PEDAGOGICAL CONDITIONS FOR IMPLEMENTING THE ADAPTIVE–INTEGRATIVE APPROACH IN TEACHING MATHEMATICS TO CHEMISTRY STUDENTS

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DOI: https://doi.org/10.5281/zenodo.21157382

Annotatsiya. *Mazkur maqolada kimyo yo'nalishi talabalariga matematikani o'qitishda adaptiv-integrativ yondashuvni amaliyotga joriy etishning pedagogik shart-sharoitlari ilmiy tahlil qilinadi. Xalqaro ilmiy adabiyotlarning tizimli tahlili asosida besh zaruriy pedagogik shart aniqlangan: fanlararo hamkorlikni institutsional qo'llab-quvvatlash; professor-o'qituvchilarning uzluksiz, mazmunga yo'naltirilgan kasbiy rivojlanishi; matematika va kimyo o'quv dasturlarining o'zaro muvofiqlashtirilishi; talabaga yo'naltirilgan, kontekstga asoslangan va modellashtirishga tayanuvchi didaktik metodlardan foydalanish; shakllantiruvchi, kompetensiyaga yo'naltirilgan baholash va o'z vaqtida fikr-mulohaza berish. Shartlarning o'zaro bog'liqligi asoslanib, ularni amaliyotga joriy etish bo'yicha amaliy tavsiyalar va keyingi tadqiqotlar uchun tekshiriladigan farazlar taklif etilgan.*

Kalit so'zlar: pedagogik shart-sharoitlar; adaptiv-integrativ yondashuv; kimyogarlar uchun matematika; fanlararo ta'lim; kasbiy rivojlanish; shakllantiruvchi baholash; modellashtirish; o'quv dasturlarini muvofiqlashtirish.

Аннотация. *В статье проводится научный анализ педагогических условий внедрения адаптивно-интегративного подхода к обучению математике студентов-химиков. На основе систематического анализа международной научной литературы выявлены пять необходимых педагогических условий: институциональная поддержка междисциплинарного сотрудничества; непрерывное, содержательно-ориентированное профессиональное развитие преподавателей; согласование учебных программ по математике и химии; применение студентоцентрированных, контекстных и моделирующих дидактических методов; формирующее, компетентностно-ориентированное оценивание со своевременной обратной связью. Обоснована взаимозависимость условий, предложены практические рекомендации по их реализации и проверяемые гипотезы для последующих эмпирических исследований.*

Ключевые слова: педагогические условия; адаптивно-интегративный подход; математика для химиков; междисциплинарное обучение; профессиональное развитие; формирующее оценивание; моделирование; согласование учебных программ.

Abstract. *This article presents a scholarly analysis of the pedagogical conditions required for implementing the adaptive–integrative approach in teaching mathematics to chemistry students. On the basis of a structured review of international peer-reviewed literature, five necessary pedagogical conditions are identified: institutional and organisational support for interdisciplinary cooperation; sustained, content-specific professional development of faculty; curricular alignment between the mathematics and chemistry components of the programme; the systematic use of student-centred, context-based and modelling-oriented didactic methods; and formative, competence-oriented assessment with timely feedback. The interdependence of the conditions is substantiated, and practical* *recommendations together with testable propositions for subsequent implementation research are proposed.*

Keywords: pedagogical conditions; adaptive–integrative approach; mathematics for chemists; interdisciplinary teaching; professional development; formative assessment; mathematical modelling; curricular alignment.

1. INTRODUCTION

The mathematics problem in undergraduate chemistry - the persistent gap between students’ mathematical preparation and the mathematical demands of their chemistry courses - has been repeatedly documented over the past two decades. A recent large-scale study of general chemistry shows that prior mathematical knowledge is among the strongest predictors of where students begin a chemistry course, even though the rate of subsequent learning proves comparatively independent of prior mathematics [1]. Building on this and related findings, an increasing body of curricular work argues that mathematics for chemists should be reorganised around chemical contexts, so that mathematical concepts are introduced as responses to recognisable chemical problems rather than as decontextualised abstractions [2]. Within this broader reform agenda, the adaptive–integrative approach treats the preparation of future chemists in mathematics as a dual task: adapting mathematical content to the professional field of chemistry, and integrating mathematical and chemical reasoning within shared tasks, modules and assessments.

