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Interactive Knowledge Construction in Medical Problem-Based Learning: A Corpus-Based Study

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Abstract

Introduction: Due to methodological limitations, process-oriented studies have analyzed a group or fragments of problem-based learning (PBL) tutorial talk. Studies that examined several PBL tutorial talk and profile talk data into linguistic categories within a mixed methods analysis are scarce. The study aims to describe the knowledge construction processes of graduate entry medical students at Derby medical school PBL hybrid curriculum in the United Kingdom.

Methods: A 253,145-word corpus was formed from the transcripts of 56 medical students and seven facilitators in seven tutorial groups. The frequent indicators of knowledge construction concepts were extracted using Wmatrix 3 programme. The concordance lines of the frequent indicators were analyzed thematically to define their functions.

Results: The frequent indicators were verbal communication words (‘say’, ‘talk’, ‘point’ and ‘lecture’) and their inflexions, writing acts and visualization tools, coordinating and subordinating connectives and conversation interactional words (‘yes’/’yeah’ and ‘No’). The indicators were often used to mobilize prior knowledge and experience, report self-directed study activities, regulate group interactional behaviours and construct knowledge.

Conclusion: Corpus methodology allowed analysis of a larger dataset than before and provided an opportunity to describe how medical students used language to construct biomedical knowledge. The study findings contributed to the current research agenda of understanding the natural occurrences in the PBL tutorials and provided evidence of how medical students are being inducted into the professional practice of medicine. Future studies could link inter-mental verbal interactions with students’ achievement and evaluate misconceptions of biomedical knowledge.

Keywords: Corpus Analysis; Knowledge Construction; Problem-Based Learning; Medical Students; Medical Education; Verbal Interactions

Abbreviations: CIWs- Conversation Interactional Words; GP- General Practitioner; IDT- Interdisciplinary Team; MDT- Multidisciplinary Team; NF- Normalized Frequency; PBL- Problem-Based Learning; RF- Raw Frequency

Introduction

Background

Medical work in the 21st century requires professionals who possess

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extensive knowledge and the ability to use that knowledge to resolve complex issues and function effectively as multidisciplinary team members [1]. The practice context involves complex cognitive activities necessary to construct a diagnosis from the patient's history and clinical examination and formulate appropriate investigation and management plans collaborating with patients, their families, and other health professionals. From both a practical and theoretical standpoint, medical educators have recognized that traditional curricula are inadequate for developing complex cognitive and collaborative skills in medical professionals [2]. The dissatisfaction with the conventional model of educating doctors constrained educators to redesign how medical professionals are trained. Medical educators have considered constructivist pedagogic designs, such as problem-based learning (PBL), as a viable alternative to conventional instructional methods [1]. In the sociocultural constructivist learning theory, knowledge is constructed through social interactions using cognitive tools [3]. Within this framework, discourse is essential to meaningful collaborative learning [2, 4] and successful participation in the practice community [5]. The PBL students' engagement in prolonged verbalizations has been predicted to promote their knowledge-building processes [6, 7]. The PBL method is known to help students develop collaborative and cognitive skills necessary for effective clinical practice [8]. PBL has been a focus of active research, and the last few decades have witnessed a surging interest in the interactions occurring in PBL classrooms. The research interest has taken various forms, including experimental studies of the cognitive processes in PBL [9, 10] and naturalistic studies of the PBL tutorials [11-14]. These naturalistic studies described knowledge elaboration, knowledge construction, reasoning, and collaborative explanation in the tutorials. Others have demonstrated how collaborative knowledge construction emerged from the conflicts of knowledge and perspectives in the PBL tutorial discourse [15, 16]. Indeed, these studies have enlightened our understanding of the interactions occurring in PBL classrooms. However, the drawback of these microanalytic studies is that they mainly analyzed one tutorial group [11, 14] or isolated fragments of PBL tutorials [12, 13]. Furthermore, Azer and Azer [17] observed that studies on group interactions in PBL need to be more sufficiently theorized. Besides, most medical education studies did not investigate language forms. Although the quantitative analysis approach could analyze large datasets, it can oversimplify the complexity of classroom verbal interactions. A compromise between macro and microanalysis approaches seems prudent to provide a complementary perspective on verbal interactions and a broader description of cognitive interactions in all relevant phases of the PBL process. An increasingly popular corpus-based analytic approach can offer such a compromise and has been proposed as suitable for identifying and analyzing the linguistic forms of knowledge-construction processes [6]. Corpus-based analyses refer to empirical investigations of naturally occurring texts using computers for automatic and interactive analyses. They include quantitative analyses and functional interpretations to describe patterns in language features [18]. In the present study, we used verbal ("say," "talk," "speak") and textual (books, diagrams, graphs, maps) communication acts, coordinating ("and," "but," "or") and subordinating connectives ("because," "so," "after"), and conversation interactional words (CIWs) ("yes," "yeah," "No-negation") as knowledge construction indicators. These indicators were used as the most promising signals of knowledge construction expressions. Knowledge construction describes how tutorial participants elaborate (e.g., specify, restate, paraphrase, exemplify, clarify, or describe), extend (add new information using linguistic forms such as "and," "also," "as well as"), and enhance (by qualifying the previous statement regarding time, place, manner, cause, or condition) each other's contributions, thereby explaining how the students build their knowledge on such contributions.

