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Intrasectional Variations of Phrase-Frames in Experimental Aerospace Engineering Research Articles

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ABSTRACT

Despite the growing interest in phrase-frames (p-frames) in research articles (RAs), no study has compared p-frames across sections in RAs. This gap motivated us to explore intrasectional variations of p-frames in aerospace engineering (AE) RAs using a corpus-driven approach. A corpus of 40 AE RAs was compiled and divided into four sections. Five-word p-frames meeting predefined criteria were extracted and manually filtered. Each of the four subcorpora was then searched for the instances of the identified p-frames, which were analyzed in terms of their structure and function. The results revealed notable variations in the structures and functions of p-frames across sections. Structurally, the Introduction, Methods, and Conclusion sections were dominated by other-content-word p-frames (types and tokens), while the Results and Discussion section preferred verb-based p-frames (tokens). Functionally, the Introduction, Methods, and Conclusion sections predominantly featured research-oriented p-frames (types and tokens), while the Results and Discussion section was dominated by text-oriented p-frames (tokens). For functional subcategories, resultative p-frames were preferred by the Introduction, Results and Discussion, and Conclusion sections, while procedure and quantification p-frames were more frequent in the Methods section, regardless of types and tokens. The results also showed a strong connection between p-frame structures, their functions, and the communicative purposes of the sections. We hope this study will contribute to EAP writing pedagogy in the AE discipline.

Keywords: Intrasectional Variations; P-Frames; Aerospace Engineering; Experimental Research Articles

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1. Introduction

Over the past decades, voluminous literature has employed corpus approaches to investigate formulaic sequences in academic genres [1–5]. These studies have demonstrated that formulaic sequences are ubiquitous in academic genres and play a crucial role in language learning for specific purposes. This body of studies has primarily centered on continuous multiword sequences, nevertheless, recent research has expanded its focus to discontinuous multiword sequences.

The discontinuous multiword sequences, known as p-frames or lexical frames, are multiword expressions with variants differing by only one word. As noted by Casal and Kessler [6] and Appel et al. [7], p-frames have great pedagogical usefulness, as they combine conventional and variable elements, highlighting both linguistic convention and creativity. Given the recognized importance of p-frames, studies have explored their use in academic writing. Research articles (RAs), as an important academic genre, are the most extensively researched. Previous research on the use of p-frames in RAs has been carried out from several perspectives. One perspective is to examine p-frames in the whole [8,9], which regard RAs as a homogeneous discourse unit. Another perspective is to investigate p-frames in specific sections of RAs, such as the Introduction section [10,11] and the Discussion section [12], which view RAs as a heterogeneous discourse unit, with p-frames assumed to be distributed differently in each section. Although some studies have compared continuous multiword sequences across sections of RAs [4,13], no study has examined how p-frames are used differently across sections. Compared to investigating p-frames in a single section, comparing p-frames across sections can provide clearer insight into the holistic distribution of these phraseological items. As such, the present study aims to investigate the intrasectional variations in the structure and function of five-word p-frames in experimental aerospace engineering (AE) RAs. The AE discipline was chosen due to the increasing number of AE research publications in international journals and the scarcity of p-frame research in this field. It is hoped that this study can contribute to the understanding of the phraseological profile across sections of experimental AE RAs and offer pedagogical value for EAP instruction.

To align with the research objectives, the following two research questions are formulated:

(1) What are the similarities and differences in the use of five-word p-frames across the IMR&DC sections in terms of structure?

(2) What are the similarities and differences in the use of five-word p-frames across the IMR&DC sections in terms of function?

2. Literature Review

2.1. Identification and Categorization of P-Frames

The identification of p-frames needs to satisfy some significant criteria, including frequency, range, variants, and slot(s). Regarding the thresholds for p-frame frequency and range, previous studies have shown some variability in how these thresholds are set. Depending on research objectives and corpus size, previous studies have typically set frequency thresholds between 10 and 40 occurrences per million words [14,15] and range thresholds from three to five texts [2,10,11] or three-quarters of the journals [8]. Although some prior studies on p-frames tend to follow the criteria of lexical bundles regarding frequency and range thresholds, studies with smaller corpora often use lower thresholds for p-frames [16]. Regarding the variants of each p-frame, previous studies have commonly set the threshold at two, meaning that each p-frame should have two or more variants. As for the open slot(s), their number can be one or more and their position can be at the beginning (* *are summarized as follows*) or at the end (*can be used to* *) or inside the p-frames (*at the * stage of*). While the p-frames can have more than one open slot, the majority of previous studies focus on p-frames with a single variable slot [10,17].