However, design proposals do not implement themselves. Research on the introduction of integrated STEM and context-based approaches in school and university programmes has shown repeatedly that whether a reform takes hold depends not on the elegance of its design but on a constellation of contextual factors: organisational structures, faculty preparation, curricular alignment, didactic practices, and assessment regimes [3, 4]. In the pedagogical tradition these factors are commonly described as “pedagogical conditions” - the necessary circumstances under which a pedagogical approach can be effective and sustained. In international research the same constellation is captured through the literature on implementation, faculty professional development, and the conditions that shape teaching practice in higher education [5, 6].

The present paper addresses a gap between the design literature on the adaptive–integrative approach and the implementation literature on educational reform. Its objective is to identify and articulate the pedagogical conditions under which the adaptive–integrative approach can be implemented in teaching mathematics to chemistry students. The objectives are threefold: (1) to derive, from peer-reviewed research, a set of necessary pedagogical conditions; (2) to relate each condition to specific empirical findings and to the design principles of the adaptive–integrative approach; and (3) to formulate practical recommendations and testable propositions for subsequent implementation research.

2. METHODS

The study is conceptual–analytical. It develops a set of pedagogical conditions on the basis of a structured narrative review of research literature on (a) integrated STEM and interdisciplinary teaching in higher education, (b) faculty professional development for evidence-based instruction, (c) context-based and modelling-oriented teaching of mathematics in scientific disciplines, and (d) formative assessment in mathematics and science. The aim of the review was to identify the contextual factors that recurrently mediate the success or failure of pedagogical reform in mathematics teaching for science students.

Sources were identified through searches in Google Scholar, ERIC, Scopus and ScienceDirect using combinations of the terms "pedagogical conditions", "integrated STEM", "interdisciplinary teaching", "professional development", "context-based learning", "mathematics for chemists", "formative assessment" and "evidence-based teaching". Priority was given to peer-reviewed journal articles and edited-volume chapters published between 2007 and 2024. Sources were screened in two stages: an initial title-and-abstract screening for thematic relevance, followed by full-text reading aimed at extracting reported barriers, supports and design features.

Recurring barriers and supports reported in the reviewed sources were grouped along five levels at which pedagogical reform must be supported: the institutional level (organisation, structures, time, resources); the faculty level (knowledge, beliefs, professional growth); the curricular level (alignment, coordination between disciplines); the didactic level (teaching methods at the level of individual lessons); and the assessment level (the kinds of evidence of learning that are elicited and how they are used). For each level, one principal pedagogical condition was formulated and anchored in the relevant peer-reviewed research.

Because the study is conceptual rather than empirical, its conclusions take the form of testable propositions rather than verified findings. A formal systematic-review protocol was not adopted, so selection bias cannot be fully excluded. The reviewed literature is dominated by North American, Western European and East Asian contexts; transfer to other educational systems requires cultural and curricular adaptation.

3. RESULTS AND ANALYSIS

The synthesis of the reviewed sources yields five necessary pedagogical conditions for the sustained implementation of the adaptive–integrative approach. They are listed in Table 1 and elaborated below. The conditions are formulated as necessary, but no single condition is claimed to be sufficient: in implementation practice they interact, and the absence of any one of them tends to undermine the others.

Table 1. Five pedagogical conditions for implementing the adaptive–integrative approach

№	Level	Pedagogical condition	Principal evidence base
1	Institutional	Organisational structures, time allocation and resources support interdisciplinary cooperation between mathematics and chemistry teaching.	[3, 4]
2	Faculty	Sustained, content-specific professional development equips mathematics and chemistry faculty with the knowledge and confidence to teach in an integrated way.	[3, 5]
3	Curricular	The mathematics and chemistry curricula are jointly designed so that mathematical content is sequenced and selected in relation to chemical needs.	[2, 7]
4	Didactic	Lessons employ student-centred, context-based and modelling-oriented methods that situate mathematical concepts in chemical phenomena.	[7, 8]

5	Assessment	Formative, competence-oriented assessment with timely feedback monitors learners’ progress and informs adaptive instruction.	[6]

