

The Effect of a Corequisite Instructional Model on Undergraduate Achievement in First-Order Ordinary Differential Equations: A Quasi-Experimental Study

Christian Sekey^{1*}, Emmanuel Antwi², Yarhands Dissou Arthur³

Department of Mathematics Education, Faculty of Applied Sciences and Mathematics Education,
University of Skills Training and Entrepreneurial Development (USTED), Ghana

*Corresponding Author

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ABSTRACT

Undergraduate students often experience difficulties learning first-order ordinary differential equations (ODEs), partly because of weaknesses in prerequisite mathematical competencies such as algebraic manipulation, function interpretation, differentiation, and integration. This study examined the effect of a corequisite instructional model, in which relevant prerequisite competencies are reinforced concurrently with ODE instruction, on students' ODE achievement and affective outcomes. A quasi-experimental pretest–posttest non-equivalent control group design was employed with 60 undergraduate Mathematics Education students, comprising 30 students in the experimental group and 30 in the control group. Data were collected using the Corequisite Diagnostic Test (CDT), Ordinary Differential Equations Achievement Test (ODE-AT), and Student Learning Perception Questionnaire (SLPQ). Descriptive statistics, Pearson correlation, independent-samples *t*-tests, and analysis of covariance (ANCOVA) were used to analyze the data. Prerequisite competencies were significantly associated with ODE achievement, with integration and differentiation showing the strongest relationships. After controlling for baseline prerequisite competence, students who received the corequisite intervention achieved significantly higher ODE posttest scores than those who received conventional instruction. The experimental group also reported more positive outcomes in self-efficacy, confidence, attitudes, and engagement. The findings suggest that embedding targeted, just-in-time prerequisite support within ODE instruction can improve both students' achievement and affective outcomes. The study highlights corequisite instruction as a promising alternative to separate remedial approaches for addressing prerequisite learning gaps in advanced undergraduate mathematics.

Keywords: Corequisite Instruction; Ordinary Differential Equations; Prerequisite Competencies; Mathematics Education; Cognitive Load; Self-Efficacy

INTRODUCTION

Ordinary differential equations (ODEs) are fundamental to mathematics and STEM education because they provide powerful tools for representing and analysing continuously changing phenomena in fields such as physics, engineering, biology, economics, and environmental science (Goriely, 2023). First-order ODEs are particularly important because they introduce students to mathematical modelling of rates of change and provide a foundation for more advanced applications of differential equations (Oyelami, 2024). Despite their importance, however, ODEs remain challenging for many undergraduate students. Studies have reported difficulties involving procedural errors, weak conceptual understanding, inappropriate selection of solution methods, and difficulties interpreting ODE solutions (Hyland et al., 2018; Borji & Martínez-Planell, 2020; Mangarin & Caballes, 2024; Habre, 2025; Makamure et al., 2025; Novitasari et al., 2025).

A significant dimension of these difficulties concerns students' ability to draw on previously learned mathematical knowledge during ODE problem solving. Although students may have studied algebra, functions, differentiation, and integration in earlier courses, they may experience difficulty retrieving, coordinating, and

applying these competencies when confronted with ODE problems (Borji & Martínez-Planell, 2020; Ishak et al., 2025). This issue is particularly important because mathematics is hierarchical, with new learning often depending on the accessibility and effective application of previously acquired knowledge (Sweller et al., 2019; Schneider & Simonsmeier, 2025). Consequently, students' difficulties in ODEs may not necessarily reflect a complete absence of prerequisite knowledge; rather, they may arise from difficulties in activating and integrating relevant mathematical competencies within the specific context of ODE problem solving.

Traditionally, students who experience difficulties with prerequisite mathematics have often been directed towards developmental or remedial coursework before enrolling in credit-bearing college mathematics. Although such approaches are intended to strengthen students' mathematical foundations, evidence has raised concerns about their effectiveness. Remedial sequences may delay students' progression through college-level courses without consistently producing improved long-term academic outcomes (Sanabria et al., 2020; Brunner et al., 2025). Moreover, concerns have been raised about the accuracy of developmental placement, as some students assigned to remedial mathematics may be capable of succeeding in college-level mathematics when provided with appropriate academic support (Scott-Clayton & Rodriguez, 2014). These concerns have encouraged the development of instructional approaches that provide academic support without separating students from credit-bearing coursework.