Once p-frame candidates have been automatically extracted, manual filtering is required to remove those that are meaningless or pedagogically irrelevant. Next, the remaining p-frames are frequently categorized based on their structures and functions. Regarding structural categorization, some studies adopt the structural categories used for lexical bundles [8]. However, the majority follow Gray and Biber's [14] taxonomy, which categorizes p-frames into three groups: verb-based frames (e.g., *the * was carried out*), other-content-word frames (e.g., *in the * stage of*), and function-word frames (*at the * of the*). In terms of functional categorization, p-frames are usually classified

using functional taxonomies applied to lexical bundles, including those by Biber et al. [1], Hyland [3], and Simpson-Vlach and Ellis [18]. Biber et al.'s [1] taxonomy was derived from lexical bundles in textbooks and classroom teaching and consists of four primary categories: discourse organizers, referential expressions, stance expressions, and special conversational functions. Hyland's [3] taxonomy was obtained from bundles in academic writing and includes three primary categories: research-oriented bundles, text-oriented bundles, and participant-oriented bundles. Simpson-Vlach and Ellis' [18] taxonomy, adapted from Biber et al. [1], was developed from lexical bundles in academic speech and writing, encompassing three main categories: referential, stance, and discourse expressions.

2.2. P-Frames in Research Articles

Early research on p-frames was conducted by Biber [19], who explored their use across different registers. In his study, he used the bundles-to-frames approach (i.e., deriving p-frames from frequent continuous lexical bundles extracted previously) to identify p-frames and found that register is a key factor influencing their use. Gray and Biber [14] were probably the first to employ the fully inductive approach (i.e. directly extracting the frequent p-frames from the corpus) to identify p-frames across registers. They found that the bundles-to-frames approach cannot fully capture the diverse range of variants of the identified p-frames and may overlook some meaningful p-frames with diverse but infrequent variants. Their findings also confirmed the existence of register variation.

RAs, as an important academic genre, have been the focus of the p-frame studies. One line of research focuses on investigating the use of p-frames in the whole RAs. For instance, Cunningham [8] explored the use of p-frames in mathematics RAs, identifying a total of 180 p-frames and establishing several functional categories, such as aboutness and coherence. However, the approach for identifying p-frames was criticized for excluding n-grams that occurred fewer than three times, thereby omitting less frequent p-frames and their variants from the analysis. To address this limitation, He et al. [9] employed the fully inductive, corpus-driven approach to analyze p-frames in business management RAs, identifying 90 three-word and 26 four-word p-frames. The structural categorization of these p-frames revealed that most three-word p-frames are non-verb content word frames, while most four-word p-frames are function word frames. One limitation of this study is that it focuses solely on the structural analysis of these p-frames, without including a functional analysis. Another line of research is to explore the use of p-frames in specific sections of RAs. To illustrate, Lu et al. [10] used the fully inductive approach to examine the use of p-frames in the Introduction sections of RAs from six social science disciplines, identifying 370 five-word and 84 six-word p-frames. The structural analysis of these p-frames showed that other-content-word frames constitute the largest proportion in five-word p-frames, while verb-based frames are most frequent in six-word p-frames. The functional analysis revealed that referential frames are the most frequent in five-word p-frames, while discourse organizing frames dominate in six-word p-frames. Later, in 2021, they furthered this study by combining p-frames with rhetorical moves and steps [11]. Moreover, Golparvar and Barabadi [12] investigated the use of p-frames in one specific section of RAs, namely the Discussion section, in higher education. Their study identified 58 four-word and 40 five-word p-frames specific to this discipline. The structural and functional analysis showed that the majority of these p-frames are other content word frames and fulfill the referential function.

To summarize, recent studies have analyzed the use of p-frames in entire RAs and in specific sections of RAs in several disciplines. These studies have not only provided lists of p-frames for researchers and EAP instructors in these disciplines, but also shown that p-frames are discipline-dependent. To date, however, no attention has been given to intrasectional variations of p-frames in RAs. As such, this study aims to address this oversight by analyzing five-word p-frames across the IMR&DC sections of AE RAs.

