lists of volunteers and the roles they were assigned would be beneficial. Pete noted volunteer assignments that would be helpful include a referee for each court, people to help setup, registration desk workers, volunteers on the floor making sure that the players have water and snacks in the rest area, runners to handle any issues and to relay round results to the tournament administrators, and tournament administrators. He thought this report might include the tournament ID, volunteer ID, their name, their phone number, when they can work, and their assigned tournament role.

Participation Certificates and Emails
Sandy thoughtfully looked at Pete's notes, "Those look great. We could also use the database to create awards and participation certificates for the tournament winners, players and volunteers as well as send out courtesy reminders before the event to remind everyone of the location and starting time." (Appendix E) "We could also inform the volunteers of their role assignment for the event in their email. After the event is over,

we could send out thank you notes to both the participants and the volunteers. Hopefully, the event will be so successful that we will want to host it next year and can use it in the future to invite people to participate in the bigger and better multi-day second annual event!"

9. WRAPPING UP

Sandy paused for a moment. "Wow, Pete! You've been a great help! Thank you for your expertise. Your knowledge of pickleball and databases has really given me a jumpstart in this project. If you are available, I would like to meet with you again after I have had some time to read through my notes and diagram out the process and database model to see if there is anything that I missed or did not understand before moving forward."

10. ASSIGNMENTS

This project offers multiple learning paths depending on the role and activities your instructor has in mind. Confirm your assigned role and tasks with your instructor.

Process Model Diagrams
Assume the role of Sandy, the MBA student. Create diagrams illustrating the functional process steps for the player registration and volunteer registration and role assignment process to verify that you have identified all of the steps and understand how the pickleball tournament event management process works.

1. Create a diagram modeling the event management process.
2. Write a short narrative to accompany your diagram to verify and support your interpretation of the process.
3. Once the narrative is written:
   a. Compare the narrative to the diagram to identify and/or clarify missing steps in the process.
   b. Compare the narrative to the actual description in the case to identify missing steps in the diagram or areas needing clarification.
4. As the diagram is developed, record any assumptions or interpretations you make, regarding the process, in a separate document.

Data Flow Diagrams
Assume the role of Sandy, the MBA student. Create a data flow diagram to illustrate the flow of data through the pickleball tournament event management process to verify that you understand how the data is collected, processed, stored, and disseminated.

1. Create a diagram modeling the flow of data through the process.
2. Write a short narrative to accompany your diagram to verify and support your interpretation of the process.
3. Once the narrative is written:
   a. Compare the narrative to the diagram to identify and/or clarify missing steps in the process.
   b. Compare the narrative to the actual description in the case to identify missing steps in the diagram or areas needing clarification.
4. As the diagram is developed, record any assumptions you make regarding the processes in a separate document.

Research Commercially Available Software Packages
Assume the role of Sandy and use AI as a starting point to help you research commercially available pickleball tournament management systems. Be sure to verify the accuracy of the results provided and delve deeper into the system recommendations. Write a short memo to Lisa describing the two best products available. In your memo, provide:

- the name of the software;
- the URL to the software's website;
- the cost;
- how the software is accessed (cloud-based or installed locally);
- a brief description of the software and its capabilities;
- pros and cons of the software; and
- your recommendation, buy or build and if buy, which one.

Systems Analysis Design and Database Development
Assume the role of Sandy, the MBA student, in building the database.

1. Accumulate the functional and technical requirements for the system.
2. Prioritize the requirements.
3. Create system development diagrams.
4. Create a data dictionary.
5. Create the database.
6. Create queries to generate records needed for player and volunteer check-in, team rosters, round results, volunteer assignments, and data needed for various mail-merged emails (e.g., participation certificates, winner award certificates,

thank you letters, and general communication).
7. Create reports for the queries including attendance, team rosters, round results, volunteer assignments, and informational emails and letters to players and volunteers.
8. Sandy needs to incorporate privacy, security, and data error handling measures throughout the database. Include a brief written report describing:
   a. the measures that were taken,
   b. the data those measures will protect, and
   c. how those measures will protect the data.
9. Use AI to generate records to populate your database.
10. As the database is developed, record any assumptions made in a short report.

Future System Enhancements
Once the initial system has been developed, future updates can be made to further enhance its capabilities such as:

1. Version 2.0 enhancements such as automated bracket team assignment, automated court assignment, and the addition of singles and youth tournaments,
2. Automation of reports and messages,
3. Enhanced privacy and security measures,
4. Integration with other systems,
5. Scalability, and
6. Data analytics.

Students may want to:

1. Write a short narrative explaining how one or more of the capabilities could be incorporated into their system and the value those capabilities would provide for the organization.
2. Incorporate one or more of the capabilities into your system.

11. POTENTIAL CHALLENGES & OBSTACLES

System Complexity
The tournament management system is somewhat complex. Students should focus on creating the people-oriented portions first (players and volunteers) and then incorporating more of the tournament management details.

Time Management
Projects normally take longer than one would expect. Breaking the project down into small goals to be completed over a period of time will allow time for asking the instructor questions that may arise.