One such approach is corequisite instruction, in which students enroll in credit-bearing coursework while simultaneously receiving targeted support for the knowledge and skills required to succeed in that course. Rather than requiring students to complete a separate remedial sequence before accessing college-level mathematics, the corequisite approach integrates necessary support with the content being studied. Evidence from gateway mathematics courses suggests that corequisite models can improve course completion and academic outcomes (Daugherty et al., 2017; Logue et al., 2019; Ran & Lin, 2022). More recent evidence has also suggested potential benefits for students' retention and persistence in STEM-related programme (Mokher & Park-Gaghan, 2025). Nevertheless, much of the existing research on corequisite instruction has concentrated on foundational or gateway mathematics, leaving limited evidence concerning its application to more advanced mathematical content.

First-order ODEs provide a particularly appropriate context for extending corequisite instruction because their solution requires students to coordinate several mathematical competencies acquired previously. Depending on the type of ODE, students may need to manipulate algebraic expressions, interpret and work with functions, differentiate, integrate, and make appropriate decisions about solution methods. Difficulties in any of these areas can interfere with students' ability to engage successfully with ODE content. A corequisite approach may therefore provide a means of addressing such difficulties within the ODE learning environment by identifying the specific competencies needed for a given topic and providing targeted, just-in-time support rather than reteaching prerequisite mathematics as a separate course.

Against this background, the present study applies a structured corequisite instructional model to first-order ODE instruction. The model integrates targeted reinforcement of relevant mathematical competencies with the teaching of ODE content, with the nature of the support determined by the specific requirements of each ODE topic. The study examines whether this approach improves undergraduate Mathematics Education students' achievement in first-order ODEs and whether it enhances their attitudes, confidence, and self-efficacy towards learning ODEs. In doing so, the study seeks to extend the application of corequisite instruction beyond foundational mathematics to a more advanced mathematical domain in which the coordination of prior mathematical knowledge is particularly important.

Three objectives guided the study: (a) to identify the prerequisite mathematical competencies required for successful engagement with first-order ODEs; (b) to determine the effect of the corequisite instructional model on students' achievement in first-order ODEs after controlling for baseline prerequisite competence; and (c) to examine the influence of the corequisite instructional model on students' attitudes, confidence, and self-efficacy towards learning first-order ODEs. The study was guided by the following hypothesis: H_1 : There is a statistically significant difference in first-order ODE achievement between students receiving the corequisite instructional model and those receiving conventional instruction after controlling for baseline prerequisite mathematical competence.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Prerequisite Knowledge and Difficulties in Learning ODEs

Research on ODE learning consistently traces students' difficulties back to unresolved gaps in prerequisite mathematics rather than to the differential equations themselves. Artigue (2011) argued that much of what appears to be a calculus problem is, on closer inspection, a difficulty in reasoning flexibly about functions and their derivatives, a claim later supported by Rasmussen (2001), who found that students capable of differentiating a function procedurally often could not explain what that derivative meant within the equation they were solving. This distinction between executing a procedure and interpreting it recurs throughout the literature and helps explain why procedural fluency alone is a poor predictor of ODE success.

Dogan-Dunlap (2006) made a related methodological point: instructional interventions that are not preceded by careful mapping of the prerequisite knowledge a topic actually requires tend to under-diagnose students' needs and, consequently, under-deliver on remediation. This has direct implications for how corequisite interventions should be designed. Rather than offering generic algebra or calculus review, an effective corequisite support structure must first identify which specific competencies, such as separating variables, applying integrating factors, and testing exactness, each ODE topic requires, and target instruction to those competencies in the sequence in which the lecture content will demand them.

The Corequisite Instructional Model

The corequisite model responds to these diagnostic and structural concerns by relocating prerequisite instruction from a separate, prior course into the same instructional space as the advanced content it supports. Kashyap and Mathew (2017) describe this repositioning as a shift from remediation as gatekeeping to remediation as scaffolding: instead of requiring students to prove readiness before encountering college-level material, the corequisite model assumes readiness can be built concurrently, at the point where it is needed.