Theoretical and Conceptual Framework

This study is based on integration of Vygotsky social constructivist theory of learning, Halliday language-based theory of learning [19] and Bakhtin theory of intertextuality [20]. The Social constructivist theory proposes knowledge and understanding arise as individuals interact with the physical, social and cultural environment [2, 19, 20]. Bakhtin proposes that knowledge develop as the voices of others are incorporated into our knowledge structures [20]. An aspect of the sociocultural theory is the community of practice perspective which proposes that individuals become members of professional practice through participation in the activities of the community [5]. As a process of initiation into a professional identity and practice, medical education entails the acquisition and use of professional tools, as well as participation in community practice activities, to develop a shared conceptual understanding and discourse practices [5]. Biomedical language is the key to learning medicine [21, 22]. Students' understanding is further developed by integrating the voices of others into their discourse practices [20]. Talking science involves describing, comparing, classifying, hypothesizing, analyzing, arguing, questioning, challenging, writing, reporting, evaluating, judging, and concluding in and through the science language [23], and using other nonverbal modalities such as models, graphs, charts, diagrams, and images [24]. During the collaborative discourse, learners externalize their ideas, prior knowledge, and beliefs as public statements, which are then discussed, negotiated, and refined, leading to shared knowledge [25] (Figure 1 below). Linguistic forms (words, phrases, and clauses) represent content knowledge, ideas, and perspectives [26, 27]. Structuring knowledge involves the logical connection of these linguistic forms during a discourse [23]. Knowledge development, to some extent, is thus analogous to language and is shaped by

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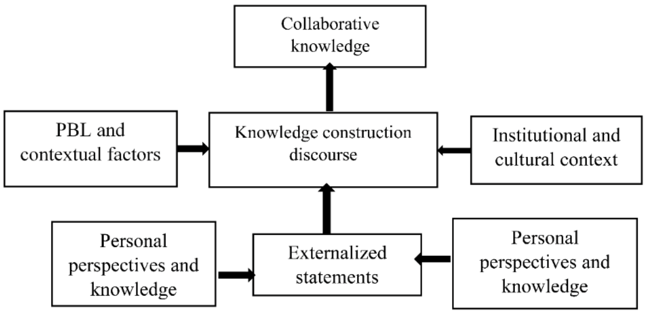

Figure 1: Essential elements of the conceptual framework for collaborative knowledge construction adapted from Stahl [25]. The lower horizontal arrows show the prior knowledge of the participants mobilized for tutorial discourse; the upper horizontal arrows show the factors influencing tutorial discourse; the vertical arrow indicates collaborative knowledge as the end product of collaborative knowledge discourse.

the language form used. The knowledge construction process is influenced by the institutional and cultural context of the discourse and the tutors' facilitation strategies.