Diagrams and Symbols
Should a student be unfamiliar with business process mapping or data flow diagrams, there are many resources available online that describe the diagrams and provide examples of the diagrams and their symbols including:

- Creately Business Process Modeling Techniques with Examples: https://creately.com/blog/bpm/business-process-modeling-techniques/
- Asana's Guide to Process Mapping Process Mapping https://asana.com/resources/process-mapping
- The tutorials associated with business modeling software such as Lucidchart, draw.io, smartdraw.com, and Viso.

12. CONCLUSION

After Sandy developed her database vision, diagrams, and mock-ups, she met again with Pete to review the details. Once she felt comfortable with the plan, she met with the shelter's board to discuss what she had found.

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APPENDIX A

Player Registration Form

Organization Name

Pickleball Tournament Fundraiser

Player Registration Form

First Name: _____ Last Name: _____

Address: _____

City/State: _____ Zip Code: _____

Email: _____ Cell phone:_____

Skill Level: (Circle one) Intermediate Advanced Gender: ___ Male ___ Female

T-Shirt Size: (Circle one) S M L XL XXL Age Class: ___Teen ___ Adult ___ Senior

Emergency Contact

Name: _____ Cell phone: _____

Events

_____ Men's Doubles Partner Name _____

Need Partner: _____ Yes _____ No Partner Skill Level: _____

_____ Women's Doubles Partner Name _____

Need Partner: _____ Yes _____ No Partner Skill Level: _____

_____ Mixed's Doubles Partner Name _____

Need Partner: _____ Yes _____ No Partner Skill Level: _____

The tournament is a double elimination tournament. You must play in the higher skill level if partners are not the same skill level. The tournament will be double elimination. Top bracket matches will be 2 out of 3 games to 11 points with a win by 2.

Fees:

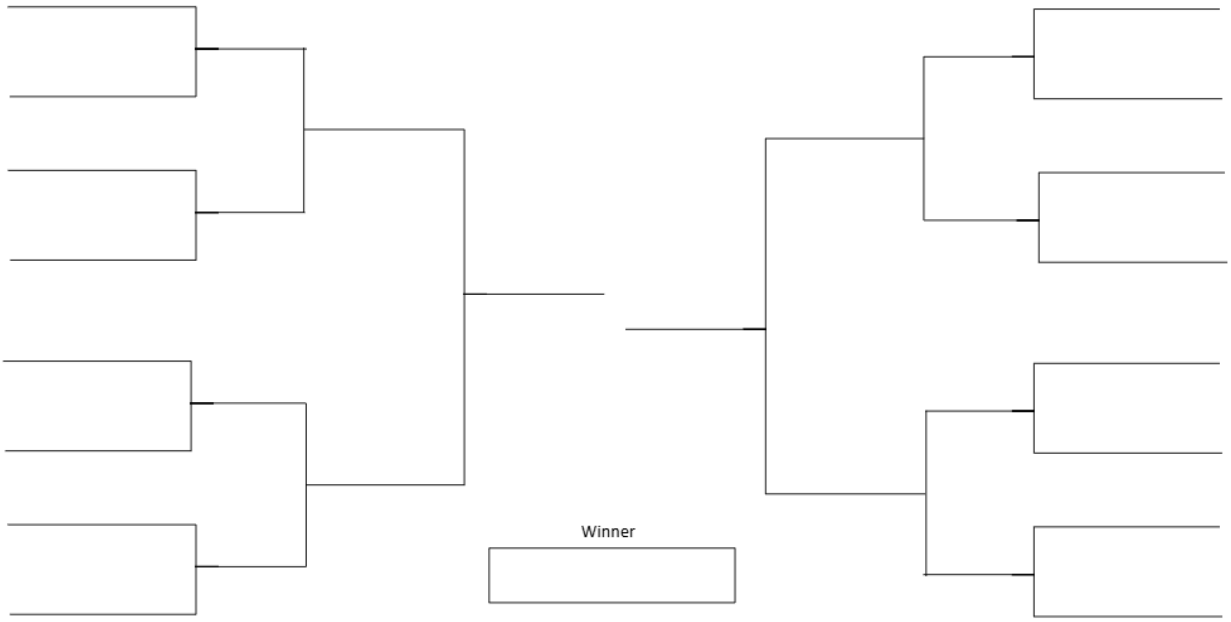
$25 per person for first tournament
$10 per person for the second

Make checks payable to Whispering Hills Animal Shelter. Amount included: _____

Liability release form included: _____ Yes _____ No

APPENDIX B

Bracket Example



APPENDIX C

Volunteer Registration Form

Organization Name

Pickleball Tournament Fundraiser

Volunteer Registration Form

First Name: _____ Last Name: _____

Address: _____

City/State: _____ Zip code: _____

Email: _____ Cell phone:_____

Age: _____ Gender: ___ Male ___ Female

Shelter Relationship: (Circle One) Volunteer Employee Administrator

T-Shirt Size: (Circle one) S M L XL XXL XXXL

Guardian Contact Info (If under 18 years old.)