Empirical support for this repositioning has grown substantially in general mathematics and statistics contexts. Martirosyan et al. (2025), drawing on faculty accounts of corequisite implementation, reported that instructors observed both improved pass rates and greater student engagement once prerequisite support was embedded directly within gateway coursework. Hodara and Jaggars (2014) offer a useful counterpoint, showing that standalone developmental sequences frequently fail to transfer: skills rehearsed in isolation from their eventual application do not reliably generalize once students encounter that application in a different course, a transfer problem corequisite instruction is explicitly designed to avoid by removing the temporal and contextual separation between skill-building and skill-use.

What remains comparatively underexplored is whether this logic holds in mathematical domains where the 'application' is itself abstract and multi-step, as is the case with first-order ODEs. Solving even a single separable equation requires the concurrent coordination of algebraic manipulation, function interpretation, differentiation, and integration; a corequisite model that succeeds here would need to reinforce several prerequisite skills in combination rather than one at a time. This complexity motivates the present study.

THEORETICAL FRAMEWORK

The study was grounded in four complementary theoretical perspectives: Constructivism, Cognitive Load Theory, Mastery Learning, and Self-Efficacy Theory. Together, these perspectives explain how targeted reinforcement of prerequisite mathematical competencies may support students' learning of first-order ordinary differential equations (ODEs).

Constructivism

Constructivism views learning as an active process in which learners construct new knowledge by connecting new experiences with existing knowledge (Vygotsky, 1978). This perspective is relevant to ODE learning because students are expected to draw on previously learned competencies in algebra, functions, differentiation,

and integration when constructing new understanding of ODE concepts. The corequisite model reflects this principle by deliberately connecting relevant prior mathematical knowledge with the ODE content being learned. Through targeted support within the Zone of Proximal Development, students are assisted to apply competencies that may not yet be readily accessible independently (Vygotsky, 1978).

Cognitive Load Theory

Cognitive Load Theory proposes that working memory has limited capacity and that excessive cognitive demands can hinder learning (Sweller et al., 2019). First-order ODE problems require students to coordinate several mathematical processes simultaneously. Difficulties in retrieving prerequisite skills may therefore consume cognitive resources needed to understand and solve the ODE. The corequisite model addresses this challenge by reinforcing relevant prerequisite competencies immediately before or during their application, thereby allowing students to devote greater cognitive resources to the new ODE content (Sweller, 2024).

Mastery Learning

Mastery Learning proposes that students can achieve high levels of competence when provided with appropriate instruction, practice, feedback, and corrective learning opportunities (Bloom, 1968; Guskey, 2022). This principle is reflected in the corequisite model through diagnostic identification of prerequisite weaknesses and targeted corrective support. Rather than reteaching prerequisite mathematics broadly, the intervention focuses on the specific competencies required for the ODE topic being studied. Thus, Mastery Learning provides a basis for the diagnostic and corrective components of the intervention.

Self-Efficacy Theory

Self-Efficacy Theory emphasises learners' beliefs about their capability to perform particular tasks (Bandura, 1997). Persistent difficulties with mathematical procedures may weaken students' confidence in solving ODE problems. The corequisite model provides structured support, guided practice, and opportunities for successful task completion, which may strengthen students' perceived mathematical capability. Self-efficacy therefore provides a theoretical basis for examining students' confidence and related affective responses to learning ODEs.

Synthesis

The four perspectives complement one another in explaining the corequisite instructional model. Constructivism emphasizes connecting new ODE knowledge with relevant prior mathematical knowledge (Vygotsky, 1978), while Cognitive Load Theory suggests that reinforcing prerequisite skills can reduce the cognitive demands associated with retrieving and applying those skills during ODE problem solving (Sweller et al., 2019; Sweller, 2024). Mastery Learning provides the basis for identifying and addressing specific prerequisite gaps through targeted instruction and feedback (Bloom, 1968; Guskey, 2022), while Self-Efficacy Theory explains how successful supported learning experiences may strengthen students' confidence in solving ODE problems (Bandura, 1997). Together, these perspectives support the use of targeted, just-in-time prerequisite reinforcement to facilitate ODE achievement and positive affective outcomes.