Condition 1: institutional and organisational support. Research on integrated STEM education has consistently identified organisational structures as a superordinate factor that subsumes most other barriers. In a large-scale needs-assessment study of integrated STEM, Stohlmann and colleagues report that the separate organisation of STEM subjects - distinct departments, separate class periods, separate funding lines - is the single most frequently cited obstacle to integration, and that adequate preparation for integrated STEM requires a considerable rethinking of pre-service courses and in-service workshops [3]. Margot and Kettler’s systematic review of teachers’ perceptions of STEM integration confirms this pattern at a wider scale and adds that lack of dedicated collaborative time and insufficient institutional incentives are repeatedly named as principal barriers [4]. For the adaptive–integrative approach, this translates into a concrete requirement: institutions must allocate time and resources for joint planning between mathematics and chemistry faculty, support shared teaching materials, and recognise integrated teaching in workload and career-progression criteria.

Condition 2: sustained, content-specific professional development. The same body of research that identifies institutional barriers also documents a pervasive readiness problem: most teachers and university lecturers have been trained in a single discipline, and they do not feel well-prepared to teach in an integrated way [3]. Margot and Kettler’s synthesis emphasises that effective professional development for integrated teaching must be sustained over time, content-specific, and aligned with the curriculum the teachers are expected to deliver [4]. In higher education, comparable findings have been reported in faculty-development programmes for evidence-based STEM teaching: Tomkin and colleagues show that significant change in instructional practice requires multi-year support structures, including learning communities and ongoing coaching, rather than short workshops [5]. For the adaptive–integrative approach, this means that the mathematics lecturers who serve chemistry students must develop their knowledge of chemical phenomena and curricula, while chemistry lecturers must develop their ability to articulate the mathematical structure of chemical reasoning.

Condition 3: curricular alignment. Even with motivated faculty and supportive institutional structures, the adaptive–integrative approach cannot operate if the mathematics and chemistry components of the programme are sequenced and structured independently. Comparative analyses of mathematics provision in science programmes show that two models predominate - a generic mathematics service course delivered by a mathematics department, and discipline-embedded mathematics taught within the science department - and that each has characteristic limitations for the transfer of mathematical reasoning to the disciplinary context [7]. The chemistry-first curriculum design proposed by Parsons and colleagues offers a constructive resolution: mathematical topics are selected and sequenced on the basis of their explanatory role in chemistry, building on recognisable chemical concepts so as to facilitate deeper understanding [2]. The curricular condition therefore requires explicit alignment documents that specify which mathematical competencies are needed, in what sequence and in connection with which chemical topics.

Condition 4: student-centred, context-based and modelling-oriented methods. Curricular alignment and faculty preparation translate into student learning only when day-to-day teaching practices situate mathematical content in authentic chemical contexts and engage students as active modellers rather than passive recipients of formulas. Bennett, Lubben and Hogarth’s synthesis of research on context-based and STS approaches in science teaching shows that situating concepts in authentic contexts improves both motivation and conceptual understanding without compromising performance on traditional measures [8]. In the specific case of mathematics-in-chemistry, an extended modelling cycle has been shown empirically to capture the transitions students must make between the chemical phenomenon and its mathematical representation; problem-solving trajectories that explicitly traverse these transitions are associated with more successful outcomes [7]. Lecturers should therefore structure lessons inductively - starting from chemical phenomena, scaffolding students through modelling steps, and returning to chemical interpretation - rather than presenting mathematical formalism first.

Condition 5: formative, competence-oriented assessment with timely feedback. If a programme states that its aim is the integrated development of mathematical and chemical competence, but examines students only on isolated computations, the intended approach is undermined by the assessment regime itself. Research on formative assessment in higher education demonstrates that frequent, low-stakes assessment with timely and actionable feedback is among the most reliably effective interventions in undergraduate teaching, with particularly clear gains in mathematics-rich subjects [6]. This implies a shift toward assessment items that probe both mathematical and chemical reasoning together - context-based tasks, project-based modelling assignments, reflective portfolios - alongside regular diagnostic checks that allow lecturers to adapt instruction to the heterogeneous mathematical backgrounds documented at scale in general chemistry [1].

