Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #49157

Impact of a curriculum and design course redesign on student's engineering design process knowledge

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Introduction

In 2024, significant changes were implemented in the first-year engineering program at the University of Virginia, leading to a major redesign of courses across the curriculum. Previously, first-year students took two separate courses: one focused on the engineering design process, technical communication, and prototyping, while the other centered on sociotechnical concepts, non-technical communication, and ethics. However, starting in 2024, these courses were integrated into a single sequence taught by one instructor to eliminate artificial distinctions between technical and sociotechnical topics. This change also allowed the incorporation of multiple design experiences, including authentic problems posed by real clients, across all sections of the course, ensuring that all students have a deep design experience in their first year. [1]

This curricular shift had ripple effects. Some technical content previously covered in a second-year biomedical engineering (BME) design course [2] was moved to the first year design course. Consequently, the second-year BME design course was restructured for the 2025 academic year. Key changes include the addition of a client-driven design project, beginning CAD training at a higher level, and adjustments in hands-on fabrication that reflected students' prior experience with 3D printing and soldering.

We wished to understand how these learning experiences – the first-year integrated design course and the second-year course revision – together and separately impacted students' engineering design process knowledge (DPK). We formed two hypotheses:

1. We hypothesized that the first-year design course would cause an increase in engineering design process knowledge at the beginning of the second-year class.
2. We further hypothesized that two intensive design projects over the course of the second-year semester – one of them client driven – would result in greater gains in engineering design process knowledge compared to previous iterations of the course, which included only one project without a real client.

This work is rooted in constructivist learning theory and its branches. When designing learning activities, we posit that embedding learning in real-world contexts (situated learning with client-driven projects) and structuring activities to promote iterative cycles (experiential learning through design-build cycles) provides maximum benefit for accumulating design process knowledge.

Background

The context of courses and curricula

The pattern of changes and our assessments of those changes is illustrated in figure 1.

Before curriculum changes

First-year engineering students with no declared major were required to complete two separate courses – the first emphasizing the engineering design process, technical communication, and prototyping (Introduction to Engineering – ENGR 1624), and the second focusing on sociotechnical concepts, non-technical communication, and ethics (Science, Technology, and Contemporary Issues – STS 1500). The design course was taught by several faculty from across the school, each using a curriculum of their own choosing. Some sections included a client, but most not. Some sections included fabricating physical devices, while some did not.

Students entered their engineering major in their second year.

Second-year BME students are required to take a course in BME design (BME Design and Discovery – BME 2000). The course emphasized skills development – in particular CAD, digital image analysis, microcontrollers and basic circuits, 3D printing, soldering, and several others. The course culminated in a design challenge that, while an actual clinical problem, did not have a client. That problem was summarized through this ill-framed problem statement:

> *"Neurology patients may undergo the same neurological tests upwards of three times a day, including in the ER to assess initial patient condition. Your team project is to create an electronic device that will make a subjective neurological test both quantitative and objective."*

Student teams chose a neurological test to render objective and quantitative. They researched and wrote a structured problem statement [3], engaged in design, and produced a working prototype. A design report was due at the end of the semester.

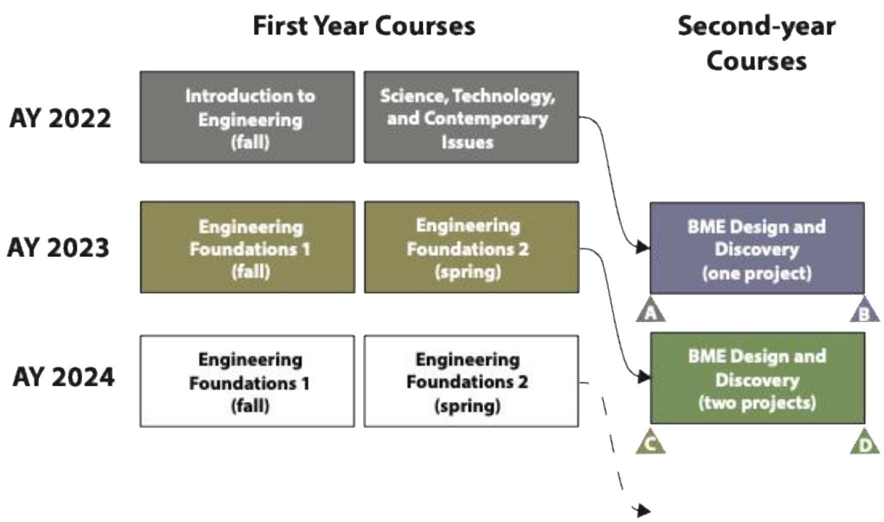

Figure 1: Timing of changes and assessments. The original curriculum (gray) was asssessed in academic year 2023. Arrows show the flow of students from the first year courses into the second-year BME design course. The revised curriculum (green) was assessed in academic year 2024. Assessments (triangles) were conducted at the beginning (A and C) and the end (B and D) of the 2nd year BME design course. Pre- and post-change comparisons of A and C reflect changes in outcome from the first year curriculum. Pre- and post-BME course comparisons (B-A and D-C) reflect changes in the BME design course.