This study aimed to illustrate how corpus-based analysis can broaden our understanding of the collaborative knowledge construction processes occurring in the PBL classroom discourse by describing and analyzing knowledge construction linguistic forms and functions across all the relevant PBL cycle sessions. The following questions were proposed to achieve this objective:

1. What are the frequency and uses of verbal communication words in students' transcripts?
2. What are the frequency and uses of textual communication words in students' transcripts?
3. What are the frequency and uses of the connective words in students' transcripts?
4. What are the tutorial transcripts' frequency and uses of conversation interactional words?
5. How was the knowledge construction achieved through verbal interactions between group members?

This investigation is expected to contribute to the ongoing interest in PBL interactive studies, provide data on how the knowledge construction language features vary across the PBL sessions, predict wider implications of the students' discourse, and evaluate how classroom practice aligns with constructive theory and educational policy.

Methods

The Problem-Based Learning Process at the Research Site

The students met three times a week for PBL tutorials. In the first session, a written or audio case scenario was presented to the tutorial group. The students engaged in case analysis, hypothesis generation, and identification of learning issues. The group members constructed differential diagnoses by taking a group member's history, who acted as a simulated case, and conducted a simulated clinical examination. A nominated member acted as a scribe and another member acted as the tutorial moderator. The second session was the reporting phase, during which students presented their self-study findings. The new understanding from the presentations enabled them to narrow down the differential diagnoses. The students then agreed on the appropriate investigations. In the third phase, the students discussed management strategies and reflected on their experiences and learning during the sessions. As this was a hybrid curriculum, the students continued attending lectures and other learning events in between tutorial sessions.

Context and Participants

The study was carried out at the University of Nottingham Medical School, Derby, UK. The school operates a hybrid PBL curriculum involving one and two-year graduate-entry medical students' cohorts. Each cohort comprises 12 PBL tutorial groups of 7 to 10 medical students. The program admits students with bachelor's, master, and doctoral degrees in various disciplines, including arts, humanities, social science, and biomedical and physical sciences. The students attend lectures, workshops, practical sessions, laboratory classes, and general practice (GP) surgeries, in addition to their PBL tutorial sessions. Most students at Derby Medical School were British, from various ethnic groups, but primarily from non-immigrant backgrounds. Participation was limited to the first-year student cohort to reduce heterogeneity in the sample due to the curriculum year. A tutor supervised each tutorial group. The case problems were asthma, chronic obstructive pulmonary disease, atrial fibrillation, sudden collapse, tuberculosis, peripheral arterial disease, and heart failure. All the students and facilitators in the 2009 and 2010 year-one cohorts were eligible to participate in the study. Of the 12 tutorial groups in each cohort, 6 of the 2009 and 5 of the 2010 cohorts participated in the study. Groups in which at least one participant declined to participate and those facilitated by temporary and new facilitators were excluded. Of the 11 participating groups, the recording in 4 groups was incomplete or inaudible due to equipment malfunction. We compiled the study corpus from the transcripts of the 7 groups with complete recordings. Students having three months' experience with the PBL curriculum were recruited.

Data Collection and Corpus Construction

The tutorials were recorded using an Olympus DS-2500 voice recorder and a Sony HD camcorder. Audio and video recordings were simultaneously made to protect the recording and guide speakers' correct assignment of utterances. After the researcher had set up the recording equipment, further

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equipment management was left to the students, who were free to exclude any interactions they did not wish to record. An outsourced professional transcriber, with English as the first language, transcribed the audio recording verbatim. The first author used the video footage to match the utterances of the tutorial participants. Transcripts were compiled by PBL session to form a subcorpora. The students' file comprised students' contributions, and the whole corpus file contained the students' and facilitators' contributions. The transcript files were converted to plain text files and uploaded to the Wmatrix 3 online software. The students' file was used for measuring the interactional word frequency, while the whole corpus file was used for concordance analysis. The study corpus contained 253,145 words, with 86,414, 108,655, and 58,076 words from the subcorpora of PBL sessions 1, 2, and 3, respectively.

