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Examining whether and how instructional coordination occurs within introductory undergraduate STEM courses

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Instructors' interactions can foster knowledge sharing around teaching and the use of research-based instructional strategies (RBIS). Coordinated teaching presents an impetus for instructors' interactions and creates opportunities for instructional improvement but also potentially limits an instructor's autonomy. In this study, we sought to characterize the extent of coordination present in introductory undergraduate courses and to understand how departments and instructors implement and experience course coordination. We examined survey data from 3,641 chemistry, mathematics, and physics instructors at three institution types and conducted follow-up interviews with a subset of 24 survey respondents to determine what types of coordination existed, what factors led to coordination, how coordination constrained instruction, and how instructors maintained autonomy within coordinated contexts. We classified three approaches to coordination at both the overall course and course component levels: independent (i.e., not coordinated), collaborative (decision-making by instructor and others), controlled (decision-making by others, not instructor). Two course components, content coverage and textbooks, were highly coordinated. These curricular components were often decided through formal or informal committees, but these decisions were seldom revisited. This limited the ability for instructors to participate in the decision-making process, the level of interactions between instructors, and the pedagogical growth that could have occurred through these conversations. Decision-making around the other two course components, instructional methods and exams, was more likely to be independently determined by the instructors, who valued this autonomy. Participants in the study identified various ways in which collaborative coordination of courses can promote but also inhibit pedagogical growth. Our findings indicate that the benefits of collaborative course coordination can

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be realized when departments develop coordinated approaches that value each instructor's autonomy, incorporate shared and ongoing decision-making, and facilitate collaborative interactions and knowledge sharing among instructors.

KEYWORDS

autonomy, coordinated, exams, institutional change, textbook, undergraduate, STEM

1. Introduction

Despite the accumulating evidence of improved student learning with active learning and other student-centered teaching practices (Braxton et al., 2000; Prince, 2004; Freeman et al., 2011, 2013; Haak et al., 2011; Rodenbusch et al., 2016), adoption of these practices has been slow within undergraduate science, technology, engineering, and mathematics (STEM) courses. Several studies have identified challenges and barriers that instructors face when adopting research-based instructional strategies (RBIS; e.g., Lund and Stains, 2015; Shadle et al., 2017; Sturtevant and Wheeler, 2019), including time restrictions and external pressure to cover large amounts of content. Instructors may also lack the pedagogical knowledge, skills, and confidence necessary to implement RBIS. Knowledgeable instructors can serve as a resource for other instructors who would like to learn more about or gain confidence in using RBIS. However, interactions between knowledgeable RBIS users and non-users are limited, and there is a need for creating opportunities to help instructors exchange RBIS knowledge (Lane et al., 2020). In the present study, we examine course coordination as one structure that provides opportunities where faculty teaching the same or similar courses can share knowledge (Lane et al., 2020, 2022; Haag et al., 2023). In particular, we sought to better understand the landscape of course coordination across the United States (US) as well as how course coordination might influence instructional practices, including as a potential driver to help instructors incorporate RBIS.

1.1. Course coordination in STEM undergraduate education

Course coordination provides an opportunity for shared teaching and has been linked to improved student outcomes (Rasmussen et al., 2021; Abdulahad et al., 2021). To date, most studies on coordination in STEM undergraduate courses have focused on mathematics (Rasmussen and Ellis, 2015; Rasmussen et al., 2019, 2021; Villalobos et al., 2020; Martinez et al., 2022). In the mathematics education literature, coordination has been defined as a system with synchronized content and instructors' interaction, typically with someone in charge (Rasmussen and Ellis, 2015; Rasmussen et al., 2019, 2021). This definition emphasizes collaborative design and regular instructors' interactions around a course or its components. However, coordination may vary. For example, a traditional model of top-down coordination focused on synchronization of content without extensive instructors' interaction has been described in an earlier study of engineering courses (Sathianathan, 1997).

These varied understandings of coordination suggest the need to distinguish between different types of coordination. In the present study, we identify three coordination types: independent where each instructor makes decisions on course components without input from others (i.e., not coordinated), collaborative coordination where every instructor is part of the decision-making process, and controlled coordination where someone other than the instructors makes decisions about course components. Within each of these coordination types, four main course components can be coordinated: (1) content coverage, including the syllabus, learning objectives, and course pacing, (2) textbooks, (3) instructional methods, and (4) exams and other assessments. Some courses may synchronize all four of these components (Bazett and Clough, 2020; Rasmussen et al., 2021) while others may synchronize some subset of the components. For example, the syllabus and pacing in a general chemistry course were synchronized in one study (Abdulahad et al., 2021). In mathematics, some institutions synchronized textbooks and content while others synchronized textbooks, content, and exams (Rasmussen and Ellis, 2015; Bazett and Clough, 2020).

1.2. Autonomy

Shared decision-making in coordinated course environments has been reported as important for transforming instructors' teaching practices (Rasmussen and Ellis, 2015; Rasmussen et al., 2019, 2021; Villalobos et al., 2020; Abdulahad et al., 2021; Martinez et al., 2022). However, instructors also indicate a need for autonomy in decision-making around their courses (Stupnisky et al., 2018; Martinez et al., 2022). Autonomy, along with competency and relevance, is a key component of self-determination theory, which describes individuals' motivation to engage in and master activities (Deci and Ryan, 2012). For instructors, autonomy includes having a sense of choice around course content and instruction (Gappa et al., 2007; Deci and Ryan, 2012). Stupnisky et al. (2018) examined how motivation influences instructors' use of RBIS and found that, for instructors at doctoral and master's institutions, autonomy was the strongest predictor of intrinsic motivation, which in turn influenced their use of RBIS (Stupnisky et al., 2018). Conversely, lack of autonomy has been identified by instructors in several STEM departments as a barrier to their engagement in teaching reform and RBIS adoption (Shadle et al., 2017; Sturtevant and Wheeler, 2019). Course coordination may create a tension between the need for shared decision-making and for supporting instructors' sense of autonomy, so effective coordination calls for attention to balancing these two needs. Indeed, course coordinators may adapt their approach to coordination in response to the degree of autonomy desired by instructors (Martinez et al., 2022).

1.3. Instructional context

To understand course coordination and its influence on RBIS adoption, it is important to consider an instructor's broader instructional context. Institution type, discipline, and instructors' appointments have been shown to influence both course coordination and RBIS adoption, but in varying ways.

RBIS adoption has been shown to vary with institution. While doctoral universities have been found to use less student-centered instruction overall (Cox et al., 2011), particular RBIS such as classroom response systems have greater adoption at large public institutions (Gibbons et al., 2017). Other studies report no difference in RBIS use among institution types (Srinivasan et al., 2018; Yik et al., 2022a,b). To date, STEM course coordination has been examined primarily at doctoral and Master's institutions with large programs (Rasmussen and Ellis, 2015; Rasmussen et al., 2021 but see Abdulahad et al., 2021). More information is needed around the context of coordination at institutions with a primarily teaching mission. To understand the institutional landscape around coordination, the present study will investigate coordination at multiple institutional types.

RBIS adoption may be influenced by discipline as instructors from different departments may have different needs. For example, greater RBIS adoption and less use of lecturing has been reported by physics instructors when compared to chemistry instructors (Lund and Stains, 2015; Yik et al., 2022a,b). Currently, the majority of research on coordination in STEM undergraduate education has been limited to mathematics (but see Fernández et al., 2021 for a study in physics and Abdulahad et al. (2021) for a study in chemistry). We contribute to filling this gap by investigating chemistry, physics, and mathematics–three disciplines that each provide foundational gateway courses for most STEM degrees.

In the present study, we investigated the following research questions:

1. What is the extent of coordination present in introductory undergraduate chemistry, mathematics, and physics courses?
2. How are departments and instructors implementing and experiencing course coordination?

2. Methods

We employed a sequential explanatory mixed methods design to address our research questions. We first collected surveys in order to characterize different types of coordination in introductory STEM courses. We then leveraged the results from the survey to invite instructors to participate in interviews. These interviews were designed to provide a more in-depth understanding of the different coordination types identified in the survey and the impact of these coordination types on instructors' teaching practices. Data collection and analyses are described below.