METHOD

Design

This study used a quasi-experimental pretest–posttest design with a non-equivalent control group. Random assignment was not feasible because students were already organized into intact class sections through the institution's scheduling system prior to the study; quasi-experimental designs of this kind are considered appropriate for classroom-based educational research, provided that statistical controls are applied to account for pre-existing group differences (Cook & Campbell, 1979; Fraenkel et al., 2023). Two intact sections were designated as the experimental and control groups. CDT pretest scores were entered as a covariate in the primary analysis to adjust for baseline differences in prerequisite knowledge between the two groups.

Participants

Participants were 60 undergraduate Mathematics Education students enrolled in a first-order ODE course at a public university in Ghana, drawn from two intact class sections ($n = 30$ per section). Purposive selection identified sections whose instructors were willing to participate and whose scheduling was compatible with the intervention. The experimental group received the corequisite intervention in addition to standard lectures; the control group received standard lectures only. Table 1 summarizes the demographic profile of the two groups. A chi-square test of independence confirmed no significant between-group differences in gender, age, or prior mathematics performance (all $p > .05$), supporting baseline comparability.

Table 1. Demographic Profile of Experimental and Control Groups

Characteristic	Exp. ($n = 30$)	%	Control ($n = 30$)	%
Male	17	56.7	16	53.3
Female	13	43.3	14	46.7
Age 18–20 years	21	70.0	20	66.7
Age 21–23 years	9	30.0	10	33.3
Prior mathematics – pass	24	80.0	23	76.7
Prior mathematics – fail	6	20.0	7	23.3

Note. Percentages are computed within each group.

Instruments

Three instruments were used in the study. The Corequisite Diagnostic Test (CDT) was administered as a pretest to assess students' entering competence in four corequisite domains: algebraic manipulation, function interpretation, differentiation, and integration. The CDT was reviewed by subject-matter experts and piloted with students outside the study sample, yielding acceptable internal consistency (Cronbach's $\alpha = .82$). The Ordinary Differential Equations Achievement Test (ODE-AT) was administered as the achievement measure. It assessed students' mastery of separable, linear, exact, and homogeneous first-order differential equations through short-answer and extended problem-solving items aligned with the course learning objectives. The instrument demonstrated good internal consistency (Cronbach's $\alpha = .85$). The Student Learning Perception Questionnaire (SLPQ) was administered following the achievement test to assess students' perceptions of the instructional experience. The five-point Likert-scale instrument measured four constructs: attitude toward learning ODEs, self-efficacy in solving ODEs, confidence in prerequisite skills, and engagement with instruction. The SLPQ demonstrated acceptable internal consistency (Cronbach's $\alpha = .78$).

The Corequisite Intervention

The corequisite intervention provided structured, just-in-time reinforcement of the specific algebraic and calculus competencies each ODE topic required. Development of the intervention began with a systematic mapping of the four-week ODE course sequence separable equations, linear equations, exact equations, and homogeneous equations onto the prerequisite skills each topic depended on, followed by the construction of short, targeted mini-lessons addressing those skills in the order the upcoming lecture would require them. Each corequisite session lasted 30–45 minutes and immediately preceded the corresponding ODE lecture. Sessions combined a brief conceptual review, worked examples, guided practice, and an explicit bridging discussion connecting the reinforced skill to the forthcoming lecture content. Table 2 summarizes the weekly schedule.

Table 2. Weekly Corequisite Intervention Schedule

Week	First-Order ODE Topic	Prerequisite Focus (Mini-Lesson)	Guided Practice
1	Separable equations	Separating variables; integrating simple expressions	Solving a given separable equation step by step

2	Linear equations	Exponential functions and their integration; simplifying products	Finding integrating factors; solving linear ODEs stepwise
3	Exact equations	Partial differentiation and integration in multivariable calculus	Computing partial derivatives; testing exactness
4	Homogeneous equations	Substitution and simplification of fractional expressions	Applying the substitution $y = vx$ to solve homogeneous ODEs

Both groups attended identical ODE lectures. The experimental group entered each lecture immediately after a targeted support session addressing that week's prerequisite demands, while the control group received no supplementary session. Post-lecture guided practice for the experimental group required the concurrent application of the newly reinforced prerequisite skill and the ODE content just presented, consolidating the link between prior and new knowledge rather than treating them as separate learning events.