After curriculum changes

Beginning in Fall 2023, the two separate first-year courses were combined into a single two-course sequence taught by one instructor to bridge the gap between technical and sociotechnical topics and provide a more integrated learning experience (Engineering Foundations 1 and 2 – ENGR 1010 and ENGR 1020). These courses integrate engineering design, communication, career development ethical reasoning, and sociotechnical thinking, and is taught by dedicated faculty who also serve as academic advisors, fostering regular, supportive interactions with students. Three brief design projects were completed in the Fall semester – one closed-ended and two open-ended but student sourced. A single authentic client-driven design problem was tackled by students in the second semester. By combining technical and sociotechnical content through evidence-based pedagogies, interdisciplinary collaboration, and professional development support, the curriculum offers a holistic and modern approach to first-year design education.[1]

In Fall 2024, to accommodate students who took this new first-year course sequence, BME 2000 was significantly updated. CAD training began with a brief review, but otherwise at a higher level, assuming that students had previously learned basic modeling, dimensioning, creation of assemblies, and finite element analysis. Digital image analysis was removed from the curriculum, as was citation management. The most significant change was for students to complete two design projects rather than one design project. The first was a closed-ended project to create a peristaltic "infusion" pump (either rotary or linear) with embedded control. The second was to address an authentic problem for a clinical client through a working proof-of-concept design. Examples include problems in reduction of hip dislocations, pulse detection during CPR, and injection of young people with monoclonal antibody drugs. Both projects required keeping electronic design notebooks (LabArchives). Structured problem statements and training in teamwork remained part of the curriculum.

Data collection

To evaluate these hypotheses, we administered an engineering design process knowledge (DPK) instrument [4], [5] at both the beginning and end of the second-year BME design course for two semesters – Spring 2024 under the original curriculum, and Fall 2024 after the curriculum change. See figure 1 for a visual representation. Students are presented a Gantt chart representing a design process. The students were presented with this prompt on the design process being represented:

> *"A Gantt chart of a design process follows. Your job is to critique the engineering design process represented by the chart – that is, to identify the good and bad things about the process.*
> *"A growing problem is wrist injury due to frequent use of colonoscopes. A major medical instrument manufacturer has come to you to design a system that reduces the rate of injury when using these tools.*
> *"No work has been done prior to what is shown in the chart."*

We then presented students the Gantt chart from [6], and a text response field to identify the good and bad aspects of the design process. Students worked for 10 minutes and entered their responses in Qualtrics. This was performed as an in-class activity on the first day of the class, and as an in-class activity at the beginning of the final exam period.

This work was approved by the University of Virginia Social and Behavioral Sciences IRB under protocol 3236.

Analysis

30 randomly selected responses from each semester were scored 0, 1, or 2 using a modification of a simplified rubric discussed in [7] and in consultation with the authors.

Pre- and post-course responses were analyzed using a rubric-based qualitative coding approach. ChatGPT was employed to assist in the analysis by categorizing student responses according to predefined rubric criteria, which aligned with levels of DPK. Each student's pre and post responses were evaluated for the presence or absence of rubric categories. ChatGPT provided consistency in applying the rubric across the dataset and sped the analysis. Further, for each rubric criterion, ChatGPT highlighted specific examples and patterns of alignment or misalignment with rubric, allowing for manual validation of the results.

Statistical comparisons were performed using SPSS. Scores were ordinal and not normally distributed. Therefore, a Wilcoxon Signed Ranks test was used for comparison of pre-post paired data. A Mann-Whitney test was used to compare beginning of semester scores between the two semesters.

Results

Before the curriculum change, there were only modest gains in DPK in the second-year BME design course.

Pre-post comparisons (A-B in figure 1) are given in Table 1. Two things are worth noting. First, the "needs assessment" level has the lowest overall score by a substantial margin. Second, the pre-post changes are all rather small, ranging from 0 to a maximum of 0.57 on a 2 point scale. The only significant gains were in documentation, design process layout and iteration, and prototyping. Each of these was a substantial focus of the class in that semester.

Table 1: Descriptive statistics and comparison of pre-post scores from Spring 2024, the original curriculum.
*A significant difference at the traditional $p<0.05$ level

		Pre		Post		Wilcoxon
Level	N	Mean	σ	Mean	σ	σ (2-tailed)
Needs assessment	30	0.37	.56	0.50	.63	0.248
Idea generation	30	1.33	.88	1.33	.84	0.927
Analysis and decision making	30	0.93	.25	1.00	.37	0.414
Prototyping and testing	30	1.67	.61	1.90	.31	0.053*
Layout of design process and iteration	30	1.50	.73	1.93	.25	0.008*
Documentation	30	0.80	.85	1.37	.93	0.011*

After the curriculum change there were substantial gains in all levels of DPK in the second-year design course.