3. Methods

3.1. Corpus

The corpus for this study consisted of 40 experimental RAs selected from five AE journals indexed in the Science Citation Index Expanded (SCIE) database. In line with Ye [20], journal selection followed two criteria: recommenda-

tions from field experts and the impact factors of the journals. Two expert informants from the AE discipline were consulted to recommend high-impact journals, with the 2023 JCR ranking list of AE journals provided as a reference to reduce subjectivity. After discussions, five journals were selected: *Chinese Journal of Aeronautics*, *Aerospace Science and Technology*, *Propulsion and Power Research*, *Acta Astronautica*, and *Aerospace*. These journals were chosen for their SCIE indexing, open access support, and a wide range of topics in aerospace research, with four ranked in Q1 and one in Q2.

The selection of articles was based on four main criteria. First, only experimental RAs were included, as previous research [21] has shown that the types of research (theoretical, quantitative, or qualitative) influence linguistic features. Second, articles must contain Introduction, Methods, Results and Discussion, and Conclusion sections. This choice is based on the researchers' observation that the experimental articles in the selected journals often merge the Results and Discussion sections while keeping the Conclusion as a separate section. Third, articles had to be published between 2022 and 2023 to minimize the impact of diachronic variation on p-frame usage. Finally, a combination of stratified and random sampling methods was employed. Stratified sampling ensured that four articles were chosen from each journal per year, while random sampling provided equal selection probability for any article meeting the first three criteria within the specified timeframe.

Once the 40 articles were selected and downloaded, all sections of each article were extracted and stored in a plain text file. Each file was carefully checked for errors that may have occurred during the conversion process, and any irrelevant content for the identification of p-frames, including figures, tables, parenthetical citations, and mathematical equations, was removed. This process resulted in a corpus of 40 AE RAs, comprising 217, 095 running words. Since the objective of this study was to compare the p-frames across the IMR&DC sections, the corpus was manually segmented into four sub-corpora, the Introduction sub-corpus (43,198 tokens) Methods sub-corpus (43,393 tokens), Results and Discussion sub-corpus (115,513 tokens), and Conclusion sub-corpus (216, 095 tokens).

3.2. Procedure

3.2.1. Identification of P-Frames

Several methodological considerations were addressed in identifying p-frames in this study. The first involved the identification approach. This study employed the fully inductive approach because it can better capture the features of p-frames compared to bundles-to-frames [14]. The second consideration was concerned with the length of p-frames. Five-word p-frames were selected for two primary reasons. First, as noted by Lu et al. [10,11], shorter p-frames often consist solely of function words or incomplete units, whereas longer p-frames are more semantically complete and specific to the genre of RAs. Second, five-word p-frames are more common than longer ones, as supported by Liu and Chen [17]. The third consideration dealt with the placement of variable slots. Following Lu et al. [10,11], this present study included five-word p-frames with open slots in medial and final positions, as initial variable slots often spanned across phrasal or clausal boundaries (e.g., * *indicating the stability of*, with variants such as *range*, *transition*, and *waves*).

Another key methodological consideration was establishing cut-off thresholds for frequency and range. To identify suitable thresholds for the corpus size and maintain a manageable number of p-frame candidates for manual analysis, a preliminary investigation was conducted using different threshold combinations, as suggested by Lu et al. [10,11]. Ultimately, this study set the frequency threshold at 22 occurrences per million words, equivalent to five occurrences in the current corpus. Additionally, each p-frame was required to appear in at least four texts. After finalizing these parameters, the analysis tool *kfNgram* [22] was employed to extract five-word p-frames.

After extracting five-word p-frames, manual filtering was conducted based on four criteria from previous studies [2,10,11]. First, candidates spanning clausal boundaries (e.g., *in the * study we*) or lacking linguistic completeness (e.g., *of this study is **) were removed. Second, candidates that functioned more effectively as lexical bundles (e.g., *one the other hand **) were excluded because their variable slots could accommodate nearly any word, making them semantically incoherent. Third, frames that were overly broad or narrow in meaning, making them of limited ped-

agogical value (e.g., *to the * of the, Institute of Mechanics and **), were filtered out. Fourth, consistent with Casal and Yoon [2], frames and variants differing only in grammatical forms were merged when their semantic consistency was evident (e.g., *the * indicate that the and the * indicated that the were merged into the * indicate(d) that the*). Recognizing that this process required extensive concordance analysis using AntConc 4.2.3 [23] and involved subjective judgment, two researchers independently filtered the candidates and resolved any discrepancies through discussion to reach an agreement. After manual filtering, a total of 360 five-word p-frames were identified. These p-frames were then matched to each of the four sections using AntConc 4.2.3 [23] and Excel.