2.1. Survey instrument

The present study on course coordination in introductory STEM courses utilized a subset of data from a national survey on factors related to RBIS adoption and class time devoted to lecturing (Yik et al., 2022a,b). Briefly, potential survey respondents came from a database of 18,337 postsecondary instructors of introductory chemistry, mathematics, and physics courses in the United States. A stratified consensus sampling approach was used to identify a representative pool of instructors across postsecondary institution types: 2-year institutions (i.e., associate's degree granting), 4-year institutions (i.e., bachelor's and Master's degree granting), and Ph.D. granting institutions (i.e., conferring doctoral degrees within the participant's own academic discipline). Contact information for these instructors was compiled by the American Institute of Physics Statistical Research Center by using publicly accessible online information and communicating with department chairs at selected institutions. Survey data was collected from 3,769 instructors between March and May 2019. Survey participants were retained if 1) their target course occurred during the 2017–2019 academic years and was not entirely online, 2) they were the primary instructor for the main whole-class meetings of the course, and 3) they responded to all four survey questions concerning decision-making in their course, leaving a total of 3,641 eligible respondents who met the inclusion criteria.

2.2. Quantitative analysis of course coordination

Participating instructors answered questions on six topics for an introductory course of their choosing: (1) general course information; (2) general instructional practices; (3) awareness and use of RBIS; (4) perceptions, beliefs, and disposition towards students and learning; (5) perspectives and experiences with teaching; and (6) academic position and demographics. Figure 1 provides an overview of how survey responses were processed and interpreted for the current study. We operationalized "course coordination" through four survey questions related to an instructor's decision-making authority over four course components: content coverage (C), textbooks (T), instructional methods (I), and exams (E). Decision-making could be either *independent* (i.e., not involving other people), *collaborative* (i.e., involving the instructor and one or more other people), or *controlled* (i.e., involving one or more other people without the instructor's input). An instructor's decision-making authority for each course component was coded according to their associated survey response (i.e., 1 = myself; 2 = myself and one or more others; 3 = one or more others). Considering the four questions together, we generated 54 different code sequences reflecting the overall "coordination pattern" (i.e., CTIE) they experienced for their course. For example, the 3311 coordination pattern represented an instructor who had no say in the content coverage and textbook selection for their course but used their preferred teaching method and created their exams independently.

To allow for more manageable comparisons across a variety of demographic variables, we identified instructors with patterns that aligned with a "coordination type" reflecting their overall decision-making for the course (i.e., independent, collaborative, controlled). We applied criteria (listed in Figure 1) to encapsulate the most meaningful and interpretable patterns. Application of these criteria led to the inclusion of 13 coordination patterns representing 85.1% (n = 3,099) of the eligible survey participants. Table 1 provides demographic information for this subset of survey participants.

We then examined representation of the three coordination types (i.e., independent, collaborative, controlled) with respect to key demographic variables (i.e., an instructor's academic discipline, their tenure status or tenure eligibility, and their type of postsecondary

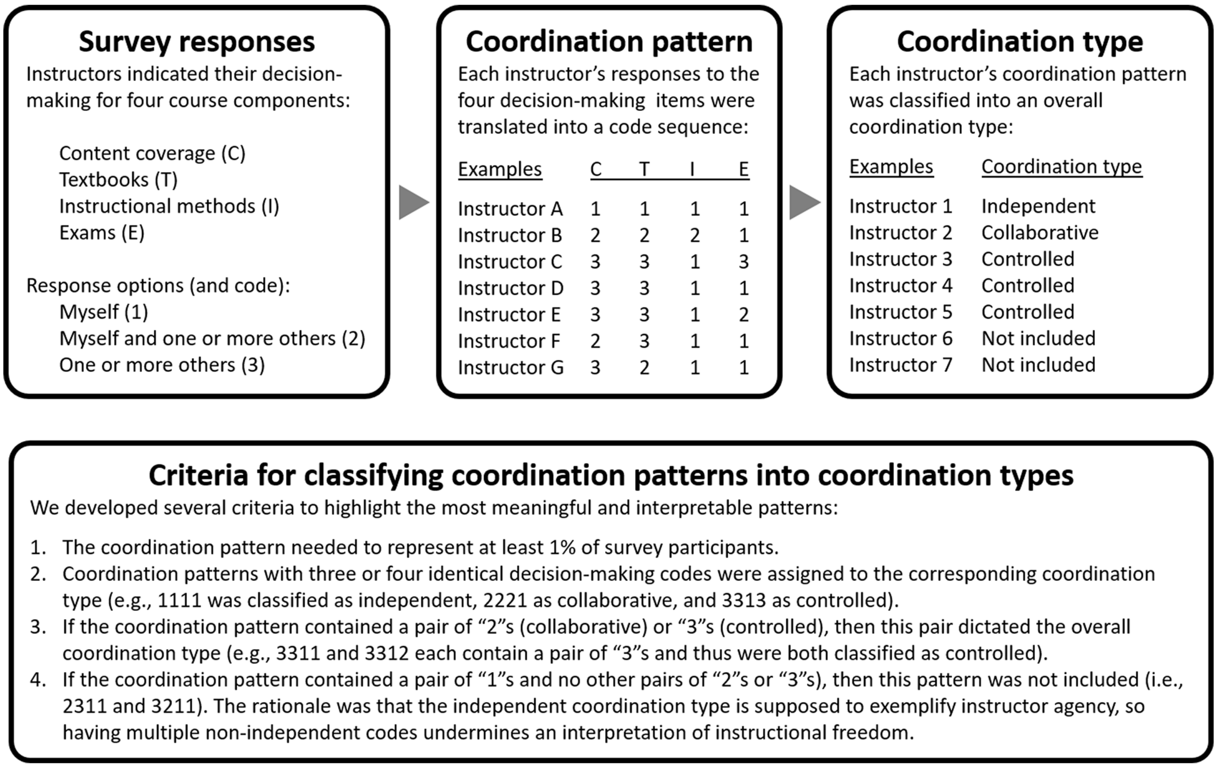

FIGURE 1
Overview of how survey responses were processed and interpreted.

institution). Coordination types were also examined in relation to self-reported RBIS use. For this analysis, instructors were classified as either "high" or "low" RBIS users based on their response to the Yes/No item, "I consistently use RBIS in my course." Additional analyses were conducted to determine whether RBIS use for particular coordination types varied across demographic characteristics.

Chi-squared tests were used to determine whether the distribution of coordination patterns varied across a given demographic or whether the proportion of RBIS users varied by coordination type.

2.3. Qualitative interview participant selection

Building on the survey responses, we sought to conduct interviews with a subset of instructors who had indicated on the original survey that they were open to being contacted for additional research. We aimed to recruit a sample with particular attributes across the three STEM disciplines. Because departmental culture and professional expectations can differ based on the relative emphasis on teaching and research, we sought representation from 4-year and Ph.D.-granting institutions. All solicited instructors were either assistant, associate, or full professors. Incorporating additional groups along these dimensions would have required a substantial increase in sample size. Thus, due to practical constraints, we were unable to include instructors teaching at 2-year institutions or holding contingent positions (e.g., lecturers, visiting scholars). We note the need for more research on both of these groups, given that they likely participate in unique and varied coordination structures.

All solicited instructors must have reported a high degree of RBIS knowledge, indicated by answering "yes" to the survey item, "I've spent time learning about RBIS and I am prepared to use them." Among these respondents, we included instructors who answered either "yes" or "no" to the survey item, "I consistently use RBIS in my course." This ensured that all interviewees would be familiar with RBIS, while enabling us to potentially decipher how other factors led to knowledgeable instructors implementing or not implementing RBIS in their courses. With respect to course coordination, we focused on instructors classified as having collaborative or controlled coordination types.

Our recruitment strategy aimed at maximizing representation across these variables (i.e., academic discipline, institution classification, self-reported RBIS use, and course coordination type). Using email addresses from the original survey, we sent invitations and reminders to small groups of instructors, with subsequent rounds of invitations being increasingly targeted to balance the given attributes in the emerging sample. Instructor and institution identities were unknown prior to selection for invitation. Table 2 provides demographic information for instructor interview participants ($n = 24$).

2.4. Interview protocol

We conducted interviews during summer 2021 *via* online video conferencing (Zoom). Interviews were administered by the same researcher (BW) and followed a semi-structured interview protocol (Supplementary Materials 1), which allowed for scripted questions

TABLE 1 Demographics of survey respondents.