Name: _____ Cell phone: _____

Emergency Contact

Name: _____ Cell phone: _____

Volunteer Interest

Time Availability of Event: ____ Morning ____ Afternoon ____ All Day

Job Role Preference (Please rank 1 to 3 with one being top interest)

____ Setup ____ Registration ____ Snacks ____ Referee ____ Runner ____ Cleanup

APPENDIX D

Pickleball Round Results Report Example

Round Results

June 2025 Doubles Pickleball Tournament

	Tournament ID	Round	Court ID	Team ID	Team Names	Score	Results
1	MenInt01	Rnd01	Crt01	MID01	Anderson/Wilson	2/3	Won
2	MenInt02	Rnd01	Crt02	MID02	Brown/James	2/3	Lost
3	MenAdv01	Rnd01	Crt03	MID03	Smith/Carter	2/3	Won
4	MenAdv02	Rnd01	Crt04	MID04	Thomas/Robins	2/3	Lost
5	WomInt01	Rnd01	Crt05	WID01	Davidson/Jones	3/5	Lost
6	WomInt02	Rnd01	Crt06	WID02	Warren/Miller	3/5	Won
7	WomAdv01	Rnd01	Crt06	WID03	Brown/Thomas	2/3	Won
8	WomAdv02	Rnd01	Crt08	WID04	Anderson/Wilson	2/3	Lost
9	MixInt01	Rnd01	Crt01	XID01	Wilson/Wilson	3/5	Won
10	MixInt01	Rnd01	Crt02	XID01	Brown/Brown	3/5	Lost

Appendix E

Email to Volunteer Report Example

Whispering Hills

Dear Amanda,

Thank you so very much for volunteering to help at the Whispering Hills' Animal Shelter pickleball tournament. The Shelter would not be able to continue without supporters like you. We are so grateful for you and your assistance.

Just a reminder, the event will start at 8:00 a.m. on Saturday, June 7th. We are asking volunteers assigned to registration to arrive 1 hour before the event starts and all other volunteers to arrive 30 minutes before their shift starts to sign in and get instructions.

You will be helping with: **Snack bar**

Just a reminder, Pickleball Pete's is located in Whispering Hills, MO at

1000 Main Street

For questions, please contact the office at (555) 555-2222.

Sincerely,

Lisa

Whispering Hills' Animal Shelter

Tel (XXX) 555-2222 100 Shelter Lane
Fax Fax (XXX) 555-2223 Whispering Hills, MO 63901

Teaching Case:

From Concept to Canvas: Leveraging Generative AI to Co-Design Business Visuals

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"AI won't replace humans – but humans with AI will replace humans without AI" (Lakhani, 2023). Using AI for problem solving and engaging with a variety of tasks is becoming a critical skill for future work. More importantly, learning how to collaborate with AI rather than allowing AI to lead is vital. This teaching case presents embedding the creation of business visuals (e.g., sample product images and posters) with Generative AI into class projects to teach collaborative and co-creation skills. Students are taught fundamentals of prompt engineering and then use those skills to design and evaluate the GenAI output to create business visuals.

Abstract

Since ChatGPT was initially introduced in 2022, a variety of Generative AI (GenAI) applications (apps) and tools have been released. To foster the skill of co-creation and collaboration with GenAI, we designed a project-based task to generate images and create posters. To let students learn the skills and explore the AI tools, we embedded image generation into two projects in an introductory course of business operations and supply chain management. In this paper, we describe the GenAI task requirements, GenAI apps/tools used, and the students' learning outcomes from the task.

Keywords: Generative AI, ChatGPT, Google Gemini, Prompt engineering, Image generation, Business operation and management.

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From Concept to Canvas: Leveraging Generative AI to Co-Design Business Visuals

Fang Chen, Bryan Hammer, Shawn Clouse and Patricia Akello

1. INTRODUCTION

Generative AI (GenAI), such as ChatGPT and Google Gemini, is an innovative technology transforming business, industries and educational practices. Since the first release of ChatGPT in November 2022, both the number of GenAI apps/tools and the functions of these GenAI tools have been evolving quickly. Within pedagogical circles, educators have proposed and experimented on methods for incorporating GenAI into teaching and learning (e.g., Firth & Triche, 2024; Huo & Siau, 2024; Jiang & Nakatani, 2025; Lang & Gurpinar, 2025; Petrovska, et al., 2024; Van Slyke et al., 2023; Xu, 2024). For example, Firth and Triche (2024) designed and implemented a project for an entry level MIS class requiring teams to create a short video to describe what Management Information Systems is. Students used text prompts to generate a photo-realistic avatar, create scripts of explaining MIS, translate the text script into a voice using a voice generator, and then merge together all elements in an AI-generated video. The teaching case by Firth and Triche showcases GenAI for content generation. Our case is also about content generation, but in a different context: product design and marketing.

In our introductory course of business operations and supply chain management, we implemented two projects. For Project 1, teams created a business plan to make a physical product. One task for the project was to create images to illustrate sample products, and a poster of the product by using AI generated images. For Project 2, teams find a local business, interview the employees and report on the organization's supply chain and business operations/processes. As part of Project 2, teams created two posters for their chosen business: one poster with an AI generated image, and the other without using AI-generated image.

Embedding the implementation of AI within a project instead of an individual assignment is based on two reasons. First, the project provides a real-world context for image generation by offering real-world boundaries, limitations and general guidance for creativity. This allows the students to use GenAI within the confines of real-world situations, rather than a sanitized situation. Second, the evaluation of the images and posters is grounded within a specific business context for each group, implying the evaluation of the output for each group will vary. This is intentional because the image and poster creation is a creative process deserving of a flexible evaluation, rather than a restrictive one which often results in student submissions all resembling one another.