3.2.2. Structural and Functional Categorizations of P-Frames

For the structural categorization, the three-way classification proposed by Gray and Biber [14] was applied, consisting of: (a) verb-based frames (containing at least one verb, e.g., *has been * in the*); (b) other-content-word frames (including at least one content word, excluding verbs, e.g., *the central * of the*); and (c) function-word frames (composed only of function words, e.g., *at the * of the*).

For the functional categorization, this study adopted Hyland's [3] taxonomy, which was specifically developed from research-focused written genres, making it suitable for the functional analysis of p-frames in AE RAs. Following a preliminary analysis of the identified p-frames, minor revisions were made to this taxonomy by incorporating the classification from Lu and Deng [24] and introducing two subcategories (objective and comparative) within the text-oriented category. The objective subcategory refers to the purpose behind conducting a study or using a method (e.g., *to explore the [influence, effect, behavior] of*). The comparative subcategory involves comparing and contrasting different elements (e.g., i*s [greater, longer, larger, lower, smaller] than that of*). The functional taxonomy used in this current research is shown in **Table 1**.

Table 1. The functional taxonomy of p-frames in the current study.

Categories	Subcategories	Examples
Research-oriented	Location	at the * of the (exit, head, end, rear)
	Procedure	the * process of the (evolution, working, whole)
	Quantification	the * length of the (flame, recess, total)
	Description	the * characteristics of the (dynamic, propagation, flame)
	Topic	rotating detonation * in the (combustor, chamber, wave)
Text-oriented	Transition signals	but the * of the * (rest, value)
	Resultative signals	the results * that the (show, manifest)
	Structuring signals	be * in table(s) # (shown, listed, summarized)
	Framing signals	with the * of the (increase, help, addition)
	Objective	in order to * the (obtain, provide, quantify)
	Comparative	was * than that in (narrower, longer, better)
Participant-oriented	Stance features	play a * role in (crucial, limited, significant, major)
	Engagement features	it should be noted * (that, in, from)

Since p-frames can serve various functions depending on their variants, and following previous studies [10,25], this research employed the variant-based method, which identifies the function of each p-frame by analyzing the meanings of its variants in their original contexts. To ensure the accuracy of the functional categorization, both authors separately assigned functional labels to the identified p-frames, achieving an inter-rater agreement of 91% before resolving any disagreements through additional discussions.

4. Results and Discussion

4.1. Overall Distribution of P-Frames in the IMR&DC Sections

Following the aforementioned methodological procedures, a total of 360 five-word p-frames were identified across all IMR&DC sections. Since p-frames can appear in a single section or be shared across multiple sections, we classified them into three types based on the criteria of Lu et al. [11]: (1) specialized p-frames (occurring in only one section), (2) semi-specialized p-frames (appearing in at least two sections, with at least two-thirds of occurrences in one section), and (3) non-specialized p-frames (occurring in at least two sections without being predominantly associated with any particular section). **Table 2** presents the overall distribution of the three types of p-frames in the IMR&DC sections. It can be seen that the non-specialized p-frames constitute the largest proportion in each section, followed by semi-specialized p-frames or specialized p-frames. Among the IMR&DC sections, the Results and Discussion section contains the highest proportion of specialized and semi-specialized p-frames. The use of p-frames across the IMR&DC sections reveals both similarities in phraseological features between certain sections and the mono-functional nature of specific p-frames within each section of the AE RAs. The findings deviate from Liu and Pan [4], who found that the Methods sections had the highest proportion of section-specific bundles in the IMRD sections. This difference may be attributed to the different types of phraseological items and distinct disciplines examined in the two studies. Our study focused on p-frames in AE RAs, lexical bundles in medical RAs were examined by Liu and Pan [4]. Due to the limited space, only the specialized p-frames in each section are listed in **Table 3**.

Table 2. Overall distribution of p-frames in the IMR&DC Sections.

P-Frames	Specialized	Semi-Specialized	Non-Specialized	Total
Introduction	7(3.4%)	5(2.5%)	191(94.1%)	203(100%)
Methods	13(5.4%)	21(8.8%)	206(85.8%)	240(100%)
Results & Discussion	41(12.4%)	119(36.1%)	170(51.5%)	330(100%)
Conclusion	2(1.4%)	0(0%)	139(98.6%)	141(100%)

Table 3. Specialized p-frames in each section.

