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Application of Chemical Simulation to Enhance Chemical Process Experience of Undergraduates

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Abstract

Undergraduate chemical process courses traditionally rely on lectures and pen-and-paper problem sets to teach mass and energy balances, unit operations, and process flow analysis, an approach that can leave students with limited felt experience of how these principles operate in a dynamic, interconnected plant-scale process. This study evaluated the effect of integrating Aspen HYSYS-based process simulation exercises into a Chemical Process Technology course on undergraduates' conceptual understanding and subjective process learning experience. A quasi-experimental pretest-posttest control group design was used with 90 third-year Chemical Engineering and Industrial Chemistry students from two intact class sections. The experimental group (n = 45) completed weekly simulation exercises modeling distillation, heat exchange, and reactor unit operations alongside conventional lectures across a 13-week module, while the control group (n = 45) received identical lecture content and problem sets without simulation exercises. Conceptual understanding was assessed with a Process Conceptual Understanding Test (PCUT) administered pre- and post-intervention, and subjective process learning experience was assessed post-intervention with the Chemical Process Learning Experience Scale (CPLES), covering engagement, self-efficacy, perceived relevance, and depth of understanding. Analysis of covariance on PCUT composite scores, controlling for pretest, showed a significant effect favoring the experimental group, $F(1, 87) = 73.36$, $p < .001$, partial $\eta^2 = .46$. Independent-samples t-tests showed the experimental group scored significantly higher than the control group on all four CPLES dimensions (all $p < .001$, $d > 1.5$). These findings suggest that integrating process simulation software into chemical process instruction meaningfully strengthens both conceptual mastery and the subjective experience of engaging with plant-scale chemical processes.

chemical process simulation, Aspen HYSYS, experiential learning, undergraduate chemical engineering education, process understanding

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Background

Chemical process courses ask undergraduates to reason about systems that are, by nature, dynamic, interconnected, and often counterintuitive: a change in reflux ratio in a distillation column affects not only separation efficiency but downstream energy demand, product purity, and overall process economics simultaneously. Conventional instruction in these courses typically relies on lectures and static, pen-and-paper mass and energy balance problems, which can convey the underlying equations without conveying the felt experience of how a real process behaves as conditions change, a gap that is difficult to close given the cost, safety requirements, and scheduling constraints of running physical pilot-scale plant equipment for undergraduate instruction (Dahm et al., 2002).

Commercial process simulation software, such as Aspen HYSYS, was originally developed for industrial process design and is increasingly incorporated into chemical engineering curricula as a means of exposing students to realistic, interactive process behavior without the cost or risk of physical plant operation. Students can construct process flowsheets, adjust operating parameters, and observe the propagated consequences across an entire simulated process in real time, a form of engagement that Dahm et al. (2002) argue is under-utilized relative to its pedagogical potential in many chemical engineering programs. This kind of engagement maps closely onto Kolb's (1984) experiential learning theory, which describes learning as a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation; process simulation offers students a form of concrete experience with plant-scale behavior that static problem sets cannot provide, potentially strengthening the full learning cycle rather than only its abstract-conceptual stage (Kolb & Kolb, 2005).

This theoretical rationale is supported by a broader engineering education literature favoring active and experiential approaches over lecture-only instruction. Prince's (2004) review of active learning research concluded that active engagement methods generally produce superior learning outcomes relative to passive lecture formats across engineering disciplines, while Felder and Silverman (1988) and Felder et al. (2000) have separately argued that engineering instruction often favors abstract, sequential modes of teaching that mismatch many students' preferred learning styles, a mismatch that simulation-based, exploratory engagement may help address. However, much of this literature addresses active learning in general terms or single-concept simulations, with comparatively less direct evidence on whether integrated, multi-unit-operation

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process simulation specifically improves both conceptual understanding and students' subjective sense of process experience within a single course.

Purpose and Research Questions

This study evaluated whether integrating Aspen HYSYS-based process simulation exercises into a Chemical Process Technology course improves undergraduates' conceptual understanding and subjective process learning experience relative to conventional lecture-based instruction. Specifically: (1) Is there a significant difference in conceptual understanding of mass balance, energy balance, unit operations principles, and process flow diagram interpretation between students receiving simulation-integrated instruction and those receiving conventional instruction, controlling for pretest performance? (2) Do students receiving simulation-integrated instruction report a significantly different subjective process learning experience, across engagement, self-efficacy, perceived relevance, and depth of understanding, than students receiving conventional instruction?