We integrated the two projects for two semesters into multiple sections. For the remainder of this paper we introduce the course, describe the two projects, discuss the image/poster-making requirements, and report the project results, our reflections, and potential improvements of the GenAI creation activities for future classes.

2. COURSE CONTENTS AND TWO PROJECTS

Our course is a second-year core course for all undergraduate business students. It is offered in a traditional face-to-face mode. The course provides an end-to-end overview of business operations and supply chain management: sourcing, manufacturing, to delivering goods and services with support from supply chain, accounting, finance, marketing, and management information systems.

One of the learning outcomes is to understand the elements involved in the design and development of a product from an operations management perspective. The design of a product includes what a sample product would look like. The task of creating images of the sample product is a great fit for GenAI usage. There are no prerequisite knowledge or skills for using GenAI. Many students had some experience using ChatGPT, but few students had experience of image generation or poster creation with GenAI.

To deepen students' understanding about business operations and provide a real-world context, we provided two team projects during the semester. For Project 1, teams are required to make a business plan to manufacture and sell a tangible/physical product so that they can think through the entire process of making and selling a product: defining the product, business strategy

(e.g., uniqueness of your product or how your business differentiates from competitors), targeted customers, designing sample products, budgeting and pricing, sourcing strategy and suppliers, facility location and layout, manufacturing process, quality standards and quality control, marketing, distributing/selling products, and the milestones for the first three years in terms of company size or sales. Please refer to Figure 1 for the content of both projects.

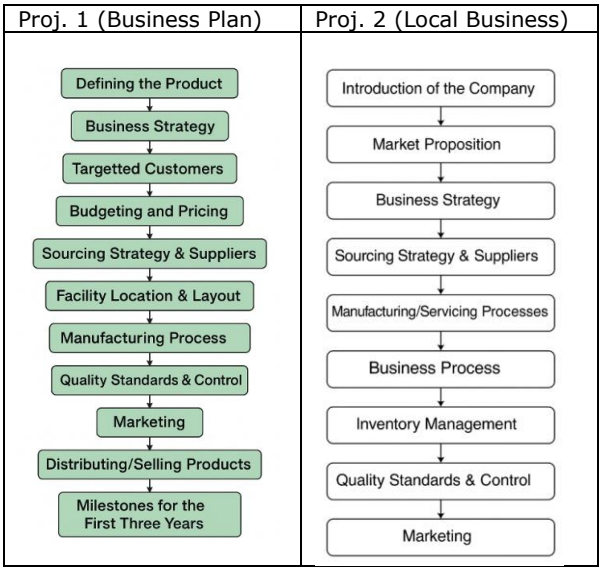

Figure 1: Project 1 and Project 2 content (both diagrams were generated with ChatGPT)

Teams make a poster to advertise or promote the product. While GenAI was allowed for the entire planning process, we only focus on using GenAI to make images for a sample product, and a poster to advertise the product. The poster has the following requirements: Product name, at least one AI generated image, price or price range of the product, location of the company or places where people could purchase the product (teams can make up a location). Please see Appendix A for the poster guideline.

Each team is required to generate at least three images for the poster and select one to be included in the poster. In a Word file, they document their conversation with the AI by including the text prompts and images generated. Students then explain in writing why they chose one of the images for the poster. For Project 2, teams selected a local business and interviewed employees to obtain information about business operations. Project 2 included the following requirements: Introduction of the company (e.g., founders, founding year, milestones of the company history, company size); company's market proposition (e.g., identifying major competitors and target customers), business strategy, sourcing strategy and suppliers, manufacturing/servicing processes, business process, inventory management, quality standards and quality control, marketing, challenges and improvements, and lessons learned.

Project 1 and Project 2 were allocated 15% and 25% of the final grade, respectively. Each poster was worth 2% of the final grade.

3. IMPLEMENTATION

Implementation

We first implemented the projects in the Fall semester of 2024 with two sections, about 90 students in total. Each class was 15 weeks long. Each team had 3 to 5 members; one section had 11 teams, and the other section had 10 teams. We continued the projects in the Spring semester of 2025 for a single section with 9 teams and 41 students. Before the project started, the instructor asked students whether they had experience using GenAI to generate images. Only a few students had experience. To prepare students for image generation and poster-making, the instructor gave a presentation illustrating some sample text prompts with resulting images and posters.

For the project, teams were allowed and encouraged to use whatever tool they felt comfortable with. The instructor also presented some well-designed sample posters from the Internet; these posters seemed to use real images. These designs showed basic visual design principles, such as color scheme, positioning and proportion of sample products vs. text, contrast between background and text/images, and designs with background image vs. without background image.

After grading the posters for Project 1, the instructor selected well-designed images of sample products and posters from both sections, included them into a presentation, gave a feedback lecture with these images and posters, explaining why each of them was an effective visual design, and posted the presentation on the course website for all teams to learn from. For Project 2, teams made a poster for a local business by including at least one AI generated image. The purpose of the poster could be a general advertisement for the business, a particular event (e.g., Christmas sales), or a

specific product or service.