Corpus-Based Methodology

The Wmatrix 3 program was used to measure elements of interactive knowledge construction. We identified four semantic (USAS) domains as the most promising sources of interactive knowledge construction expressions. These are listed below (Table 1) with their alphanumeric USAS tag, USAS semantic domain name, and examples of the words that each contains. We measured the frequency of verbal communication acts from the UCREL semantic domains of Q2.1, Q2.2, and Q3 and the textual communication acts from the Q1.2, Q4.1, and Q4.2 semantic domains. We measured the frequency of conjunctive words from the UCREL semantic domains of Z5 and retrieved the markers of collaborative knowledge from the UCREL semantic domains of Z4 (Table 1 below). Each semantic domain was opened to reveal the word frequency list, which was then inspected and disambiguated. More information about the Wmatrix 3 program can be found at http://ucrel.lancs.ac.uk/wmatrix/

Table 1: UCREL semantic tagsets: This table shows verbal and textual communication acts, conjunction words, and conversational interaction words as the knowledge construction framework elements with their corresponding UCREL Semantic Tag domains and examples.

Semantic Domain	UCREL Semantic Tagset		Examples
Verbal communication	Q2.1	Linguistic actions	say, talk
	Q2.2	Speech acts	lecture (s)
	Q3	Speech and grammar	read/reading
Textual communication	Q1.2	Paper and documents	notes/diagram
	Q4.1	The media: Books	book, textbooks
	Q4.2	The media: Papers, etc.	journal article
Grammatical	Z5	Coordinating connectives	"and," "or," "but"
	Z5	Subordinating connectives	"because," "so"
Discourse	Z4	Interactional words	"yes," "yeah," "No"

Corpus Analysis Procedure

Corpus analysis is a mixed methods process that uses a computer program to analyze a corpus [28].

Quantitative Analysis: We used Wmatrix 3 to retrieve the semantic frequency profile of the words in the corpus. The semantic categories of interest were selected and opened to generate the word list, which was arranged in frequency order from highest to lowest. Descriptive statistics were used to report the knowledge construction indicators in each semantic domain as raw frequency (RF) and normalized frequency (NF) per 100 text words.

Qualitative Analysis: The indicator word of interest was selected to generate concordance lines in the context of the surrounding words. The concordance lines for each set of indicators were exported to an Excel spreadsheet. The indicator words' function in the context of the surrounding words was determined and entered into the Excel spreadsheet. The additional discourse units that followed the word-in-context were interpreted and coded.

Informed Consent and Ethical Issues

The participating tutors and students received verbal and written information about the research (including the study objectives, participants' expectations and involvement, and their right to withdraw from participating at any time without repercussion). Each group member signed a consent form for participating, recording the tutorial interactions, and publishing the study results. Participation was entirely voluntary. The audio and video recordings were kept in a safe locker in the office of the second author, and the materials were accessible only to the research team. We anonymized the participants in the corpus and reported the study results in aggregates to safeguard the anonymity of the research participants. The study was approved by the University of Nottingham Ethics Committee (Project ID Number: D/9/2008).

Results

In total, 56 medical students and 7 facilitators from the first-year cohort participated in the study. Of the students, 32 were male and 24 were female. There were three female and four male tutors. They were from the departments of basic medical sciences, nursing, sociology, general medicine, pathology, and clinical medicine. Various verbal, textual, conjunction, and interactional words were present in the data. For space constraint, the frequency presentation and further analysis were confined to only those that occurred ten or more times in any PBL session. Based on this rationale, the frequency results are presented first, followed by the concordance analysis results in the following sections.

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Verbal Communication Words

Frequency of Verbal Communication Words: Table 2 shows the frequencies of the commonly occurring verbal communication words. We analyzed 61.6% of the 3,193 verbal communication words extracted using the Wmatrix 3 program. The term "say" and its inflections were most prevalent overall and across the tutorials, followed by "talk" and "point" and their inflections. The words "lecture" and "read" and their inflections occurred with modest frequencies, while "told" and "mentioned" occurred the least. Table 2 shows that verbal communication words were most prevalent in the second tutorial session, but references to lectures were most frequent in the first tutorial session.