Method

Research Design and Participants

This study used a quasi-experimental, nonequivalent control group design with pretest and posttest measures for conceptual understanding, and a posttest-only comparison for subjective process experience, since the latter construct concerns students' response to a specific instructional approach that a pre-intervention baseline cannot meaningfully anticipate. Participants were 90 third-year undergraduates (49 male, 41 female) drawn from Chemical Engineering and Industrial Chemistry programmes at a Nigerian university, with one intact class section ($n = 45$) assigned to the experimental condition and a second ($n = 45$) to the control condition. Groups did not differ significantly on pretest composite conceptual scores, $t(88) = 1.19$, $p = .238$, or on prior exposure to process simulation software, $\chi^2(1) = 0.52$, $p = .471$. Full demographic characteristics are presented in Table 1.

Table 1

Demographic Characteristics of Participants (N = 90)

Characteristic	Category	n	%
Sex	Male	49	54.4

	Female	41	45.6
Programme	Chemical Engineering	38	42.2
	Industrial Chemistry	52	57.8
Prior process simulator use	Yes	19	21.1
	No	71	78.9
Group	Experimental (simulation-integrated)	45	50.0
	Control (conventional)	45	50.0

Note. Percentages may not sum to 100 due to rounding.

Simulation-Integrated Instruction

The experimental group completed weekly 90-minute Aspen HYSYS-based simulation exercises across a 13-week Chemical Process Technology module, modeling three core unit operations in sequence: binary distillation column design and reflux optimization, shell-and-tube heat exchanger sizing, and continuous stirred-tank reactor (CSTR) performance under varying feed and temperature conditions. Each session followed a structured format: a brief instructor-led orientation connecting the simulation task to the week's lecture content, guided student manipulation of process variables within the simulation with real-time observation of propagated effects across the flowsheet, and a closing discussion in which students compared simulated outcomes to their hand-calculated predictions. The control group received identical lecture content and an equivalent number of hand-calculation problem sets addressing the same three unit operations, without simulation software, ensuring that total instructional contact time and topic coverage were held constant across conditions.

Instrumentation

Conceptual understanding was measured using the Process Conceptual Understanding Test (PCUT), a 30-item instrument covering four domains: mass balance, energy balance, unit operations principles, and process flow diagram interpretation, with domain and composite scores expressed on a 0–10 scale for reporting consistency. Internal consistency was acceptable to good (composite $\alpha = .84$; domain $\alpha s = .73–.81$). Subjective process learning experience was measured using the Chemical Process Learning Experience Scale (CPLES), a 20-item, 5-point

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Likert instrument covering four dimensions: engagement, self-efficacy, perceived relevance, and depth of understanding, administered only at posttest and only to characterize students' response to the instructional approach actually experienced during the module. CPLES internal consistency was high (composite α = .88; dimension αs = .79–.86).

Procedure and Data Analysis

Both groups completed the PCUT pretest during the week preceding the module and the PCUT and CPLES posttest during the week following its conclusion, administered by the same trained, condition-blind assessors. A one-way ANCOVA was conducted on PCUT composite posttest scores, using PCUT pretest composite scores as the covariate, to address Research Question 1, with assumption checks confirming linearity, homogeneity of regression slopes, and homogeneity of variance were met. Independent-samples t-tests compared experimental and control group posttest scores on each of the four CPLES dimensions to address Research Question 2. All analyses used α = .05.

Results

Conceptual Understanding

Descriptive statistics for the experimental group's PCUT pretest and posttest domain and composite scores are presented in Table 2. Both groups improved from pretest to posttest across all four domains; however, the experimental group's gains were consistently larger, particularly in process flow diagram interpretation.

Table 2

Descriptive Statistics for Process Conceptual Understanding Test Scores, Experimental Group (n = 45)

Conceptual Domain	Pretest M	Pretest SD	Posttest M	Posttest SD
Mass balance	5.24	1.31	8.16	1.02
Energy balance	4.68	1.42	7.74	1.15
Unit operations principles	5.02	1.36	7.58	1.10
Process flow diagram interpretation	4.15	1.48	7.92	1.08

Composite score	4.77	1.09	7.85	0.91

Note. Scores are standardized to a 0–10 scale for each domain and the composite. M = mean; SD = standard deviation.

For the control group, composite PCUT scores rose from a pretest mean of 4.71 (SD = 1.14) to a posttest mean of 6.42 (SD = 1.21), a smaller gain than in the experimental group. The ANCOVA revealed a significant effect of group on posttest composite scores, $F(1, 87) = 73.36$, $p < .001$, partial $\eta^2 = .46$, a large effect indicating instruction type accounted for approximately 46% of posttest variance after adjusting for baseline. The covariate was also significant, $F(1, 87) = 17.94$, $p < .001$, partial $\eta^2 = .17$ (Table 3).