All teams in 2024 did a great job except for two teams, all teams in 2025 did a great job except for one team. One poster looked very cluttered, and the other two looked somewhat artificial, and thus did not look like posters for real companies. One team also told the instructor that they hoped they could use the real image of the products in the poster for the real business. As a result, we made a change for Project 2 (real business) for 2025. Teams needed to make two posters, one with an AI generated image, and one with a real/regular image. The purpose was for teams to see different effects with or without AI images.

Businesses/Products for the Projects

Teams made business plans for a variety of products, the majority of which fall into one of three categories:

1. Environmentally friendly products that use recycled materials, such as sandals with used car tire for soles, plastic cowboy hats and sunglass frames made from recycled plastic.
2. Key chains made from recycled corks and bottle caps; products made from locally/regionally sourced raw materials and serve the local/regional markets, such as fresh juice truck, burger truck, and fruity beer; or products with minimalism, such as re-usable tote-bag with cotton fabric and simple prints.
3. Products for outdoor activities such as shoes, jackets, facial mask for skiing, knee braces and jumping ropes.

For Project 2, the majority of teams chose to interview a company in retail industry for their project, such as a local store that sells lumber and building supplies, fertilizers, soil complements, teas, or athletic gear; or a chain store operated locally (e.g., Albertsons), and food or service industry, such as a cafeteria, restaurant, bakery, brewery, or healthcare.

GenAI Tools Used and Sample Posters

Teams used a variety of apps as listed below:

- Google Gemini
- ChatGPT
- Media Magic
- Midjourney.com
- Imagine.art
- Co-pilot
- Adobe AI
- Canva AI

Some teams used two apps to make posters. For example, using ChatGPT to generate an image, and using Canva to apply a poster template and add texts. Figure 2 provides some example posters.

Poster 1 Poster 2

Poster 3 Poster 4

Figure 2: Sample Posters

(Poster 2&4: business plans; Poster 1&3: real business. Business names and addresses were removed.)

Evaluating Posters

For posters with AI images, 40% of the poster grade was the inclusion of at least one AI generated image regardless of the quality of the AI image. Forty-five percent of the mark was to include other necessary components (e.g., product name or company name, price or price range of the product, location of the company or places to purchase the product). Fifteen percent of the mark was for the visual design (e.g., the product and the functions of the product are clearly specified or illustrated, and the usage of color, text font style and size are appropriate, etc.). Please refer to Appendix A for scoring rubric.

The effectiveness of visual design was subjective in nature; therefore, it was difficult to quantify the quality. Moreover, we wanted students to freely experiment with the tool to align the output with what they wanted to achieve; thus, we did not penalize them for "poor" visual design, which

could orient students to guess about the instructors' preferences, thus dampening their motivation and restricting their creativity.

As a result, we did not deduct marks for visual design unless the readability was an issue. Instead, we made detailed comments about the effectiveness of their visual design, so that students knew how to improve their future work if the design was not visually appealing or aligned with the product functions/features. Students seemed to like this marking mechanism. Teams felt proud when their work was showcased to the class as good examples so that all teams could learn from them. Learning the effectiveness of visual design could only be achieved by using numerous examples.

Other Business Visuals Generated with AI

In addition to creating images for sample products and created posters, some teams created images for company logos, packaging boxes, production facilities, and store fronts. These teams also created additional images to help illustrate the content for presentations. For example, a team planning to brew fruity beer used AI to generate images of a lemon orchard. Another team proposing to operate a burger truck used an AI-generated image to show the inside layout of the truck. Other teams used AI-generated images to illustrate meeting scenarios and business milestones.

The project description does not require students to generate images for these usages; however, once students learned how to generate images, they applied them to other parts of the projects. We were glad to see that by giving students a concrete task they surprised us with their creativity. We hope this "spill over" learning effect could be carried into other courses/areas. For example, most classes in business schools would require students to make presentations with Power Point slides. Students could generate AI images for these presentations.

4. STUDENTS' FEEDBACK

Teams were required to write a reflection paper about the projects. In the 2024 reflection paper, students included at least 3 AI generated images, their associated text prompts, and explain why they chose a particular image for their poster. To understand more about students' interactions with AI, the instructor added a list of questions for students to answer in the reflection paper in the projects of 2025. Please refer to Appendix B for Project 1 (business plan), and Appendix C for Project 2 (real business).

Instead of summarizing students' reflection by individual questions, we identified the major themes below, and we focused on summarizing the reflection papers from the 2025 class.

Human-AI Interaction: Fun & Challenging

Most of the teams specified that their human-AI interactions were both fun and challenging. They liked the freedom, efficiency, and creativity that GenAI provided but felt frustrated when GenAI could not deliver the visuals that met their requirements. Some of the frustrations were related to the poor quality of text generated by the AI.

The rendered text was either unclear (e.g., letters with broken strokes) or incorrect (e.g., "thrifted' would be spelled as "thriftd" or "thrifhd"). Another issue with AI image generation was that GenAI tended to generate a new image every time a user asked for a modification. This AI behavior was frustrating when a small change was desired, but not made.