Pre-post comparisons for the revised second-year design course (C-D in figure 1) are given in Table 2. Note that the pre-post gains are substantial, and in fact significantly changed with p values below 0.001 for all levels of DPK. Rank-biserial correlation was used as a measure of effect size in this non-parametric analysis, and this effect size is large for all levels.

Table 2: Descriptive statistics and comparison of pre-post scores from Fall 2024, the revised curriculum.
*A significant difference at the traditional p<0.05 level

		Pre		Post		Wilcoxon	Rank-biserial correlation
Criterion	N	Mean	σ	Mean	σ	σ (2-tailed)	r
Needs assessment	30	0.47	.57	1.20	.71	<0.001*	0.86
Idea generation	30	1.07	.25	1.77	.43	<0.001*	0.84
Analysis and decision making	30	1.00	.26	1.93	.25	<0.001*	0.97
Prototyping and testing	30	1.10	.31	2.00	0.00	<0.001*	0.95
Layout of design process and iteration	30	1.37	.49	2.00	0.00	<0.001*	0.80
Documentation	30	1.00	.37	1.93	.37	<0.001*	0.93

DPK at the beginning of the semester, before and after curriculum changes, were mostly the same.

This is represented in figure 1 as comparing assessments A and C. The data suggest that any changes in DPK that result from the first-year curriculum are not durable – that is, if DPK improves in the first year, most of those improvements do not persist over the summer and into the fall semester. In fact, the only two levels of DPK that were different between the old and new curricula were Idea generation, and Prototyping and testing (Table 3).

Table 3: Old and new first-year curricula compared by pre-semester scores in the second year. *Significant difference at the traditional p<0.05 level.

	Mann-Whitney
Level	σ (2-tailed)
Needs assessment	0.449
Idea generation	0.035*
Analysis and decision making	0.321
Prototyping and testing	<0.001*
Layout of design process and iteration	0.174
Documentation	0.164

Discussion

The DPK instrument is a leading indicator of the behaviors students will exhibit when given an actual design problem [8]. Will they conduct proper needs assessment, for example? We therefore have a vested interest in identifying activities that increase design process knowledge, learning when in students' development they acquire it, and importantly whether that knowledge persists.

Our data suggest that either repeated or client-driven design experiences have a strong, positive impact on DPK. Since both interventions occurred in the same semester, we cannot discriminate the two, but our suspicion is that the client-driven experience had the greater impact, particularly when it comes to needs assessment. That particular level of DPK was not covered in the closed-ended pump design project.

These results are consistent with the findings of Saterbak and Volz who reported similar gains in DPK as the result of a first-year client-based design project [7]. Others have shown gains in DPK as the result of a single team-based design experience in the freshman year, though this used an entirely different DPK instrument [9]. In contrast, Ernst and coworkers who showed using the same instrument that hands-on, hands-off, and client-based projects in a first-year engineering course do not differ greatly in students' learning of the engineering design process [10]. This begs the question, what are the necessary qualities, quantities, and timings of design experiences that lead to meaningful gains in design process knowledge?

Surprisingly, we did not see gains in DPK at the beginning of the Fall semester relative to the beginning of the Spring semester, before the introduction of hands-on client-driven design experiences to all first-year engineering students in our school. This raises the question of whether DPK is transferrable as a skill, or whether it is volatile and lost over time. Here too there is disagreement in the literature. Bailey found that fourth-year students generally demonstrated no better process knowledge than did first-year students [11], indicating that either DPK isn't being delivered longitudinally through their curricula, or that knowledge is lost over time, or both. In contrast, McKenna found "high transfer of students' conceptions of generating alternatives and building mock-ups between the first-year course and subsequent upper-level courses. However, there is a significant drop in the "research" category for both upper-level cohorts." [12] This suggests that DPK is either retained or it is boosted downstream of an initial intervention. This is clearly an area in need of further study.

There are two obvious limitations to this study. First, there were multiple changes taking place during the period of observation. We find no differences in the beginning of semester measurements, though, and so we feel that this concern is minor. Semester on semester measurements in the future may show how variable DPK is on a per-semester or a per-class basis.

Second, while manual scoring of this instrument is notoriously labor-intensive, our method of scoring the DPK instrument using a generative AI tool is unproven. AI tools may eventually be trained on hand-scored data to give truly robust results. Our approach was not to use a trained model, but rather to rely on an existing LLM to compare student-written text against a rubric. The scores and examples ChatGPT provided for student responses were checked along the way, and ChatGPT was able to provide an explanation of every score it provided. Still, the model is sensitive to the phrasing of the rubric, the phrasing of the objective that is posed, and even the number of student responses submitted at a time. We are given confidence by a recent study showing that ratings of written student assignments in physics by ChatGPT can reach human-level interrater reliability [13]. Future work can test our approach against hand-scoring to determine its reliability. AI tools offer the promise of making this DPK assessment approach more widespread in its use.

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