Institution		Race/ethnicity	
2-Year	28.5	American Indian and/or Alaska Native	0.7
4-Year	38.9	Central Asian	0.3
Ph.D. granting	32.6	East Asian	3.8
		South Asian	2.2
Discipline		Southeast Asian	1.8
Chemistry	34.4	Black and/or African American	2.6
Mathematics	33.7	Hispanic and/or Latinx	3.9
Physics	31.8	Native Hawaiian and/or Pacific Islander	0.1
		European	67.9
Academic rank		Middle Eastern and/or North African	1.9
Professor	30.0	Multi-racial	3.1
Associate professor	19.5	Not listed or prefer not to answer	4.7
Assistant professor	14.9		
Lecturer/instructor	19.6	**Gender**	
Visiting professor	2.5	Woman	28.3
Postdoctoral scholar	0.5	Man	56.3
Graduate student	0.9	Transgender	0.1
		Gender fluid	0.2
Tenure status		Agender	0.1
Tenured	46.7	Not listed or prefer not to answer	2.3
Tenure-track	12.9		
Non tenure	23.9		

Numbers represent percent of total respondents included in the quantitative analysis (n =3,099). Percentages not adding to one hundred reflect missing responses.

TABLE 2 Demographics of interview participants (n =24). Numbers represent participants having each attribute.

Institution		Tenure status	
4-Year	8	Tenured	13
Ph.D. granting	16	Tenure-track	9
		Non tenure	2
Discipline			
Chemistry	11	**Race/Ethnicity**	
Mathematics	7	East Asian	1
Physics	6	Southeast Asian	1
		European	22
Academic rank			
Professor	4	**Gender**	
Associate professor	10	Woman	12
Assistant professor	10	Man	12

and unscripted follow-up prompts to probe participant responses. We asked instructors to consider the same introductory-level course and time period they reported on the original survey (i.e., pre-COVID-19 pandemic conditions). The interview questions asked about their professional background (e.g., years at current institution, teaching experience, job expectations), instructional practices (e.g., preferred pedagogical approach, familiarity with and use of RBIS), and their perception of how the coordinated aspects of their course impacted their instructional practices. The interviews lasted 45–60 min. Audio recordings were uploaded to an automated transcription service (Temi), and the resulting transcripts were manually checked, corrected, and de-identified by the interviewing researcher (BW). All data collection was carried out under Western Michigan University IRB Project Number 17-06-10.

2.5. Transcript analysis

Our qualitative analysis aimed to characterize the different course coordination structures in which instructors participated and to explore how instructors perceived coordination to influence their related teaching practices. Five members of the research team (BC, AM, LP, MS, BW) conducted thematic analysis of the transcripts (Boyatzis, 1998; Saldaña, 2015) using a deductive approach centered on the four course components (i.e., content coverage, textbook, instructional methods, and exams) and RBIS use. Our collaborative process proceeded through four stages.

The first stage focused on familiarizing ourselves with the data and deciding how to structure the ensuing analysis. We read through four interviews, with each researcher assigned to two transcripts and one researcher (BW) reading all four transcripts. The researchers annotated the transcripts by noting cases where the participant described coordination structures, influences on their teaching practices, or other factors related to departmental history, norms, processes, or expectations. Using these interviews as examples, the researchers discussed the information expected in the full data set and focused subsequent analyses on the four course components and RBIS use.

The second stage consisted of processing the remaining interviews. We followed the same pattern of having two researchers read each transcript along with BW, who read all the transcripts to ensure that one person was familiar with the complete dataset. Each researcher independently added annotations to their interview transcripts regarding coordination, RBIS use, and department norms. We started with a group of eight transcripts, discussed nascent themes, made minor adjustments to the annotation process, and then read the remaining 16 transcripts.

The third stage involved translating previous annotations into summaries of the coordination each instructor experienced with respect to the four course components and ways in which this might have impacted their instruction. For each participant, BW reviewed the annotated transcripts and summarized their coordination structures along with a general indication of whether the participant perceived these circumstances to be supportive of their desired teaching practices. This information was organized within a spreadsheet thereby allowing us to visualize participant summaries with respect to other attributes reported in the original survey (e.g., institution type, coordination pattern, RBIS use). Using this summary document, the researchers independently identified and then collaboratively discussed emerging themes for each course component.

The fourth stage involved verification, sense making, and elaboration for emergent themes. For each participant summary, we returned to the original transcripts, reexamined relevant sections, and summarized their experience for each course component with respect to four questions: (1) what types of coordination exist, (2) what factors led to coordination, (3) to what extent are instructors constrained by coordination, and (4) how do instructors experience autonomy within coordination? One researcher again read through the summaries, documenting salient themes, identifying representative quotes, and synthesizing emerging findings for each course component. The other researchers reviewed this narrative to ensure that the final themes and findings accurately captured the breadth of participant experiences.

The validity of our results is supported by several aspects of the interview and analysis process. Our selection of interview participants was informed by prior survey results and designed to include a wide range of contexts and experiences. The interviews focused on a particular course within a limited timeframe, which allowed participants to focus on specific situations and events. Follow-up prompts enabled the interviewee to further describe and clarify their relevant experiences. Three members of the research team (BC, LP, and MS) participated in a previous study that identified shared teaching as influencing faculty knowledge sharing. Two additional members of the research team (AM and BW) who had no prior experience investigating faculty knowledge sharing helped minimize this potential bias during the analysis of coordinated teaching experiences, with BW conducting interviews and leading the analysis. Our research team met continually throughout the analysis process to refine our approach, develop themes, and minimize personal bias. The final stage of analysis served to ensure that our findings were grounded in and reflective of participant words.

3. Results

3.1. Prevalence of course coordination

Surveyed instructors answered four questions regarding their decision-making authority over the four course components (Figure 2). Among these instructors, content coverage and textbooks appeared to be similarly coordinated, with collaborative decision-making being most common. Decision-making for instructional methods and examinations was highly independent, indicating a general absence of coordination for these components.

To summarize overall coordination experiences, we considered coordination patterns across the four course components and classified common and interpretable patterns into overall coordination types. For example, a coordination pattern of 2111 indicated that the course content was collaboratively chosen among course instructors but the instructors had autonomy for the other course components; thus, this was a pattern that we categorized as an independent coordination type. When patterns were sorted into independent, collaborative, and controlled coordination types (Table 3), we saw that collaborative course coordination was the most common coordination type (45.1%). Roughly one-third of instructors (30.0%) had little or no external influence on the design and execution of their course. Few instructors (10%) described their course in a way that was classified as being externally controlled.

3.2. Coordination types across disciplines, appointment, and institution types

Coordination types varied across the three disciplines [$\chi^2(4,3{,}099) = 468.647$, $p < 0.001$, $V = 0.275$; Figure 3A]. The majority of chemistry (64%) and mathematics (54%) courses were conducted in a collaborative manner. Mathematics courses were more likely to be classified as controlled (24%) compared to courses in the other two disciplines. Physics instructors, on the other hand, were more likely to work independently, with 57% categorized as an independent coordination type.

Coordination type showed minor variation between tenured, tenure track, and non-tenure track instructor appointments [$\chi^2(4, 2{,}588) = 97.645$, $p < 0.001$, $V = 0.137$; Figure 3B]. The most common coordination type across all three appointments was collaborative (between 58 and 46%). Non-tenure track instructors were more likely to report a controlled coordination type, but this coordination type still represented only a minority of the courses taught by non-tenure track instructors (19%).

Variation was also observed across institution types [$\chi^2(4, 3{,}098) = 91.051$, $p < 0.001$, $V = 0.121$; Figure 3C]. Collaborative coordination was again most prevalent across the three institution types, ranging from 46% of the instructors at 2-year institutions to 59% at 4-year institutions. With respect to the other less common coordination types, 2-year instructors were more likely to work independently, while instructors at Ph.D.-granting institutions were more likely to work under controlled conditions compared to instructors at the other institutions.

3.3. Course coordination and RBIS use

In our previous analysis of the full survey results, we explored factors related to the prevalence of lecturing in introductory chemistry, mathematics, and physics courses (Yik et al., 2022a,b). Course coordination was included as one of 17 factors and was represented by responses to one item about decision-making for instructional methods (I). This variable was treated as binary: independent (option 1 = myself) or coordinated (options 2 = myself and one or more others and 3 = one or more others). Multilevel modeling showed that coordinated decision-making for instructional methods was associated with decreased lecturing during class time. However, most of the instructors reported in the survey complete independence for this course component. In the present study, which uses a subset of that sample, we similarly see that 87% of instructors reported independent decision-making for their instructional methods (Figure 2). The overall coordination types experienced by instructors depended more on decision-making for content coverage, textbook, and exams and less on coordination of instructional methods. This finding prompted us to further explore the relationship between overall coordination type and RBIS use.