Interactive & Iterative Co-creation Process

The image generation and poster-making process was an interactive and iterative process. Students usually had a general idea about how the product would look before they generated the first image. Some teams searched for sample posters to inspire their own posters; some teams did not rely on inspiration because they already had an idea of how their products or posters would look like.

This interaction and iteration followed a trial-and-error process. As students reviewed generated images, they learned to specify requirements more explicitly in subsequent prompts. The outputs also exposed implicit assumptions, prompting revisions to their designs. As one team commented, "*Each generated image revealed something new about specifying the layout, lighting, and color use. This influenced changes in both prompt wording and design expectations*." Prompt refinements included adding or removing elements, adjusting text, and modifying visual components such as the color scheme.

This iteration process was guided by students' overall design purpose or taste, which could be illustrated by the process of Poster 3 in Figure 2. This poster was made for a local beer brewery. This team combined two images: the background of a hops field, and the center image of a beer bottle with a glass of beer. The brewery owner had German heritage; therefore, the team tried to add German elements into their design. Their first AI image was a German beer stein; the

second image was a beer bottle and glass with a Bavaria hops field in the background, and a big old German house on the left side. They determined that a beer bottle and a glass of beer were more visually effective than a beer stein, leading them to generate a third image featuring both, with appropriate labeling. The background was generated separately; in the revised version, the houses are smaller and situated in the hops field, allowing the product (beer) to stand out more clearly. This team used Canva for image generation and a poster template. The red band highlighting the company's name and address is visually striking, and the overall design conveys a high-quality product with a sense of enjoyment. Personal taste and subjective judgment played an important role throughout the iterative process.

Effective Text Prompts

Teams relied on various styles of text prompts that were effective for image generation. Some teams specified a general approach, some formulated specific techniques, and others commented that effective prompts were context dependent. For example, the following prompts from two distinct teams specified a general approach:

> *When developing a prompt, it should not be too complicated or too vague, it is important to strike a balance.*
>
> *An effective text prompt is a prompt that is specific enough to have basic needs but also simple enough to allow the generator (AI) to understand.*

Other teams specified more specific techniques, as illustrated by the two examples below:

> *An effective text prompt is detailed and concise that lays out what you want in the image such as the subject and background.*
>
> *Effective text prompts, we realized, required a descriptive but focused layout or mood when applying a new prompt, as well as including color and lighting cues and mentioning the desired elements wanted for the end design.*
>
> *This prompt formula generally yielded good results: "Generate an image of [main desired image], [background description], [realism level], [lighting choice]."*

Another team commented that effective text prompts were context dependent.

> *The effectiveness of a prompt depends on your expectations. Since I was open to various vintage earring styles, a specific prompt wasn't needed. However, when strict guidelines are required, they must be clear for the best result. Detailed guidelines for the vintage outfit image led to a quick find, while the simpler hat prompt took more time to match the poster design.*

Posters with AI vs. Non-AI images

In the reflection paper, students were asked to answer 3 prompts: 1) how much time they spent to create each of the posters (AI poster and non-AI poster), 2) which one was easier to create, and 3) which one was more visually appealing. Students spent 30 minutes to 2 hours on each poster. Some students said creating posters with natural images was easier because they simply chose an image, used a poster template, and added text to the template; whereas other teams said relying on natural images was more difficult because it was time consuming to find a natural image that meet their requirements and to format posters manually.

As for which one is more visually appealing, some teams indicated that their AI poster looked more visually appealing while others specified the opposite. Two teams had insightful comparisons about the two styles: Instead of directly comparing two posters just on the "look and feel," they said the posters provide different purposes. For example, one team (i.e., posters for a bakery) said, "The AI poster looks more appealing. It has more of an aesthetic to it than the non-AI one which is more informational."

The other team (i.e., posters for wood products) said,

> *Visually, the (Non-AI) poster took on a more informational and grounded style. It resembled a company catalog or in-store flyer, which helped give it an authentic and practical appeal. The clean alignment of pricing, product names, and contact information made it very clear and easy to read. However, compared to the AI poster, it lacked a bit of flair or emotional draw*.

This suggests the poster design choice is not simply about the visual appeal, but also the function of how the poster is expected to be implemented or used.

Students' Perceptions about AI's role

The 2025 students were asked who contributed

more to the posters with AI images, a human or AI. The majority of teams did not directly specify who contributed more; instead, they emphasized the different roles that humans and AI played in the co-creation process. As the comments below indicate, humans play the role of conceptualizer and governor while AI is the executor that vision.

> *The AI tool significantly contributed to the visual foundation of the AI-assisted poster. However, human input remained essential for conceptualization, prompt engineering, image selection, and finalizing the general look of the poster.*
>
> *The AI's limitations means that there needs to be continued human involvement for direction, evaluation, and control.*
>
> *This project showed us how using AI gave us a huge advantage in terms of time, quality, and creativity. However, AI didn't do everything. It didn't know our target audience, understand class expectations, or catch every visual inconsistency. It was a powerful tool, but we were decision-makers.*

Students Perceptions about AI's Impact on Job Market

Students in 2025 were asked to reflect on the following statement within the context of the workplace: "AI won't replace humans – but humans with AI will replace humans without AI". All teams agreed with this statement. They commented that AI would replace standardized and repetitive work easily, but a lot of work still needs to be done with human involvement and guidance, as illustrated by the following comments.