Procedure

The CDT pretest was administered to both groups at the start of the study to establish baseline prerequisite competence and to permit statistical adjustment for initial group differences. The ODE-AT posttest and the SLPQ were administered to both groups at the end of the four-week intervention period within a single scheduled session. Demographic information was collected at the outset via a brief background questionnaire. All instruments were administered under standardized conditions, with both groups completing the same instruments at the same scheduled points to minimize measurement inequivalence.

DATA ANALYSIS

Quantitative data were analyzed using descriptive and inferential statistics appropriate for the study design. Descriptive statistics, means, standard deviations, and frequency distributions, summarized the distribution of pretest and posttest scores in both groups. The primary inferential analysis was Analysis of Covariance (ANCOVA), with ODE-AT posttest scores as the dependent variable, group membership as the independent variable, and CDT pretest scores as the covariate. ANCOVA was selected because it estimates the intervention effect while statistically controlling for baseline differences in prerequisite skill, offering a more precise evaluation of treatment impact than a simple comparison of posttest averages. Prior to conducting the ANCOVA, the linearity of the covariate–outcome relationship, the homogeneity of regression slopes across groups, the normality of residuals, and the equality of error variances were each verified. Effect sizes were reported as partial eta-squared, and SLPQ Likert-scale responses were summarized descriptively and compared across groups using independent-samples t-tests.

Ethical Considerations

Ethical approval was obtained from the institutional ethics review board prior to data collection. Participation was voluntary, and all students gave informed written consent after full disclosure of the study's purpose, procedures, and the confidential handling of their data. Students in the control group were assured that equivalent corequisite support materials would be made available to them after the study concluded. Anonymity was maintained throughout data analysis and reporting through the use of participant codes, and no academic penalties or incentives were attached to participation or non-participation.

RESULTS

Prerequisite Competency Profiles and Their Relationship to ODE Achievement

The first objective was to identify the prerequisite competencies most strongly associated with mastery of first-order ODEs. The CDT was administered at the start of the study to measure competence in four domains: algebraic manipulation, function interpretation, differentiation, and integration. The overall CDT means for the experimental ($M = 51.4$, $SD = 8.73$) and control ($M = 50.1$, $SD = 9.21$) groups were closely comparable, and an

independent-samples t-test confirmed the difference was not statistically significant, $t(58) = 0.57$, $p = .573$. This equivalence was important for the subsequent ANCOVA, since it reduced the likelihood that any posttest differences reflected pre-existing disparities in prerequisite knowledge rather than the intervention itself.

Table 3. CDT Subscale Mean Scores and Between-Group Comparisons

Prerequisite Domain	Exp. M	Exp. SD	Ctrl. M	Ctrl. SD	t(58)	P
Algebraic manipulation	13.2	2.81	12.9	3.04	0.41	.686
Function interpretation	10.8	2.47	10.4	2.62	0.62	.538
Differentiation	14.1	3.15	13.7	3.09	0.50	.621
Integration	13.3	2.93	13.1	2.85	0.27	.787

Note. None of the between-group subscale differences reached statistical significance (all p-values two-tailed).

Across all four subscales, the experimental and control groups scored within a narrow range of one another. What is notable, however, is the absolute level of performance: across both groups, the highest mean subscale scores were obtained in differentiation and integration, while function interpretation yielded the lowest means. This pattern suggests that although students had been exposed to differentiation and integration procedures, their conceptual understanding of functions, a foundational requirement for interpreting ODE solutions, remained comparatively underdeveloped, echoing the distinction Artigue (2011) and Rasmussen (2001) draw between procedural execution and interpretive understanding.

To examine the predictive relationship between prerequisite competency and subsequent achievement, Pearson correlations were computed between each CDT subscale and ODE-AT posttest scores for both groups (Table 4).