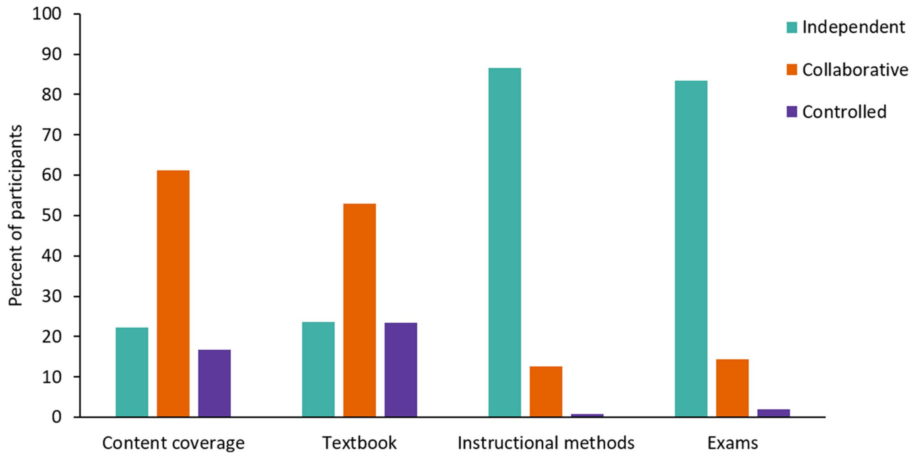

FIGURE 2
Decision-making authority among instructors of undergraduate chemistry, mathematics, and physics introductory courses in the United States (n =3,641). Decision-making was determined based on instructor responses to survey items for the four course components: Independent=myself (coded 1), Collaborative=myself and one or more others (coded 2), and Controlled=one or more others (coded 3).

TABLE 3 Coordination types and corresponding coordination patterns for respondents included in study analyses.

Coordination type	Coordination pattern	Percent of participants	
Independent	1111	12.8	30.0
	2111	7.9	
	1211	6.1	
	1311	2.1	
	3111	1.1	
Collaborative	2211	32.3	45.1
	2212	3.9	
	2222	3.7	
	2221	3.6	
	2312	1.6	
Controlled	3311	7.1	10.0
	3321	1.9	
	3313	1.0	

Coordination patterns are listed in order for content coverage (C), textbook (T), instructional methods (I), and exams (E). Codes shown represent decision-making based on myself = 1, myself and one or more others = 2, or one or more others = 3. Numbers represent percent of total respondents included in study analyses (n = 3,099). Only patterns representing >1% of survey participants were retained. Patterns 2311 (5.4%) and 3211 (1.9%) were not classified due to ambiguity in their coordination type.

For this analysis, we compared the percent of instructors reporting high RBIS use as a means to determine whether a connection existed between coordination type and the tendency to implement RBIS. The percent of high RBIS users varied across coordination types, although with a small effect size [$\chi^2(2, 2{,}776) = 28.728$, $p < 0.001$, V = 0.102; Figure 4]. Independent and collaborative courses had a similar proportion of high RBIS users (49 and 53%, respectively), while controlled coordination types were less likely to be taught by high RBIS users (37%).

We then explored the relationship between coordination type and RBIS use within disciplines, appointments, and institution types (See Supplementary Table 1 for associated statistical tests). With respect to discipline (Figure 5A), chemistry and physics both showed a relationship between coordination type and RBIS use, whereas mathematics did not. Across appointments (Figure 5B), being tenured or being in a non-tenure line position led to a relationship between coordination type and RBIS use, whereas being a pre-tenure instructor did not. Finally, for institution type (Figure 5C), 4-year and Ph.D.-granting institutions had relationships between coordination type and RBIS use, whereas 2-year institutions did not. In cases showing relationships, this implies that coordination type had some type of connection with RBIS use, such as the coordination type influencing teaching practices or people with certain teaching practices tending to be selected for those courses. Conversely, the cases showing no relationship imply that the instructors taught a certain way, irrespective of the broader coordination type.

While the survey results provided quantitative insights into how often institutions coordinated the four course components (i.e., content, textbooks, instructional methods, and exams), they did not provide a nuanced understanding of how departments coordinate these components and how this coordination affects associated instruction. We thus interviewed 24 instructors at Ph.D. granting and 4-year institutions that had either a collaborative or controlled coordination type. These interviews allowed us to expand on the survey results by providing more details about the setup of the coordination, the factors that led to the coordination as well as the extent to which coordination constrained their teaching and impacted their instructional autonomy. Supplementary Table 2 displays the variation in decision-making authority that each of these interviewees experienced for each of the four course components. In the next sections, we present interviewees' perspectives on and experiences with the coordination of these four course components.

In interpreting and presenting qualitative results, we focused on the patterns and themes that emerged and used semi-quantitative

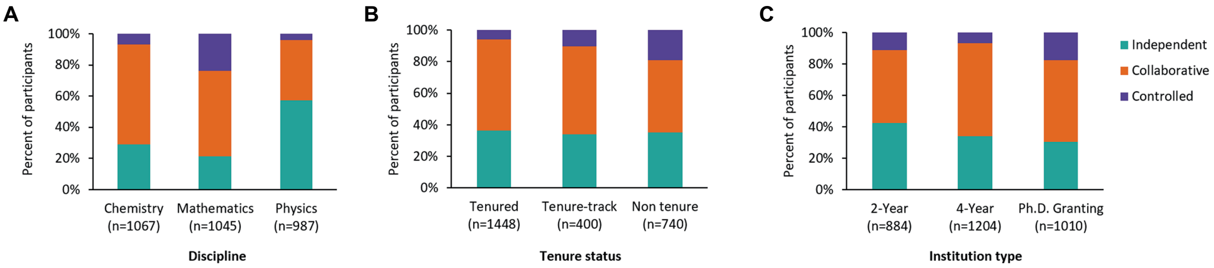

FIGURE 3
Percent of coordination type by **(A)** discipline, **(B)** appointment, and **(C)** institution type.

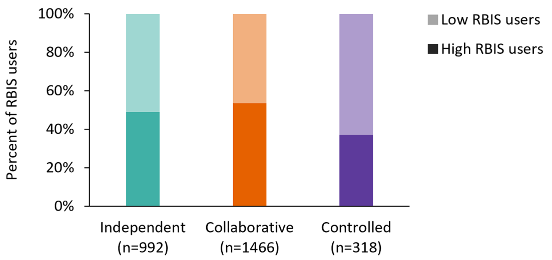

FIGURE 4
Percent of high RBIS users for each coordination type.

phrases to convey regularities and peculiarities observed within the data. We avoided further quantification that could potentially misrepresent the generalizability of the findings (Neale et al., 2014; Monrouxe and Rees, 2020).

3.4. Content coverage

3.4.1. What types of coordination exist?

The survey data indicated that the coordination of course content was most commonly done through collaborative decision-making. Interviewees described that coordination could occur for various course aspects, including syllabi, readings, general topics, scheduling, and content order. Collaborative decision-making took a variety of formats. Some participants mentioned formal committees as having responsibility for determining content and potentially other parts of the course.

> "*We have a committee of people, for groups of courses…and it's those groups that make, you know, decisions about textbook and content and things like that. Anything that is going to affect the whole department, all those decisions go through those.*" (#24 Math)

In some cases, course content was determined at the department level, for example by establishing a master syllabus containing shared topics. In other cases, a subset of instructors not part of a formal committee decided on content coverage. This group could include current course instructors, past instructors, and the department chair, such as a group described by one participant as including

> "*all of the people that teach Chem I, and that's a little bit of a fluid group because sometimes it includes people that have taught it in the past but won't be teaching it in the upcoming year.*" (#4 Chemistry)

Finally, some instructors in controlled settings indicated that a course coordinator established the syllabus topics, potentially consulting with other instructors on specific issues.

3.4.2. What factors led to coordination?

The most common reason for coordination of content coverage was to prepare students for subsequent courses in a similar manner regardless of section or instructor. This was particularly common in collaborative instances but also present in controlled cases.

> "*It is, you know, especially in courses that are prerequisites for others, part of it is what prepares a Calc II student to be ready for Calc III. You know, what's a Calc III person? You're gonna be able to say, yes, you have seen that. I know you're looking at me funny, but you definitely saw that in your Calc II class.*" (#25 Math)

Synchronization with an associated lab course also influenced content in both controlled and collaborative instances. Instructors found coordination necessary to prepare students with the content that would be necessary for understanding the upcoming lab.