Sections	Specialized P-Frames
Introduction	have been * on the, studied the * characteristics of, studied the * of the, studies have been conducted *, the * study aims to, there have been * studies, have been proposed to *
Methods	a * diagram of the, a high-speed camera is *, a schematic diagram of *, at a * rate of, at a sampling * of, experiment was carried out *, experimental * is shown in, injected into the * through, parameters are * in table, schematic of the experimental *, the measurement * of the, the schematic * of the, was * to measure the
Results and Discussion	as can be seen *, can be * from figure, can be * in fig(ure), corresponds to the * of, has been observed * the, in the * region of, because the * of the, can be seen * fig(ure), compared * that of the, compared to the * of, indicating that the * of, indicating the * of the, is * different from that, is * than that in, is much * than that, it can be * seen, it is * to note, it is evident * the, it is worth * that, may be * to the, near the * edge of, propagate in the * direction, related to the * of, results * shown in fig, results are * in figure, shows the * results of, similar to the * in, the * condition of the, the * reason is that, the * results indicate that, the * results of the, the * wave propagates in, the rate of * of, the results are * in, these results * that the, this * be attributed to, which * consistent with the, which * similar to the, which is * than the, which is * with the, will be discussed in *
Conclusion	main * are summarized as, main conclusions are * as

4.2. Structural Categorization of P-Frames across the IMR&DC Sections

Table 4 presents the distribution of three structural categories of p-frames by type and token across the IMR&DC sections. It can be seen that all sections are dominated by other-content-word p-frames (types and tokens), followed by verb-based and function-word p-frames, except in the Results and Discussion section, where verb-based p-frames (44.7%) slightly exceed other-content-word p-frames (43.4%) in terms of tokens. These findings are largely consistent with those of Lu et al. [10] and Golparvar and Barabadi [12], who also reported that other-content-word p-frames were the most frequent group among five-word p-frames, followed by verb-based and function-word p-frames, in RA Introduction sections of social sciences and RA Discussion sections of higher education, respectively. The slightly more frequent use of verb-based p-frames than other-content-word p-frames in the Results and Discussion section in the present study may be attributed to the significant presence of tables and figures in this section of AE RAs, with about 15 tables and figures per article. When reporting their findings, AE authors often refer to these graphic data to guide readers. As such, *verb-based p-frames such as is/are * in figure(s) #, is/are * in table(s) #, can be * from figure,* and *can be * in figure*, are frequently used in this section.

Table 4. Distribution of structural categories across the IMR&DC sections.

Structural Categories	Types				Tokens			
	I	M	R&D	C	I	M	R&D	C
Verb-based	79 (38.9%)	90 (37.5%)	140 (42.4%)	50 (35.5%)	235 (42.3%)	396 (38.0%)	1275 (44.7%)	100 (38.7%)
Other Content-word	101 (49.8%)	130 (54.2%)	163 (49.4%)	76 (53.9%)	259 (46.6%)	529 (50.7%)	1238 (43.4%)	124 (48.1%)
Function-word	23 (11.3%)	20 (8.3%)	27 (8.2%)	15 (10.6%)	62 (11.2%)	118 (11.3%)	340 (11.9%)	34 (13.2%)
Total	203(100%)	240(100%)	330(100%)	141(100%)	556 (100%)	1043 (100%)	2853 (100%)	258 (100%)

4.3. Functional Categorization of P-Frames across the IMR&DC Sections

Table 5 summarizes the distribution of functional categories of p-frames across the IMR&DC sections in terms of type and token. All sections contain the three functional categories (i.e., research-oriented p-frames, text-oriented p-frames, and participant-oriented p-frames), as well as multifunctional p-frames. Among these four functional groups, research-oriented p-frames rank as the largest group in terms of both type and token in the Introduction, Methods, and Conclusion sections, followed by text-oriented, multifunctional, and participant-oriented p-frames. The prominence of the research-oriented p-frames in three sections highlights its crucial role in the field of AE. This finding aligns with that of Nekrasova-Beker and Becker [26], who studied the five-word p-frames in engineering textbooks and found that research-oriented p-frames are more prevalent than other functional categories. Additionally, this finding appears to be in line with that of Hyland [3] and Pan et al. [27], who discovered that the research-oriented bundles rank as the largest category in science and engineering RAs. This alignment might be because of the stringent quantitative analysis emphasized in hard science disciplines, especially engineering. In contrast, the Results and Discussion section exhibits a shift in focus, with text-oriented p-frames constituting the largest group in terms of token (51.2%). This indicates that the Results and Discussion section highlights the reporting and interpre-