> *AI didn't do the work for us—it extended our capabilities. It helped us communicate better, iterate faster, and present more effectively. But we still had to guide it with intent, filter the outputs, and make critical decisions. Students who pair human judgment with AI will absolutely outperform those who don't.*
>
> *GenAI was like a silent team member that made everything smoother—from generating visuals to organizing our research. While it didn't replace our creativity or teamwork, it absolutely elevated our performance. We now better understand how to use AI as a collaborative partner rather than a replacement.*

These comments emphasize the idea that humans and AI complement each other, rather than the idea that AI will replace humans entirely.

5. REFLECTIONS

Traditional learning vs. learning with AI

One revelation of this image generation practice was that learning GenAI can be "exploratory" in nature, not only in the sense of learning it via trial and errors, but also in the sense of loosely defined quality of the final deliverables and certain level of vagueness and uncertainty during the processes of achieving the final deliverables. For example, the effectiveness of visual design was only loosely defined with examples. We only provided limited guidance about the image generation process and did not provide any instructions about how to make a poster.

In the traditional way of teaching and learning, instructors are usually expected to be an expert in the tasks assigned to students. For example, if an instructor needs to teach using Python or Power BI to engage data analysis and make actionable recommendations about the analysis results, she must go through the entire process by herself and know the tools very well so that she can teach the skills. With GenAI tools, it is different; we can specify what the final deliverable would look like and let students figure out the process largely by themselves. All we need to do is to design the tasks with a clear learning objective and specifics of the final deliverables and let students experiment. Using mountain hiking as an analogy, in the traditional teaching, the entire class would hike the same trail, experience the same process, and reach the same peak. In our GenAI practice, the instructor stationed at the base camp on the mountain, informs what students should bring back from the hiking trip (e.g., photos of certain species of trees, shrubs, rocks, birds, or flowers), then allow them to choose the hiking routes (e.g., different apps/tools, and different processes, such as using one tool for image generation, and another tool for assembling and final touch).

The instructor does not need to have the experience of hiking all trails (e.g., obtaining the experience of using all candidate GenAI tools). Students won't reach the same peak either, meaning their learning would be different. For example, some students used AI-generated images for other parts of the projects, it is likely that these students may start to use AI-generated images for other courses, whereas other students may not carry this learning over to other courses.

Study Limitations and Future Improvements
We used GenAI primarily for image generation and poster making, the final deliverables of both projects are Power Point slides, posters, and live presentations. There is no formal report for the projects, as a result, there was little concern that students used GenAI to compose their reports. If a written report is part of the final deliverables, then the instructor would need to specify clearly whether students can use GenAI to compose the reports.

We did not discuss the potential ethical and legal issues associated with using GenAI tools to create images/posters for potential commercial use. For future projects, we will take this opportunity to introduce these concepts to the students due to their importance and relevancy (Ladwig, et al., 2025). Instead of giving a lecture about this, we plan to design team discussions about ethical and legal issues with GenAI, particularly focusing on attribution, copyright, and responsible-use boundaries. The instructor will summarize teams' discussion, complement them with additional insights and guidance.

Our summarizations of GenAI usage were obtained from three face-to-face classes at the lower level of the business core. Generalization of our observations and findings to other contexts will be limited. For example, over-reliance on AI needs to be considered when instructors allow students to use AI for problem solving, such as using AI to generate graphs out of datasets (data analytics) or using AI to solve Accounting and Finance problems.

Tips for Adapting to Other Courses
Our task of creating business visuals could be adapted to other MIS courses. For example, in the system analysis and design course, if students have a project to improve a company's website, students can use AI to generate the website navigation diagram, the user interface design diagram, and images for the websites. In a database course, students could manually draw ERD diagrams, then use AI to generate ERD diagrams, and finally do a comparison of both diagrams.

Reflecting on our tasks of image generation and poster creation, we found that effective AI usage in classrooms could include the items listed in Table 1. The learning objectives need to include critical thinking in addition to prompt engineering. This could be best achieved by embedding the tasks in a business context, so that students would have business requirements to engage AI, and also use the business context to evaluate whether their final deliverables would meet the business needs. It is very important for students to submit their human-AI interaction process, their decision rationale, and reflection about human and AI's roles in the tasks. These documentations not only provide evidence that students put serious effort into the work, but also explicitly require them to engage in critical thinking throughout the process.

Items	Notes
Learning objectives	• Prompt engineering • Critical thinking
Tasks	• Tasks embedded in business context
Instructional activities	• Showing examples • Listing resources
Deliverables	• Final Results (e.g., poster, data graph, python codes, solutions of an Accounting and Finance calculation problem) • Human-AI interaction process • Reflection about human role and AI's role
Giving feedback	• Showing good examples from students • Showing the principles/techniques by these examples

Table 1: Projects with AI Components

6. CONCLUSION

In this teaching case, we detailed how to embed image generation and poster creation into two projects. The grade allocation for each poster was only 2%, but almost all teams put serious effort into this task, which was reflected by their final deliverables. They used a variety of GenAI applications/tools to generate images and learned prompt engineering by evaluating and refining their prompt based on the output. The iterative process helped them to see how their own designs and ideas would affect the output, therefore gaining the understanding that AI is not an "automatic intelligence" that can replace all human work, rather an "artificial intelligence", which still needs human's guidance, direction, and input to humanize and contextualize it for the actual usage.