Table 3

Summary of Analysis of Covariance (ANCOVA) for Posttest Composite PCUT Scores

Source	**SS**	**df**	**MS**	**F**	**p**	**$\eta^2 p$**
Pretest (covariate)	15.28	1	15.28	17.94	< .001	.171
Group	62.47	1	62.47	73.36	< .001	.458
Error	74.06	87	0.85	—	—	—
Total	153.61	89	—	—	—	—

Note. SS = sum of squares; MS = mean square; $\eta^2 p$ = partial eta squared.

Subjective Process Learning Experience

Table 4 presents independent-samples t-test results comparing CPLES posttest scores between groups. The experimental group scored significantly higher than the control group on all four dimensions: engagement, $t(88) = 7.84$, $p < .001$, $d = 1.66$; self-efficacy, $t(88) = 7.61$, $p < .001$, $d = 1.61$; perceived relevance, $t(88) = 7.39$, $p < .001$, $d = 1.56$; and depth of understanding, $t(88) = 7.28$, $p < .001$, $d = 1.54$. All four effect sizes exceeded conventional benchmarks for a large effect, with engagement showing the largest group difference.

Table 4

Independent-Samples t-Test Comparing Posttest CPLES Scores Between Groups

Experience Dimension	**Exp. M**	**Exp. SD**	**Ctrl. M**	**Ctrl. SD**	**t(88)**	**p**	**d**

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Engagement	4.32	0.48	3.41	0.61	7.84	< .001	1.66
Self-efficacy	4.18	0.52	3.29	0.58	7.61	< .001	1.61
Perceived relevance	4.46	0.44	3.65	0.59	7.39	< .001	1.56
Depth of understanding	4.25	0.50	3.38	0.63	7.28	< .001	1.54

Note. Exp. = experimental group (n = 45); Ctrl. = control group (n = 45). Scores are on a 1–5 Likert scale. d = Cohen's d.

Discussion

This study examined whether integrating Aspen HYSYS-based process simulation into a Chemical Process Technology course improves undergraduates' conceptual understanding and subjective process learning experience relative to conventional instruction. Both hypotheses were supported: the simulation-integrated group showed significantly greater conceptual gains, with a large effect size, and reported significantly more positive process learning experience across all four measured dimensions, also with large effect sizes. These findings extend Dahm et al.'s (2002) observation that process simulation software remains under-utilized relative to its pedagogical potential by providing direct comparative evidence of its benefit for both cognitive and experiential outcomes within a single undergraduate course.

The particularly large gain in process flow diagram interpretation is consistent with the nature of simulation engagement: constructing and manipulating a flowsheet in Aspen HYSYS requires students to repeatedly read, adjust, and reason about flow diagrams as dynamic representations of an interconnected process, practice that static problem sets provide far less directly. The strong CPLES results, particularly for engagement and perceived relevance, align with Kolb's (1984) experiential learning framework: simulation exercises supplied a form of concrete, interactive experience with process behavior that lecture and hand-calculation alone could not replicate, plausibly supporting a fuller traversal of Kolb's experiential learning cycle from concrete experience through reflective observation to abstract conceptualization and renewed experimentation (Kolb & Kolb, 2005). These findings also resonate with Prince's (2004) broader conclusion that active learning approaches outperform passive instruction in engineering education, and with Felder and Silverman's (1988) argument that instructional formats extending beyond abstract, sequential lecture delivery can better engage the diversity of learning styles present in engineering classrooms.

This study is limited by its quasi-experimental reliance on intact class sections at a single institution, a single course module covering three unit operations, and a posttest-only design for the CPLES that cannot rule out the possibility that the experimental group's more positive reported experience partly reflects the novelty of simulation software rather than a durable pedagogical effect. The 13-week duration also does not permit conclusions about retention of conceptual gains into subsequent, more advanced process design coursework. Future research should incorporate delayed follow-up testing, extend the simulation-integrated approach to additional unit operations and process design content, and examine whether the observed experiential gains are sustained once the novelty of simulation software use diminishes over an academic programme.

Conclusion

Integrating Aspen HYSYS-based process simulation into undergraduate chemical process instruction produced significantly greater conceptual understanding gains and a significantly more positive subjective process learning experience, across engagement, self-efficacy, perceived relevance, and depth of understanding, than conventional lecture-based instruction alone. These findings support process simulation software as a valuable pedagogical complement for chemical process education, consistent with experiential learning theory, and suggest that its integration into undergraduate curricula can strengthen both what students understand about chemical processes and how meaningfully they experience learning about them.

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