tation of results in a manner that is more concerned with structure, clarity, and accessibility for the reader. Text-oriented p-frames, which help guide the reader through the research narrative, are significant in this section where the author must not only present findings but also offer a reasoned analysis that links back to the research objectives. The preferred use of this type of p-frames in the Results and Discussion section may also reflect the need for precision in conveying complex data and nuanced interpretations to the AE academic community.

Table 5. Distribution of functional categories across the IMR&DC sections.

Functional Categories	Type				Token			
	I	M	R&D	C	I	M	R&D	C
Research-oriented	87 (42.8%)	126 (52.5%)	141 (42.7%)	61 (43.3%)	220 (39.6%)	534 (51.2%)	936 (32.8%)	99 (38.4%)
Text-oriented	74 (36.5%)	62 (25.8%)	119 (36.1%)	45 (31.9%)	182 (32.7%)	310 (29.7%)	1216 (42.6%)	82 (31.8%)
Participant-oriented	11 (5.4%)	14 (5.8%)	28 (8.5%)	11 (7.8%)	44 (7.9%)	26 (2.5%)	157 (5.5%)	23 (8.9%)
Multi-function	31 (15.3%)	38 (15.8%)	42 (12.7%)	24 (17.0%)	110 (19.8%)	173 (16.6%)	544 (19.1%)	54 (20.9%)
Total	203 (100%)	240 (100%)	330 (100%)	141 (100%)	556 (100%)	1043 (100%)	2853 (100%)	258 (100%)

Moreover, a closer look at the data reveals that although research-oriented p-frames constitute the largest group in the Introduction, Methods, and Conclusion sections, their proportions vary. The Methods section has the highest proportion of research-oriented p-frames in terms of both type (52.5%) and token (51.2%). This finding shows consistency with that of Liu and Pan [4], who compared the lexical bundles across sections in medical RAs and found that the Methods section is dominated by research-oriented bundles. Research-oriented bundles or p-frames facilitate clear descriptions of research objects, models, equipment, and procedures. Their frequent use in the Methods section ensures objective documentation, helping readers assess the reliability of the study and replicate its methods.

4.4. Functional Subcategories of P-Frames across the IMR&DC Sections

Table 6 shows the distribution of functional subcategories across the IMR&DC sections. It can be seen that some functional subcategories are preferred by different sections. For example, resultative p-frames rank as the largest or second largest subcategory by type or token in the Introduction, Results and Discussion, and Conclusion sections. As noted by Hyland [3], resultative signals introduce authors' interpretations and comprehension of research processes and findings. The frequent use of resultative p-frames in these three sections appears to align with their communicative purposes. To illustrate, the Introduction section uses resultative p-frames such *as the results * that the, found that the * of*, *it * found that the*, and *the obtained results * that* to describe the findings of previous studies and make generalizations, which is one of the communicative purposes of this section. The Results and Discussion section uses the resultative p-frames such as *it can be seen **, *the results * that the*, *it can be found **, *the * indicate that the*, *which is * by the*, and *lead to the * of* to report, interpret, explain, and generalize the findings of the present study. The Conclusion section employs the resultative p-frames such as *main * are summarized as*, *main conclusions are * as*, and *the results * that the* to summarize the finding or indicate the implications. The convergent and divergent uses of resultative p-frames in these three sections highlight the similarities and differences in the communicative purposes of these sections.

Table 6. Distribution of functional subcategories across the IMR&DC sections.