Interdependence of the conditions. The five conditions are not independent. Institutional support without faculty preparation produces poorly executed integration; faculty preparation without curricular alignment produces isolated good lessons that do not accumulate into competence; curricular alignment without supportive didactics produces well-structured but inert content; supportive didactics without formative assessment cannot diagnose and correct misconceptions; and formative assessment without the other four conditions degenerates into testing for its own sake. The convergence of these dependencies across the literature on integrated STEM [3, 4], faculty professional development [5], context-based teaching [8] and formative assessment [6] justifies treating the conditions as a connected system rather than as a checklist.

4. DISCUSSION

The five conditions identified above bring together strands of research that are usually treated separately. The integrated-STEM and interdisciplinary-teaching literature [3, 4] has documented the institutional and faculty preconditions for effective integration but has tended to focus on school rather than university contexts; the curriculum-design literature for mathematics-in-science [2, 7] has clarified what curricular alignment should look like but has paid less attention to the institutional supports it requires; the context-based and modelling literature [8] has demonstrated the value of student-centred didactics but has not always engaged with the assessment regimes that sustain or undermine such practices; and the formative-assessment literature in higher education [6] has produced convergent evidence on effective feedback without explicitly addressing its role within integrated approaches. By drawing these strands together, the present paper identifies the pedagogical conditions under which the adaptive–integrative approach can plausibly succeed in teaching mathematics to chemistry students.

Three aspects of the analysis deserve closer scrutiny. First, the institutional condition is the easiest to neglect because it is the least visible in everyday teaching practice. Reform initiatives that focus exclusively on lesson design routinely founder on the absence of dedicated collaborative time and on incentive structures that reward mono-disciplinary rather than integrative teaching [3, 4]. Second, the faculty condition is the slowest to fulfil because deep changes in instructional practice require multi-year support structures rather than short workshops [5]. Third, the alignment between curriculum, didactics and assessment is sometimes assumed rather than designed; the literature reviewed here suggests that explicit alignment documents - specifying which mathematical competencies are needed in connection with which chemical topics and how they will be assessed - are an important implementation tool.

The principal limitation of the present work is its conceptual nature. The five conditions are grounded in well-established research traditions, but their joint operation in the specific context of mathematics teaching for chemistry students has not yet been tested in a coordinated empirical design. Subsequent work should pursue at least three lines of investigation: (i) implementation case studies of programmes that have attempted to fulfil all five conditions; (ii) quasi-experimental comparison of cohorts in which the conditions are more versus less fully present, with outcomes measured on both mathematical and chemical competence; and (iii) design-based research on the practical instruments - alignment documents, collaborative-time protocols, formative-assessment item banks - that operationalise the conditions in routine practice.

5. CONCLUSION AND PRACTICAL RECOMMENDATIONS

The adaptive–integrative approach to teaching mathematics to chemistry students is unlikely to succeed as a stand-alone lesson-design strategy. Its sustained implementation requires a connected system of pedagogical conditions operating at five levels: institutional support for interdisciplinary cooperation, sustained content-specific professional development of faculty, curricular alignment between mathematics and chemistry, student-centred and modelling-oriented didactics, and formative competence-oriented assessment with timely feedback.

On the basis of the analysis, the following practical recommendations are proposed for higher education institutions: (1) allocate dedicated joint-planning time for mathematics and chemistry faculty and recognise integrated teaching in workload and career-progression criteria; (2) organise multi-year, content-specific professional development programmes, including learning communities and peer coaching, rather than one-off workshops; (3) develop explicit curriculum-alignment documents that specify which mathematical competencies are required, in what sequence and in connection with which chemical topics; (4) restructure lessons inductively, starting from chemical phenomena and guiding students through the full modelling cycle; and (5) introduce regular, low-stakes formative assessment instruments - context-based tasks, modelling assignments and diagnostic checks - that allow instruction to be adapted to students' heterogeneous mathematical backgrounds.

The joint fulfilment of these conditions defines the practical agenda for institutions seeking to reform the mathematical preparation of future chemists, and their empirical validation through implementation case studies and quasi-experimental research constitutes a promising direction for future work.

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