> "*We were also, at that time, streamlining with the labs. So we could say, 'and in the lab this week, you worked on precipitating calcium carbonate and here's the stoichiometry that goes with that.' So we tried as much as possible to integrate things that they were seeing in the lab, into the classroom as well.*" (#2 Chemistry)

Departmental or disciplinary norms also influenced content coordination. Some participants reported controlled coordination when they inherited department content norms established before the interviewees arrived at their institutions. Disciplinary content was considered to be very standardized, particularly within introductory chemistry.

> "*Basically the homology of course content across gen chem across the nation is extraordinarily high … Everybody agrees what's going to be in gen chem one. There's a few outliers there, but I would say 90% of all people are teaching pretty much the same content in their first semester, or at least in their first two semesters, even if they rearranged the topics.*" (#8 Chemistry)

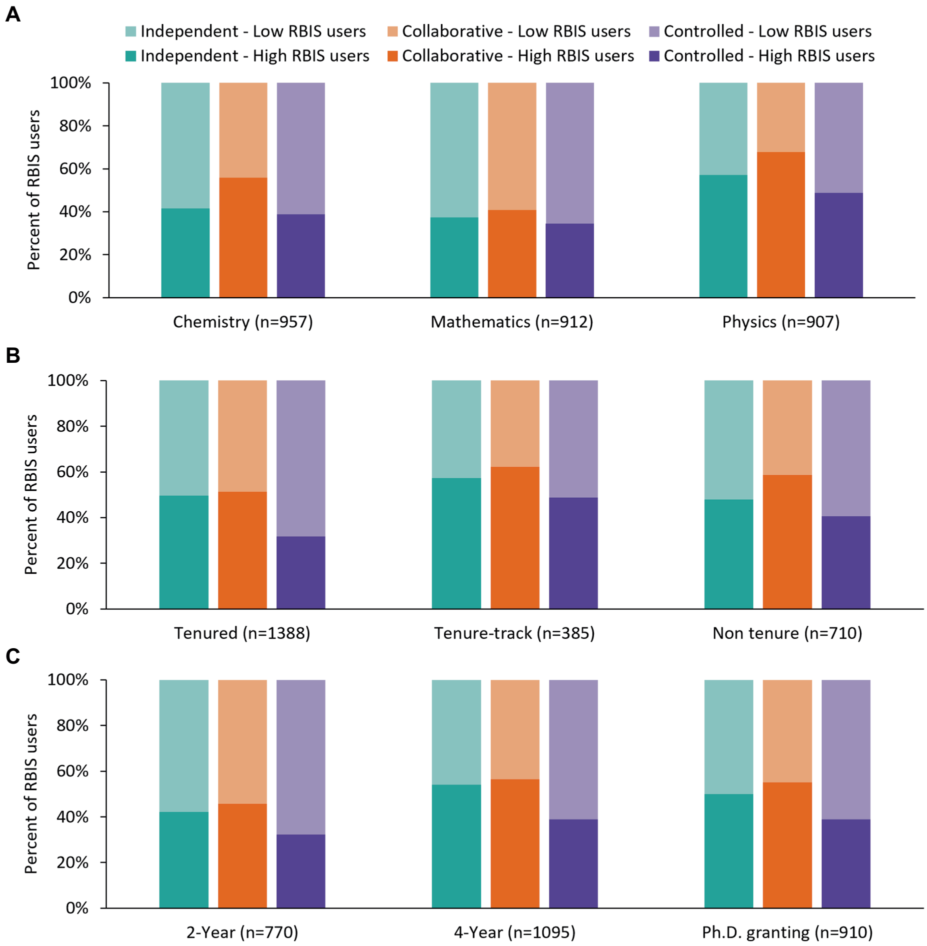

FIGURE 5
Prevalence of RBIS users by coordination type by **(A)** discipline, **(B)** appointment, and **(C)** institution type. See Supplementary Table 1 for statistical results.

External influences on coordination included adhering to state requirements, alignment with engineering accreditation (ABET), and preparing students for courses across the institution.

> *"For the content, the course was required by the engineering major at [Institution] and that's an accredited major. And so I think there was probably some amount of discussion of which topics needed to be in the course so that it fulfilled the engineering requirements."* (#5 Physics)

Other components of the course such as the course catalog, master syllabus, common exams, or textbook influenced content.

> *"They just go through one chapter a week starting at chapter one and ending a chapter eight or nine or whatever it is."* (#1 Physics)

In one unique situation, a department began collaborative coordination after hiring several new instructors, including part-time instructors with high turnover. Coordination was needed to ensure students were equally prepared regardless of their course section.

> *"So it was a concern about, you know, varying quality of students having not seen what they needed to when they've gotten to Calc II for instance or coming out of Pre-Calculus not having what they need … We have a lot of instructors cycling through. We have a lot of part-time instructors that will come and teach for a year and then leave. We've hired 20 instructors and tenure track folks maybe in the last two years, so we have a lot of new people coming in and we just really, myself and some of my colleagues that were on [a grant] project, were really wanting to put in some sort of standard for people to cover."* (#24 Math)

3.4.3. To what extent are instructors constrained by coordination?

Several of the reasons for content coordination were highlighted by the interviewees as constraints as well. For example, external requirements, such as state mandated or professional accreditation requirements, that dictated content coverage limited the ability of instructors to implement certain curricula.

> "*We can't really just decide to maybe start using modeling instruction and teaching half the content, because when the accreditation board comes to [Institution], they actually ask you for, you know final exams to make sure that the amount of content that is required is being taught…It's a much larger sort of organizational requirement that you know, is coming from much higher on down.*" (#6 Physics)

Synchronizing laboratory and lecture content and having rigid curricula or required topics were factors for coordination that interviewees also identified as constraints. For example, one interviewee described how the associated lab content drove lecture content.

> "*The lecture reacts to the lab more than the other way round, because there isn't anybody really who is going to take the time to redesign the lab right now.*" (#16 Chemistry)

Another constraint related to the large volume of content to cover. Participants often felt that it limited their perceived ability to make changes or additions to the material, which some instructors cited as a barrier to broader RBIS implementation.

> *"It can be tough for sure when there's just so much to cover in a week that I can't get through it. I'd rather be able to do more think-pair-share sometimes and I'm like, 'yeah, we just don't have time for that. We gotta keep moving.'"* (#20 Math)

3.4.4. How do instructors experience autonomy within coordination?

Despite potential constraints, some instructors still exercised a degree of autonomy in designing and implementing their course content. Instructors were able to make independent decisions about some of the topics taught or the pace, order, or depth at which they explored the content. For example, one interviewee with state mandated requirements to cover a large volume of content was able to find some flexibility in being able to select a subset of required topics and dictating the topic order.

> "*As a practical matter, it's impossible to cover all 22 topics in Physics I in any sort of depth in the course. And so the unofficial rule of thumb is that we only need to cover about 80% of those 22 or so topics. Some people do more, some people stick to the script. But which 80% of the topics is up to the individual instructor in terms of the course book and the course material…I feel I have a lot of flexibility actually…My freedom and my flexibility comes into not just picking the 80% which I think is of interest to the students but also the order that I present the topics to the students.*" (#11 Physics)

Another participant described how they could make time for RBIS by making minor adjustments to the content coverage.

> "*There are some points that you need to cover, but there is also quite a bit of flexibility I would say within each one of those bigger topics. So if I felt I wanted the students to work in groups in order to discuss this, I could omit something within that chapter and maybe not go into as much depth as another one. And so we do have flexibility kind of on a chapter by chapter basis as to what students are covering.*" (#21 Chemistry)

3.5. Textbook

3.5.1. What types of coordination exist?

Similarly to content coverage, the survey data indicated that the textbook was most often decided collaboratively. For most instructors who participated in the interviews, the choice of a textbook was coordinated across course sections; only two instructors described being completely autonomous in this regard. Many interviewed instructors were collaboratively involved in textbook selection *via* participation in a departmental committee devoted to the course. Within this committee, instructors could share their opinion and vote on their preferred text, and instructors then used the textbook chosen by the committee.