Categories	Subcategories	Type				Token			
		I	M	R&D	C	I	M	R&D	C
Research-oriented	Location	20 (9.9%)	30 (12.5%)	39 (11.8%)	23 (16.3%)	35 (6.3%)	102 (9.8%)	293 (10.3%)	33 (12.8%)
	Procedure	21 (10.3%)	34 (14.2%)	31 (9.4%)	12 (8.5%)	62 (11.1%)	157 (15.1%)	159 (5.6%)	21 (8.1%)
	Quantification	23 (11.3%)	42 (17.5%)	46 (13.9%)	15 (10.6%)	43 (7.7%)	213 (20.4%)	355 (12.4%)	26 (10.1%)
	Description	16 (7.9%)	18 (7.5%)	16 (4.8%)	7 (5.0%)	61 (11.0%)	53 (5.1%)	68 (2.4%)	13 (5.0%)
	Topic	7 (3.4%)	2 (0.8%)	9 (2.7%)	4 (2.8%)	19 (3.4%)	9 (0.9%)	61 (2.1%)	6 (2.3%)
Text-oriented	Transition	1 (0.5%)	1 (0.4%)	5 (1.5%)	2 (1.4%)	1 (0.2%)	2 (0.2%)	26 (0.9%)	2 (0.8%)
	Resultative	32 (15.7%)	9 (3.8%)	41 (12.4%)	18 (12.8%)	77 (13.8%)	19 (1.8%)	415 (14.5%)	31 (12.0%)
	Structuring	5 (2.5%)	17 (7.1%)	23 (7.0%)	3 (2.1%)	14 (2.5%)	182 (17.4%)	443 (15.5%)	12 (4.7%)
	Framing	16 (7.9%)	16 (6.7%)	23 (7.0%)	11 (7.8%)	31 (5.6%)	46 (4.4%)	179 (6.3%)	23 (8.9%)
	Objective	15 (7.4%)	14 (5.8%)	14 (4.2%)	8 (5.7%)	50 (9.0%)	51 (4.9%)	43 (1.5%)	10 (3.9%)
	Comparative	1 (2.5%)	5 (2.1%)	13 (3.9%)	3 (2.1%)	9 (1.6%)	10 (1.0%)	110 (3.9%)	4 (1.6%)
Participant-Oriented	Stance	11 (5.4%)	11 (4.6%)	24 (7.3%)	11 (7.8%)	44 (7.9%)	14 (1.3%)	134 (4.7%)	23 (8.9%)
	Engagement	0 (0.0%)	3 (1.3%)	4 (1.2%)	0 (0.0%)	0 (0.0%)	12 (1.2%)	23 (0.8%)	0 (0.0%)
Multi-function		31 (15.3%)	38 (15.8%)	42 (12.7%)	24 (17.0%)	110 (19.8%)	173 (16.6%)	544 (19.1%)	54 (20.9%)
Total		203 (100%)	240 (100%)	330 (100%)	141 (100%)	556 (100%)	1043 (100%)	2853 (100%)	258 (100%)

The functional subcategory 'structuring signals' shows a high proportion in both Methods and Results and Discussion sections, particularly in terms of tokens (17.4% and 15.5%, respectively). However, a close examination of the structuring p-frames in these two sections reveals that they are used to achieve different communicative purposes. In the Methods section, the structuring p-frames are primarily used to describe the schematic of the experimental system or facilities, such as *schematic of the experimental* *, t*he schematic * of the*, and *a schematic diagram of* *. On the other hand, the structuring p-frames in the Results and Discussion section are mainly used to describe the figures or tables where results are displayed, such as *results * shown in fig*, *results are * in figure*, and *can be * from figure*. As pointed out by Hyland [3], structuring signals, acting as text-reflexive markers, are used to direct readers to other parts of the text. The use of structuring p-frames enables authors to organize and present complex information clearly, and therefore helps to achieve the communicative purposes of these two sections.

From **Table 6**, it can also be seen that certain functional subcategories are more prominent in specific sections. For example, the Methods section contains the highest proportion of procedure p-frames compared to the other sections, accounting for 14.2% of types and 15.1% of tokens. The procedure p-frames are primarily utilized to describe experimental procedures, operating procedures of the experimental facilities, data acquisition, and analysis methods, such as *be used to * the*, *the * analysis of the*, *the * process of the*, and *was * injected into the*. These p-frames match with the communicative purposes of the Methods section in AE RAs, encompassing describing experimental

setup, experimental procedures, data acquisition and analysis procedures. The preference for procedure p-frames facilitates a clear and objective presentation of these aspects. Additionally, the reliance on these p-frames also reflects the necessity for precision and standardization in reporting experimental procedures, which ensures reproducibility and transparency. This finding aligns with Salazar's [28] observation of the prominence of procedure bundles in the Methods section of biomedical RAs and Liu and Pan's [4] finding that the Methods section of medical RAs contains the highest proportion of procedure bundles compared to the Introduction, Results, and Discussion sections. The cross-disciplinary consistency in the frequent use of procedural expressions indicates that procedural reporting is a common characteristic across science and technology fields. This alignment may stem from the fact that describing procedures is a crucial activity-based skill in science and technology disciplines [29].