Using AI in business and training business professionals to use AI are becoming a new norm. A report by Boston Consulting Group (BCG) (Bedard, et al., 2025) highlights that "AI fluency" has transitioned from an optional skill to a baseline requirement for professional roles. As business educators, we need to incorporate AI training into our curricula and broader learning processes. Beginning with the creation of business visuals offers a low-risk entry point; this approach prioritizes creative output and mitigates the risk of academic shortcuts, making it an ideal strategy for instructors who are new to integrating AI into their teaching.

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APPENDIX A
Poster Creation Guideline and Marking Rubric

Poster Format (2% of the final grade): PDF, just one page

Poster Content

- Product name (or company name)
- At least one AI generated image
- Price or price range of the product (not required for real business, unless it is a promotion)
- Location (if it is a cafeteria, where this cafeteria is located. If it is a product, where people can buy it, you can make up a location for business plan)

A Word file that documents your team's process of creating the poster (1% of the final grade). At minimum you should include the following:

- Your team number, all members' name
- Include at least three images generated by AI, specify why you chose the one that you used in the poster (maximum image to include is 6)
- App or apps that you used to generate AI images
- Text prompt that you used to generate images
- Did you do your own poster design, or did you use online app (template or AI to generate the poster)? Yes, you can use the online template for your poster design, please cite the website.

Poster Marking Rubric

Poster (Full mark is 2)	Full Marks	Received Marks	Marking Notes
File Format (should be PDF)	0.05		
Product name (or company name)	0.2		
At least one AI generated image	0.8		
Price or price range of the product	0.35		
Location (where is the business located or where to buy the products)	0.3		
Visual design (e.g., sample product and the functions of the product are clearly specified/illustrated, and the usage of color, text font style and size are appropriate, etc.)	0.3		
Total	2		
Comments			

APPENDIX B
Project 1 Reflection Paper Guideline

Purpose: Visual design with AI. You will need to document this process.
Format: A Word document with 2 pages.

- 1 inch all around for the margin.
- Font: Arial 12.
- Single line
- Your team number, all members' name

Submission: Name your file as "Proj1-TeamX-Reflection". Replace "X" with your real team number. Upload the Word into the digital dropbox named "Proj1-Reflection".

Content:
Document your process of creating the poster with AI images.

- What is your original idea for the image used in the poster?
- Did you search for some sample posters online for similar products? If yes, did the search help you refine your idea of the poster design? If yes, how?
- Specify App or apps that you used for image generation.
- Include at least three images generated by AI, maximum image to include is 6. For each image, write down the text prompt that you used.
- Specify why you chose the image that you used in the poster.
- If you use a poster template for the poster design, please specify the app that you use for the poster design.
- Your reflection about creating a poster with AI images:

  Overall, is it fun, or frustrating, etc?
  Did the images generated by AI help you refine your design, or refine your text prompt? In your opinion, what are effective text prompt?

- What did your team learn from this project in addition to poster design?

APPENDIX C
Project 2 Reflection Paper Guideline

Purpose: Document and reflect your teams' interaction with GenAI.
You are encouraged to use Generative AI (GenAI) such as ChatGPT for this project, including generate images for posters. The instructor would like to know how you interacted with GenAI for problem solving and creation.

Format: A Word document with 3 or 4 pages.

Content:
The first part is about using GenAI to generate images and create posters, and the second part is about using GenAI for the other parts of the project.

Part 1: Using AI to generate images and create posters.

- Specify App or apps that you used for image generation.
- If you use a poster template for the poster design, please specify the app that you use for the poster design.
- What is your original idea for the image used in the poster?
- Did you search for some sample posters online for similar products? If yes, did the search help you refine your idea of the poster design? If yes, how?
- Include at least three images generated by AI, maximum image to include is 6. For each image, write down the text prompt that you used. Did the images generated by AI help you refine your design, or refine your text prompts?
- In your opinion, what are effective text prompt for your image generation?

For this project, each team is required to create two posters, one poster with at least one AI-generated image (Poster-with-AI), and the other poster without AI image (Poster-without-AI).

- How much time did your team used to create Poster-with-AI and Poster-without-AI respectively? (If you did not record, give an estimation here)
- Which one is easier to create: Poster-with-AI or Poster-without-AI respectively. Which part took most of your time? (e.g., generating a desired image).
- For the Poster-with-AI creation, who contributed more to the finalized poster: you or the AI tool? For your design process, which part is better for human to do, and which part is better for AI to do?
- Specify why you chose the image that you used in the poster.
- Among the two posters that your team created, which one (Poster-with-AI and Poster-without-AI) looks more visually appealing to you? Why?

Part 2: Using GenAI for the other parts of the project

Karim Lakhani, a Harward Business School Professor, specified that "AI won't replace humans – but humans with AI will replace humans without AI". Do you agree with his statement? Please elaborate based on your experiences with GenAI.