> "*We have a committee that selects the textbook for general chemistry. So once that's chosen, all sections have to use the same book. And of course we don't always agree on what's the best book, but I kind of understand the philosophy there is that you want some uniformity across sections.*" (#15 Chemistry)

The survey data also showed that for a fifth of the participants, the textbook had been decided for them. The interviews provided insight into how this controlled decision-making process took place. For most of the instructors interviewed who were not involved in the selection of the textbook, the decision occurred within a departmental committee prior to their hiring, followed by a lack of further consideration of this selection.

> "*It was a departmental decision a couple of years before I joined the faculty. So if I had been in the department at the time when the decision was made, I would have had input, but the decision was made basically when we moved to the studio format, which happened just before I joined. The department might revisit that sometime in the future, but in the nine years I was there, it was never a subject of discussion.*" (#5 Physics)

Regardless of how the textbook was originally chosen, instructors mentioned significant challenges associated with changing the textbook.

> "*The faculty there have already chosen the textbook, and they were just–you know how faculty are very resistant to change–they absolutely can't change anything, even though it's for the better. So we have to use that textbook again and whatever.*" (#12 Chemistry)

3.5.2. What factors led to coordination?

There were two main reasons for textbook coordination, which occurred in both collaborative and controlled decision-making contexts. The most common reason was to ensure student exposure to the same content regardless of their course section.

> "*We very much agreed on a book so that it was easy for students…that they didn't have to feel like one instructor was teaching totally differently from another.*" (#2 Chemistry)

Having a common textbook functioned as a mechanism to standardize content across course sections, thereby ensuring similar preparation for the next course in the sequence.

> "*But for math majors, you have to take Calc I, you have to then go on to Calc II. And so everybody who's teaching Calc II would expect that Calc I has covered a certain amount of material so that they know where they can pick up without having the students kind of lost on day one with, 'Well, we didn't talk about that in Calc I.*'" (#23 Math)

The other reason was to reduce costs for students within one course or across multiple courses. For example, students may need to switch to another course section taught by a different instructor or to retake the course with a different instructor. They may also have to take the next course in the sequence with a different instructor. In these situations, it is more cost effective for all instructors to require the same textbook, especially given the high cost of many textbooks used in introductory STEM courses.

> "*We had a discussion as a department about reducing textbook expenses for students. One common problem we had was that because at that time, instructors could choose our own textbook. Most of us all chose the same textbook, but instructors were free to choose whatever textbook they wanted to use. So students that switched between sections or have Physics I with one instructor and Physics II with a different instructor often had to purchase two textbooks. So we realized that was not fair to the students.*" (#10 Physics)

3.5.3. To what extent are instructors constrained by coordination?

The main constraint experienced by instructors using common textbooks related to the order of the topics presented in the textbook. This order often dictated the order of experiments performed in the associated laboratory course, which instructors felt compelled to follow so that students were prepared to perform these experiments.

> "*Our department uses the traditional Brown Lemay textbook and I am a fan of the Chemical Thinking curriculum. So I have Frankensteined the Chemical Thinking types of activities within the order of the Brown Lemay textbook…So the labs are tied to the order of that textbook. And so that's what I mean by the Frankensteining the Chemical Thinking curriculum onto the Brown Lemay is that I, I definitely still feel that I need to go in the same order that the labs are going in.*" (#14 Chemistry)

Moreover, a few instructors indicated that the textbook did not always match the content students needed to be successful. For example, one instructor noted how they had to deviate from the textbook in order to adequately account for their incoming student preparation.

> "*I discovered this only after I'd been teaching for about a week, that the students who had taken the sections taught by the popular teachers had not covered the syllabus. In fact, one of them had not covered integration at all. So I wound up having to teach integration. There was no way around it. As a result, I did not cover what was in my syllabus…That is the reality. So the thing is, your text is chosen by committee and you're supposed to cover whatever you can cover, but you wind up having to make compromises with reality.*" (#18 Math)

Instructors also perceived that the selected textbook sometimes did not contain topics or approaches that aligned with the content requirements for downstream courses.

> "*My main frustration there is…the textbook doesn't give you any room to do anything very useful with, right? Like, the specific thing I can think of is I was told I should spend more time talking about how concepts of momentum and energy work in special relativity. And particularly with momentum, the textbook just doesn't do anything with it. So you can't give people any problems involving that required thought. They're really just kind of dumb number plug-in problems. But…that's more of a frustration with the textbook than anything.*" (#9 Physics)

3.5.4. How do instructors experience autonomy within coordination?

Despite these constraints, many instructors described having some level of autonomy with their use of the textbook. For example, some instructors mentioned that they could still choose what to emphasize within required chapters as well as the order in which to teach the chapters. Others used the textbook as a resource for students rather than as a primary instructional tool.

> "*I think standardizing the textbook is important, but some people just don't want to fight about it and just say, 'Yeah, that's fine, that'll be the textbook, but I'm not going to use it. It's just going to be notes.*'" (#4 Chemistry)

Finally, many felt that the textbook did not hinder their pedagogical approach in the classroom. They ignored how the textbook presents certain concepts and developed their own activities.

> "*I think that the textbook makes very little difference and people get a bit too hung up on like how the textbook teaches something. And it's like, well, what percent of your students do you think are actually reading the textbook very carefully to follow the explanation that's being used…There are certain things that I don't like about the textbook. I just don't teach it that way. I just go, okay, well, the textbook does this, and I think that's stupid. This is how we're going to do it in this class. And students are just like, 'Yeah, that's fine. That's cool.' But if you do a reasonable job at explaining it in a way that makes sense to them, you know what I mean? Plus like I'm teaching using a flipped approach and I'm doing 14 chapters a semester, so I don't feel as constrained by [the textbook]. You know, I can do whatever I want in my class. I can change the way that I'm teaching within the constraint of, I have to teach all these chapters. I think that *that* is more of a constraint than what textbook you're using, right?*" (#6 Physics)

3.6. Instructional methods

Echoing the results from the survey data, nearly all the instructors reported during interviews that there was no coordination of their instructional methods, and the few remaining instructors reported independent decision-making for their instruction in their survey responses but did not elaborate on this in the interview. Given the general lack of coordination in instructional methods, we provide a brief summary of the limited information obtained from interviews.

Interviewees described that independent teaching was needed to support an instructor's preferred instructional style and to maintain instructional autonomy. Instructors felt that each instructor should be allowed to teach in a manner that is comfortable to them and that being constrained to teach outside that style would be unnatural and lead to poor performance. Instructors also mentioned that instructional independence allowed them to bring their own background experience into the course and share varied perspectives on problem solving with students.

> *"Our chair at the time was very much of the position that everybody needs to find a teaching style that works for them and they are comfortable with…She was very, very instructor-centered in that, if it worked for us, she was okay with us using it."* (#2 Chemistry)

Interviewees stated that autonomy was an important part of the culture that should be reflected in instructional practices.

> *"I think that was a point where, either by culture or maybe by particular people in the department previously voicing a sense that people should have autonomy over that. I got a feeling that there was kind of a line that everyone agreed on that maybe they had previously discussed, but not in my presence, that you as the instructor had the freedom to do essentially what you wanted in the classroom, as long as it didn't disrupt these things that needed to be coordinated and uniform."* (#5 Physics)

While instructors had independence in their instructional methods, they noted indirect ways that broader interactions with their colleagues helped them innovate, including through ideas and materials sharing as well as mutual support.

> *"The way that we discuss what we're doing, that we said, 'Hey, I've tried out this thing and I'll tweak this part next time, but on the whole it went really well." You know, nobody's forcing anybody to do anything. No one's asking anyone to be in the classroom in a way that's not natural for them, but, you know, I think there's plenty of leeway…People are going to hand you a billion ideas and you can engage with them however that makes sense."* (#25 Math)

On the other hand, one instructor member noted that the course coordinator can significantly dictate the type of instruction supported (e.g., instructor-centered versus student-centered teaching).

3.7. Exams

3.7.1. What types of coordination exist?

Similar to the survey participants, most instructors interviewed did not have explicit coordination structures for course exams. However, several instructors referenced prior experiences with coordinated exams (e.g., for the same course, for a different course, or at a prior institution), which enabled them to compare and contrast different approaches. Conversely, some instructors mentioned that their department had previously discussed or attempted exam coordination but this idea faced strong instructors' opposition.