Table 4. Pearson Correlations Between CDT Subscales and ODE-AT Posttest Scores

CDT Subscale	r (Experimental)	r (Control)	p (Exp.)	p (Ctrl.)
Algebraic manipulation	.61	.58	< .001	< .001
Function interpretation	.54	.51	< .001	< .001
Differentiation	.67	.63	< .001	< .001
Integration	.72	.68	< .001	< .001
Total CDT score	.76	.71	< .001	< .001

Note. All correlations were statistically significant at $p < .001$.

Every CDT subscale correlated positively and significantly with ODE-AT posttest performance in both groups. The strongest associations were observed for integration ($r = .72$ experimental; $r = .68$ control) and differentiation ($r = .67$; $r = .63$), reflecting the central role of these operations in solving first-order ODEs. The total CDT score was the strongest overall predictor ($r = .76$ and $.71$, respectively). These moderate-to-strong coefficients indicate that the domains assessed by the CDT were not arbitrary but substantively related to ODE performance, reinforcing the importance of careful prerequisite mapping before designing targeted interventions (Dogan-Dunlap, 2006).

Effect of the Corequisite Model on ODE Achievement

The second objective was to evaluate the impact of the corequisite instructional model on students' ODE achievement. An ANCOVA was performed with ODE-AT posttest scores as the dependent variable, group membership as the independent variable, and CDT pretest scores as the covariate. Preliminary checks confirmed that the assumptions underlying ANCOVA were satisfied: the covariate, outcome relationship was linear ($b = 0.61$, $p < .001$); the homogeneity-of-regression-slopes assumption held, as the Group $\times$ CDT interaction was

non-significant, $F(1, 56) = 0.83$, $p = .367$; residuals were normally distributed (Shapiro-Wilk $W = 0.98$, $p = .412$); and error variances were equal across groups (Levene's $F(1, 58) = 1.14$, $p = .291$).

Table 5. ANCOVA Summary: ODE-AT Posttest Scores by Group, Controlling for CDT Pretest

Source	SS	Df	MS	F	P	η^2p
CDT pretest (covariate)	1,842.6	1	1,842.6	38.24	< .001	.403
Group (intervention)	2,105.3	1	2,105.3	43.69	< .001	.432
Error	2,747.8	57	48.2	—	—	—
Total	6,695.7	59	—	—	—	—

The ANCOVA revealed a significant main effect of group on ODE-AT posttest scores after controlling for CDT pretest performance, $F(1, 57) = 43.69$, $p < .001$, $\eta^2p = .432$. This large effect size indicates that group membership, whether a student received the corequisite intervention or conventional instruction, accounted for approximately 43% of the variance in posttest achievement beyond what was explained by initial prerequisite knowledge. The CDT covariate was itself significantly associated with posttest performance, $F(1, 57) = 38.24$, $p < .001$, $\eta^2p = .403$, confirming that entering levels of prerequisite knowledge independently predicted ODE achievement regardless of group assignment.

Table 6. Adjusted and Unadjusted ODE-AT Posttest Means by Group

Group	Unadj. Posttest M	Adj. Posttest M	Adj. SD	95% CI
Experimental	74.8	74.3	7.61	[71.8, 76.8]
Control	61.6	62.1	8.43	[59.2, 65.0]

Note. Adjusted means control for CDT pretest scores.

After adjusting for the CDT covariate, the experimental group achieved a mean ODE-AT score of 74.3, 95% CI [71.8, 76.8], compared with 62.1, 95% CI [59.2, 65.0], for the control group, an adjusted mean difference of approximately 12.2 points. The unadjusted means told a similar story (74.8 versus 61.6), indicating that statistical adjustment for baseline differences had a relatively minor effect on the direction and magnitude of the group difference, which strengthens confidence that the corequisite intervention, rather than pre-existing ability differences, drove the observed achievement gains. By convention, partial eta-squared values above .14 are considered large in educational research (Cohen, 1988), placing the present effect well within that range.

Attitudes, Confidence, and Self-Efficacy

The third objective examined the influence of the corequisite model on students' attitudes, confidence, and self-efficacy, assessed via the SLPQ at the close of the intervention period. Table 7 reports the mean scores for both groups on each of the four constructs, along with independent-samples t-test results.