In addition to procedure p-frames, another functional subcategory 'quantification' is also more frequent in the Methods section than in other sections, making up 17.5% of types and 20.4% tokens. This subcategory emphasizes both connections between entities and their scale [30]. The quantification p-frames are primarily used to express measurements and precision when describing experiments, such as *the * frequency of the*, *the * ratio of the*, *the * amplitude of*, *the * temperature of the*, and *the * diameter of the*. The use of these p-frames aligns with the communicative purposes of the Methods section, including describing experimental system or setup, its key parameters, and operating conditions. The frequent use of quantification p-frames in the Methods section of AE RAs may be attributed to the rigorous quantitative analysis required by the AE discipline, which heavily relies on numerical data and measurements [31].

5. Conclusions

Unlike previous studies on p-frames that focused on their use in the whole RAs or individual sections of RAs, the current study identified the most frequent five-word p-frames and explored their structures and functions across the IMR&DC sections of AE RAs. The non-specialized p-frames across the IMR&DC sections and semi-specialized p-frames primarily in one section, along with the specialized p-frames unique to each section, reveal shared phraseological features among the sections and distinct features within each section of the AE RAs.

The present study identified both similarities and differences in the use of p-frame structures and functions across the IMR&DC sections of AE RAs. In terms of structure, the Introduction, Methods, and Conclusion sections were dominated by other-content-word p-frames, both in types and tokens, whereas in Results and Discussion section, verb-based p-frames outnumbered other-content-word p-frames in tokens. In terms of function, the Introduction, Methods, and Conclusion sections were dominated by research-oriented p-frames in terms of both types and tokens, while the Results and Discussion section was dominated by text-oriented p-frames in terms of tokens. As for the functional subcategories, some are favored by multiple sections. For instance, resultative p-frames were preferred by the Introduction, Results and Discussion, and Conclusion sections in terms of both types and tokens. Structuring p-frames were more common in the Methods and Results and Discussion sections. Some functional categories were more prominent in one specific section. For example, procedure and quantification p-frames, regardless of types or tokens, are more frequent in the Methods section than in other sections. A detailed analysis of the p-frames across the IMR&DC sections revealed a strong connection between p-frame structures, their functions, and the communicative purposes of the sections. This finding contributes to our understanding of p-frames. Prior p-frame studies have demonstrated that registers [14], disciplines [8,9], and writer groups [15,32,33] are key factors influencing the structural and functional use of p-frames. The results of the present study indicate that the section also plays a significant role in shaping the use of p-frame structures and functions.

Our results have potential implications for teaching English for AE academic writing. This study generated a list of p-frames categorized by sections that could be incorporated into instruction to improve students' understanding of the connection between p-frames and sections. The specialized p-frames in each section, the semi-specialized p-frames used primarily in one section, and the non-specialized p-frames from multiple sections may help students grasp the intrasectional similarities and differences in AE RAs. By analyzing the structures and functions of p-frames

across the IMR&DC sections, certain usage patterns can be identified that characterize individual or multiple sections in AE academic writing. However, it is important to recognize that p-frames with the same structure or function may fulfill different communicative purposes in different sections. EAP instructors should clearly explain these differences to students to deepen their understanding of how p-frames are used in different sections. We also hope that our results can assist novice AE researchers in writing experimental RAs.

Since this study only examined intrasectional p-frame variations in experimental AE RAs, the results cannot be generalized to other types of AE RAs or RAs from other disciplines. Future research could explore intrasectional p-frame variations in other AE RAs and RAs from different fields, and investigate how p-frames relate to rhetorical moves within each section.

Author Contributions

Conceptualization, X.Z. and I.P.; methodology, X.Z. and I.P.; software, X.Z.; validation, X.Z. and I.P.; formal analysis, X.Z.; investigation, X.Z.; resources, X.Z.; data curation, X.Z.; writing—original draft preparation, X.Z.; writing—review and editing, I.P.; visualization, X.Z.; supervision, I.P.; project administration, I.P. All authors have read and agreed to the published version of the manuscript.

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The author declares no conflict of interest.

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