> *"One of the questions that we've had off and on for many years is should we have any kind of coordination in the exams? Some schools have common exams that all students take…The faculty have overwhelmingly refused to even consider anything like that… Personally, I think it would be a good idea, that it can be done in a good way."* (#19 Math)

While many instructors had complete control over their exam content, participants also described ways that their departments shared exam norms and standards. For example, department chairs might have used messaging to communicate an expectation for similarity across sections. Some departments had formal mechanisms or informal cultures that supported the sharing of exam materials, which enabled instructors to repurpose questions and bring their exams into accord with other instructors. Similarity in exam content across sections also stemmed from an initial instructor developing structures that other instructors adopted.

A few instructors identified ways in which their exams arose through direct coordination. Some instructors participated in teaching teams where all of the instructors collaborated to plan, write, and revise exam questions together. Alternatively, they may have agreed to give a number of common questions on the final exam. Collaboration also occurred through a designated course coordinator who helped the group navigate a joint exam development process. In each of these cases, the participating group took into account various instructors' perspectives, expected contributions from all instructors, and strove to achieve consensus content.

Finally, a few other instructors worked in contexts where some or all of their exam content fell under external control. Within chemistry, some instructors who wrote their own midterm or unit exams were required to administer a standardized American Chemical Society (ACS) exam for their final. Some departments granted their course coordinator a higher degree of authority over exam development, due to the practical need for one person to finalize the exam and manage subsequent administration. Alternatively, a few participants taught in courses where a course coordinator—who may not even be teaching a section of the course—determined the exam content with minimal instructors' input.

> *"The course coordinator writes the exam, sends the exam to the rest of the faculty and says, do you approve of this? Nobody responds. And so basically the course coordinator by themselves has written the exam."* (#22 Math)

3.7.2. What factors led to coordination?

Participants offered a variety of explanations for exam independence. On a practical level, some instructors viewed writing their own exams as more efficient and expressed that it can become unmanageable to coordinate exams across many course sections. Instructors recognized the benefit that writing exams led to questions that aligned more closely in tone and content with other aspects of their course and enabled them to use their preferred question formats, feedback mechanisms, delivery methods, and exam schedule.

> *"When you're taking a class with a certain person, you get used to their voice. And so having an exam that's written in their voice more or less is kind of a way to take some of the discomfort out of exams, so that they don't have to then contend with, 'Hey, here's this whole body of knowledge I'm getting tested on. And it's written in a way that didn't make sense to me. Right?' In my class, they've seen the notes that I've written for them. They see the things that I put on our LMS. They see my emails. They're familiar with a certain writing style and a certain voice. And so I try to actually write that way in my exam again, to make it a little bit more comfortable."* (#2 Chemistry)

Furthermore, instructors felt that exam independence allowed them to present material in the best way they saw fit and to focus instruction more on learning than on exam preparation. Finally, instructors saw independent exam construction as consistent with the broader philosophical role of instructor's independence and academic freedom.

Conversely, the most common impetus for increased exam coordination stemmed from a desire to establish a certain degree of standardization across course sections, including equivalence in course content, experiences, grades, and future preparation.

> *"The main thing that matters to me is grade equity. Both like inside of a course and across courses and sort of, as I said, like, it should not be a matter of luck in terms of what section you end up in and who's teaching it whether or not you pass, you know what I mean? If, if, if you were going to get a B in one class, then like you should get a B or something close to it in the other classes."* (#4 Chemistry)

As an external standard, the ACS exam was particularly seen as a potential way to direct shared content coverage. Participants noted that shared exam infrastructure helped establish departmental norms for new instructors rotating into teaching assignments.

Participants cited other ways that coordination helped them develop better exams and use recommended teaching practices. Some viewed joint exam construction as more efficient, since instructors pooled their collective writing and grading efforts. Working together on exams enabled a department to identify core course learning objectives, discuss alignment with other course components, and establish the preparation needed for subsequent courses.

> *"I think that helps because the creation of the exam is a communal thing. So what it means is, you know, I write two problems for a topic, one for the practice, one for the exam, someone else writes two problems for a different topic, and before we do this, we make a list of learning objectives. And that's something that someone who's teaching traditionally wouldn't necessarily think of, right? Like what is it that I want students to be able to do to demonstrate that they've learned?"* (#6 Physics)

Instructors working closely together shared ideas, provided each other with feedback, and kept exams from becoming stale. Exam writing and grading created a forum where instructors collectively calibrated their student expectations, potentially helping to elevate the expected student performance level. Instructors saw shared exam content, such as the ACS exam, as a way to gather meaningful information on student outcomes to inform instructional improvement.

> *"I think at the moment our current approach to this, which is to let people do whatever they want, means that we're not using evidence to improve our teaching. And we're not systematically evaluating our teaching to decide if we can do better. And I feel like without coordination, it's almost impossible to do because it's very hard for an individual instructor to get data, meaningful data, on what they're doing and whether what they do changes things, you know, because without the coordination of a large sample size, without multiple people doing the teaching, you know, it's pretty hard to get data that's meaningful."* (#8 Chemistry)

Finally, shared exams enabled instructors to highlight their role in helping students prepare for an external challenge.

> *"I felt like I had to make sure my students were prepared for a test as opposed to making sure they understood the material at large. But at the same time I felt more like I was definitely on their side…I still had assignments that I could write, so I had free reign on that one, but there were exams that every student taking that class, no matter who the instructor was, had to take the same exam. So I definitely got a sense of like I was on the student side, like it was not adversarial."* (#23 Math)

3.7.3. To what extent are instructors constrained by coordination?

Interestingly, many of the reasons behind exam coordination were also cited as pitfalls for this approach. Shared assessments, including ACS exams, pressured instructors to cover certain material in a certain way and potentially inhibited the use of innovative exam approaches, such as mastery-grading. Taken to the extreme, one instructor worried that movement toward highly standardized courses could make instructors obsolete, since their role would reduce to simply delivering predetermined materials. Information sharing about student exam performance across sections could also lead instructors to focus more on exam preparation than learning.

> *"I think there's a danger in using those types of tests; there's a tendency to want to 'teach to the test.' So, as a faculty member, we would be aware of what questions are on the test. And so you would tend to kind of emphasize those. I mean, I think the same thing happens in K-12 with a lot of those standardized exams."* (#15 Chemistry)

Instructors expressed concerns about shared exams being lower in quality. The inherent scaling of shared exams to multiple sections and large student numbers dictated the use of closed-ended question formats, which differed from the formats used for other formative activities. This scaling also created opportunity for academic dishonesty, due to an inability to limit communication between students across sections. Instructors had disagreements with the exam content, such as with an ACS exam or in cases where the course coordinator writing exams was disconnected from the course.

> *"I really want to emphasize energy versus forces. That's really nice for me. Except if the course coordinator writes exam problems that are only about energy or only about forces, my students are going to be screwed."* (#1 Physics)

The development of shared exams also depended on cohesive social dynamics and supportive departmental policies. Creating a joint product required that colleagues contributed their fair share, and some individuals may not have participated actively in the process if they viewed teaching as unimportant or exam writing as service work. Discussing course content and student performance required a culture of openness, sharing, and trust around teaching.

> *"There needs to be a little bit more of a culture of people sharing what's going on in their classrooms for there to be these common exams, because otherwise it seems like this giant hurdle of getting together and finding the time to make the exams together, and I think that it's just so much easier for me to make my own exam than to add this additional administrative tasks, making sure that they're coordinated."* (#14 Chemistry)

Furthermore, some instructors worried that exam results could serve as a basis to penalize instructors, a particularly daunting prospect for contingent instructors.

3.7.4. How do instructors experience autonomy within coordination?

Many departments maintained independent exams because they recognized that the goal of achieving a baseline degree of similarity across course sections could be achieved outside the constraints of shared exams. Open communication, materials sharing, and collegial relationships often provided sufficient means for instructors to align their sections while writing their own exams. In some cases, the department chair provided overarching guidelines.

> *"My leadership style in the department is to be a little more careful to make sure that the rigor in different sections is consistent. But mostly what I'm asking is you know, I sort of put out there that here are my ranges of grades. Just be aware that, you know, we're trying to hold to an average of around this, trying not to curve too much."* (#16 Chemistry)

Furthermore, a department might use common exams strategically to bring sections into alignment, and then relax this practice.

> *"There was a common final exam my very first semester. And after that, I think we kind of got rid of it, because at that point in time, once you have a common final exam for several semesters, everyone is covering the material related to that exam. You don't necessarily need the common final exam the following semester."* (#21 Chemistry)

For departments using common exams, the primary way that instructors maintained autonomy was to be involved in the exam development process. A consensus approach to exam construction helped ensure that each instructor could implement their desired teaching approach and that the exam content aligned with the various course sections.