Table 7. SLPQ Construct Means, Standard Deviations, and Between-Group Comparisons

SLPQ Construct	Exp. M	Exp. SD	Ctrl. M	Ctrl. SD	P
Attitude toward ODE learning	4.21	0.54	3.47	0.71	< .001
Self-efficacy in solving ODEs	4.08	0.61	3.31	0.78	< .001
Confidence in prerequisite skills	4.33	0.48	3.19	0.83	< .001
Engagement with instructional model	4.17	0.57	3.38	0.76	< .001
Overall SLPQ composite	4.20	0.50	3.34	0.72	< .001

Note. Responses were recorded on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). All between-group differences were statistically significant.

Students in the experimental group reported markedly more positive perceptions across all four constructs. The largest between-group gap was in confidence in prerequisite skills (experimental $M = 4.33$, $SD = 0.48$; control $M = 3.19$, $SD = 0.83$), a difference exceeding a full-scale point. Attitude toward ODE learning and self-efficacy in solving ODEs also showed sizeable differences. Because control students had no structured supplementary model to engage with, the engagement comparison must be interpreted cautiously; nonetheless, the experimental group's high rating on this construct ($M = 4.17$) indicates the corequisite format was well received. The composite SLPQ score placed experimental students in the 'agree' range of the scale ($M = 4.20$), while control students averaged just above the neutral midpoint ($M = 3.34$), a difference reflecting a meaningful divergence in the affective and motivational experience of the two groups over the intervention period.

DISCUSSION

The findings indicate that students' prerequisite competence was closely related to their achievement in first-order ordinary differential equations (ODEs). All four Corequisite Diagnostic Test (CDT) domains were significantly associated with ODE achievement, with differentiation and integration showing the strongest relationships. This pattern is theoretically plausible because these skills are directly involved in solving the ODE types addressed in the study. The findings therefore support the use of targeted prerequisite diagnosis rather than broad, undifferentiated remediation when preparing students for advanced mathematics content.

The central finding was that students who received corequisite instruction achieved significantly higher adjusted posttest scores than those in the conventional instruction group, $F(1, 57) = 43.69$, $p < .001$, $\eta^2_p = .432$. This extends previous corequisite research, which has largely focused on gateway mathematics, algebra, and quantitative reasoning courses (Daugherty et al., 2017; Kashyap & Mathew, 2017; Logue et al., 2019; Ran & Lin, 2022), to the more advanced context of first-order ODEs. Unlike many gateway courses, ODEs require students to coordinate several prerequisite competencies while simultaneously learning new concepts and procedures. The results suggest that embedding targeted prerequisite support within ODE instruction can help students manage these demands more effectively.

The findings are also consistent with Cognitive Load Theory (Sweller et al., 2019). By addressing specific prerequisite gaps immediately before the related ODE content, the intervention may have reduced the cognitive demands associated with recalling or reconstructing foundational procedures while students were learning new material. Rather than requiring students to divide their attention between unresolved prerequisite difficulties and new ODE concepts, the corequisite approach provided the relevant support at the point of need. This interpretation is particularly relevant to students entering advanced mathematics courses with uneven prerequisite knowledge.

The findings further reflect a constructivist perspective, particularly the role of instructional scaffolding in supporting learners as they move toward independent performance (Vygotsky, 1978). The intervention did not replace ODE instruction with general remediation; instead, prerequisite skills were reinforced in direct connection with the mathematical content being introduced. This alignment may have helped students connect existing knowledge with new ODE concepts and procedures. The absence of significant baseline differences between the groups, together with the similarity between the adjusted and unadjusted achievement patterns, provides additional support for interpreting the observed posttest difference as being associated with the instructional condition, although causal claims should remain appropriately cautious given the quasi-experimental design.

The affective findings provide an important complement to the achievement results. Students exposed to the corequisite model reported more favourable perceptions across the assessed learning constructs, including self-efficacy and confidence in prerequisite skills. This pattern is consistent with Bandura's (1997) emphasis on mastery experiences as an important source of self-efficacy. Repeated opportunities to successfully practise prerequisite skills before applying them to ODE problems may have helped students develop greater confidence in their capacity to engage with challenging content. The findings therefore suggest that corequisite instruction may support not only students' mathematical performance but also their perceived readiness to learn advanced mathematics.

Two features of the intervention are particularly noteworthy. First, support was provided just in time, immediately before the relevant ODE content, rather than through a separate prerequisite course or generalized review. Second, the reinforced skills were explicitly linked to the ODE procedures that followed. These features distinguish the model from conventional remediation and may explain why prerequisite support was more directly connected to students' ongoing learning. Overall, the findings suggest that a carefully aligned corequisite model can provide a practical means of integrating prerequisite reinforcement into advanced mathematics instruction while supporting both achievement and students' learning perceptions.

Teaching Implications

The findings have several implications for teaching first-order ordinary differential equations (ODEs) and other advanced mathematics courses in which prerequisite knowledge is critical. First, prerequisite reinforcement should be integrated into regular instruction rather than treated as a separate remedial activity. A brief diagnostic assessment at the beginning of a course can identify specific gaps in algebraic manipulation, function interpretation, differentiation, and integration, enabling instructors to provide targeted support based on students' actual needs.

Second, the timing and alignment of support are important. Rather than providing generic prerequisite review, instructors can incorporate brief, topic-specific corequisite activities immediately before or during relevant ODE lessons. For example, a short review of integrating factors can precede instruction on first-order linear equations. This just-in-time approach allows students to reactivate the required knowledge when it is needed for new learning.

Third, prerequisite review should be explicitly connected to the ODE content that follows. Brief bridging explanations and worked examples can help students see how a reinforced skill is used in solving the target ODE problem. Such connections may make prerequisite support more meaningful and reduce the perception that review activities are unrelated to the main course.

Finally, the observed improvements in students' learning perceptions suggest that corequisite instruction may have affective as well as academic value. Providing structured opportunities for students to successfully apply reinforced prerequisite skills may strengthen their confidence and self-efficacy in approaching ODE problems. At the departmental level, the findings support consideration of corequisite models as an alternative to relying exclusively on prerequisite courses or developmental instruction, particularly where students can benefit from targeted support while remaining in credit-bearing ODE coursework.

CONCLUSION, LIMITATIONS, AND DIRECTIONS FOR FUTURE RESEARCH

This study provides evidence that a structured corequisite instructional model can support undergraduate learning of first-order ordinary differential equations (ODEs). Students' competencies in algebraic manipulation, function interpretation, differentiation, and integration were significantly related to ODE achievement, supporting the value of diagnosing and addressing specific prerequisite gaps. More importantly, students who received targeted prerequisite support integrated into ODE instruction achieved significantly higher posttest scores than those receiving conventional instruction and reported more favourable learning perceptions, including greater confidence, self-efficacy, and engagement. These findings suggest that embedding just-in-time prerequisite reinforcement within advanced mathematics instruction may provide a practical alternative to separating prerequisite remediation from credit-bearing coursework.

The findings should, however, be interpreted in light of several limitations. The use of intact classes in a quasi-experimental design rather than random assignment limits the strength of causal inference. In addition, the study was conducted at a single institution and focused on a four-week instructional unit, which limits the generalizability of the findings to other contexts, student populations, and areas of differential equations. The affective outcomes were also based on self-report measures and may therefore be influenced by response bias. Finally, the study did not examine whether the observed achievement and affective gains were sustained beyond the intervention period.

Future research should replicate the study with larger, multi-institutional samples and, where feasible, randomized or stronger quasi-experimental designs. Longitudinal studies could examine whether the benefits of corequisite instruction persist into subsequent mathematics courses. Research could also extend the model to other advanced mathematics domains, such as higher-order equations, systems of ODEs, and numerical methods, to determine whether its effectiveness extends beyond first-order ODEs. In addition, qualitative and mixed-method studies could investigate students' experiences of corequisite support and examine potential mechanisms, such as changes in mathematics anxiety, confidence, and engagement, that may explain its effectiveness. Overall, the findings support corequisite instruction as a promising approach for integrating prerequisite support into advanced mathematics learning.

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