> *"The instructors should be involved in composing the exam. There's no point in having an exam if you're not going to be testing the students on what they actually did when they were preparing for the exam."* (#18 Math)

Taking on the role of course coordinator gave instructors a greater influence on the exam process, but this position involved a greater workload and faced limits with respect to its influence on exam development.

Instructors saw additional ways in which common exam components did not restrict their courses. For example, small class sizes and associated student variation undermined the ability to draw conclusions about course outcomes. With respect to ACS exams, instructors felt comfortable skipping a few topics under the presumption that this would not significantly affect test scores. Some departments also lacked functional actions or consequences related to ACS scores. Finally, one department with a common final exam allowed each instructor to determine its proportion within overall course grades. Each of these situations thus enabled instructors to minimize or ignore constraints associated with administering a common exam.

4. Discussion

This study aimed to characterize the extent of coordination present in introductory undergraduate chemistry, mathematics, and physics courses as well as how departments and instructors implement and experience course coordination. We specifically probed the level of coordination of four course components: the content being covered, the textbook, the instructional methods employed in the course, and the design of exams.

Some nuances were observed in the coordination taking place between appointment types and institution types. These nuances were most present with respect to the proportion of controlled coordination types. However, in all cases, the collaborative coordination type was the most common and the controlled type was the least common. More variation was observed when comparing coordination types across disciplines. Physics instructors were more likely to work independently when compared to mathematics and chemistry instructors. Conversely, mathematics instructors were more likely to work under a controlled coordination type when compared to chemistry and physics instructors. This latter situation may underlie the push in the mathematics education research literature to promote collaborative, rather than controlled, decision making (Rasmussen et al., 2021).

Instructors most commonly made decisions collaboratively on the curricular components (textbook and content coverage) of their introductory STEM courses. Those were most often decided collectively by a group of instructors within a department as part of a formal or informal committee. Some interviewees had been part of the curricular selection processes during their time at their institution. For other interviewees, the curricular decisions had been made collaboratively years or decades prior to them teaching at their institution, but the interviewees themselves had not participated in the process. Both types of interviewees (those who participated in the decision process and those who did not) spoke about a lack of departmental procedures and structures to systematically and regularly consider the previously made curricular choices. Therefore, even though survey participants and interviewees indicated that curricular components are selected collaboratively for most introductory STEM courses, the interviews data revealed that instructors of these courses have infrequent opportunities to discuss and influence these aspects of the course. Contrary to curricular components, instructional methods and exam development were primarily decided individually and independently of other instructors.

Taken together, these results indicate that instructors have limited interactions when making decisions about the four course components, even when these components are reported to be decided in a collaborative manner. This suggests that individuals participating in coordinated courses have limited opportunities to engage in knowledge sharing. The mathematics literature on course coordination highlights that some of the benefits of coordinated courses come from the regular interactions that take place between instructors when making decisions related to course components (Rasmussen et al., 2019). These interactions help develop a sense of community among the instructors and facilitate pedagogical growth. Our interview data suggest that most of the instructors in this study do not necessarily experience these benefits. Departments interested in implementing collaborative coordination thus need to put in place processes and structures to ensure that frequent interactions occur among instructors, that decisions about various components of the course are regularly revisited, and that pedagogical practices are shared.

One structural tool advocated by mathematics education researchers to support collaboration between instructors and promote pedagogical growth is the appointment of a course coordinator (Martinez et al., 2022). However, our findings suggest that this position will not necessarily promote instructional change and could potentially reinforce the status quo. This was evident with one of the interviewees, a physics education researcher who desired to implement RBIS in the target course. When they were course coordinator, they were able to implement some research-based instructional approaches. However, it took a significant level of effort, education, and negotiation on their part to convince the other instructors to make these changes. When they were no longer the course coordinator, the practices reverted back to teacher-centered methods. This situation highlights the importance of the course coordinator developing effective coordination strategies that help departments articulate and pursue a shared vision. A study conducted by Martinez et al. (2022) shed some light on the characteristics of effective course coordinators. They interviewed mathematics course coordinators and instructors about effective coordination practices, which led them to develop a framework that describes two orientations to a coordinator's position and the professional development approaches associated with each of these orientations. The Humanistic-Growth Orientation "refers to an approach that facilitates the personal and professional growth of the instructors teaching in the coordinated course. The Resource-Managerial Orientation refers to an approach that leverages the knowledge, experience and logistical management skills of the coordinator to facilitate the effective delivery of a multi-section course" (Martinez et al., 2022, p. 332). The authors do not advocate that coordinators follow one or the other orientation but consider a mixture of both. They suggest that department chairs interested in appointing a course coordinator leverage this framework to identify the ideal candidate.

Instructors in this study vocalized their desire for autonomy with respect to instructional methods and exam design, and some worried that additional coordination could lead to loss of their autonomy. These findings relate to prior research on instructional reform. The literature has demonstrated that decisions imposed upon instructors without proper support are least effective in promoting instructional change (Henderson et al., 2011). Recent research on course coordination in mathematics has pointed out this need for individual instructor's autonomy and coined the phrase "coordinated independence" (Rasmussen and Ellis, 2015). This phrase "is intended to embrace how in-step elements of a calculus program work together with elements that allow for individual autonomy" (Rasmussen and Ellis, 2015, p.114). A course coordinator who intends to enhance the learner-centeredness of their course thus needs to carefully think about the approach they take. The framework describing characteristics of effective course coordinators provides valuable insight about how to achieve this balance (Martinez et al., 2022).

Although the majority of instructors in this study described having a high level of autonomy with respect to their instructional methods, the overarching course coordination type did seem to relate to their uptake of RBIS. Indeed, the survey data indicates that instructors who worked within a controlled coordination structure were less likely to be high RBIS users when compared to instructors who worked independently or within a collaborative structure. In the controlled structure, the curricular components of the course were decided by entities other than the instructor themselves. The interviews shed some light on aspects of course coordination that influence the level of use of RBIS. For example, external expectations for content coverage was often reported by interviewees as a hindrance to their ability to employ RBIS. However, the collaborative design of exams was seen by some as a vehicle for instructional innovation and knowledge sharing. Interviewees mentioned for example that it helped promote conversations about the conceptual focus of the course and introduce new pedagogical concepts such as learning objectives to some of the instructors that were part of the collaboration. We thus see in our data the growth in pedagogical knowledge and skills that collaborative coordination of some course components can engender in participating instructors.

In considering the generalizability of our findings, we wish to call attention to a few features of our study participants. The quantitative survey sample contained broad representation from across the US higher education system. In recruiting the smaller interview sample, we made concerted efforts to achieve representation across certain characteristics (i.e., academic discipline, institution classification, self-reported RBIS use, course coordination type), but we were unable to include 2-year institutions and contingent appointments as it would have made the sample prohibitively large. Thus, we highlight the need for research focused on both of these groups, given that they may participate in unique and varied coordination structures. We also note that the interview sample (which was selected without knowledge of individual identities) lacked representation of certain minoritized racial/ethnic backgrounds and gender identities, so additional work is needed to understand whether the experiences of individuals from these groups aligns with or differs from the broader sample.

This study builds on previous research in mathematics education, which focused on exemplary models of coordination that prioritize instructors' interactions and component synchronization as means to improve teaching practices and student outcomes. As departments consider implementing or revising the diverse range of coordination patterns observed in this study, they will want to consider the interplay between coordination, instructional agency, and innovation. Their changes can involve creating more opportunities for shared and ongoing decision-making and facilitating interactions that build community and enable pedagogical knowledge sharing. These changes represent feasible steps that can be taken on the way to more collaborative coordination that supports innovative teaching practices.

Data availability statement

De-identified data will be shared by the authors upon request in accordance with IRB guidelines.

Ethics statement

The studies involving human participants were reviewed and approved by Western Michigan University IRB Project Number 17-06-10. The patients/participants provided their written informed consent to participate in this study.

Author contributions

BC, LP, and MS designed the study, contributed to the data collection and analysis, and drafted the manuscript. BW contributed to the data collection and analysis as well as the writing of the manuscript. AM contributed to the data analysis. NA, MD, CH, EJ, JR, and MS designed the survey and contributed to the data collection. JR and BY contributed to the data analysis. AM, NA, MD, CH, EJ, JR, BY, BE, SS, JS, and JZ provided feedback on the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1156781/full#supplementary-material

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