Most Common Functions of Verbal Communication Words: As seen in table 3, the markers of verbal communication words were used to ask clarifying and explanatory questions, reach an agreement, elaborate and extend contributions, and recount peers', teachers', and anonymous statements. They also drew argument support from lecture notes and study materials, regulated group discussions, and appraised peers' contributions.

Textual Communication Words

Frequency of Textual Communication Words: There were six types of frequent textual communication words, accounting for 66.9% of the total 505 words extracted with the Wmatrix 3 program (Table 4). The textual word "write" and its inflections had the highest frequencies overall, while the word "book/formulary/dictionary" ranked second. "list/notes" and "diagrams/charts/graphs" were the students' third and fourth most frequently mentioned textual words, respectively, in their tutorial talk. However, "look_up" and its variants and "paper/journal/article" were the least frequently mentioned words.

Table 2: Raw and normalized frequency per 100 frequently used verbally communicated text words across the PBL tutorial sessions: This table shows the raw frequency (RF) and normalized frequency (NF) per 100 text words of the frequently used verbal communication words across the PBL tutorial sessions (PBL 1, 2, and 3) as measured from the semantic verbal communication domain (Q2.1, Q2.2, and Q3) of the Wmatrix 3 program.

Word	PBL 1		PBL 2		PBL 3		Total	
	RF	NF	RF	NF	RF	NF	RF	NF
say/says/saying/said	408	0.47	472	0.43	266	0.46	1146	0.45
talk/talking/talked	88	0.1	119	0.11	57	0.1	264	0.1
point(s)	70	0.08	87	0.08	54	0.09	211	0.08
Told	11	0.01	36	0.03	16	0.03	63	0.02
mentioned	10	0.01	16	0.01	10	0.01	36	0.01
lecture(s)	70	0.08	37	0.03	30	0.05	137	0.05
read/reading	24	0.03	55	0.05	30	0.05	109	0.04
	681	0.79	822	0.76	463	0.8	1966	0.78

Table 3: Common functions of verbal communication words.

Function	Example
Questions	M2: "...is that what you are saying?"; M3: "what are we talking about?"; M4: "Do you get what I am saying?"; F2: "Did he say why?"
Elaboration	M2: "… he is just saying…"; M2: "I am not saying …."
Agreement	M4: "I see what Matt is saying…"
Extension	M2: "I agree……., but… I am trying to say..."
Recount	M3: "…you remember what Gemma said…"; F2: "…. you remember them saying, ….": F2: "…. the GP said to me ….": F2: "John Frayne said….": M1: "…we talked about... atrial fibrillation.": M2: "…. Danny talked about the ions ….": M4: "I was told to look at palliative care …."
Regulate	M2: "He said we do not need to go into ……"
	M2: "...guys, too much cross-talk ……"
	M5: "…we have a lecture coming up …"
Argument support	F2: "…. from what I have read ….": M3: "In the lecture, we are told it affects ….": F2: "According to the lecture ….it is….."
Appraisal	M1: "That is a good point."

Table 4: Raw and normalized frequency per 100 frequently used text words for communication across the PBL tutorial sessions**:** This table shows the raw frequency (RF) and normalized frequency (NF) per 100 text words of the frequently used textual communication words across the PBL tutorial sessions (PBL1, 2, and 3) as measured from the semantic textual communication domain (Q1.2, Q4.1, and Q4.2) of the Wmatrix 3 program.

Word	PBL 1		PBL 2		PBL 3		Total	
	RF	NF	RF	NF	RF	NF	RF	NF
list/note(s)	26	0.03	25	0.02	12	0.02	63	0.02
write/wrote/written/writing/	43	0.05	20	0.02	18	0.03	81	0.03
look_up/looking_up/looked_up	20	0.02	10	0.01	5	0.01	35	0.01
diagram(s)/chart/map/graph(s)	16	0.02	20	0.02	20	0.03	56	0.02
book(s)/formulary/dictionary	24	0.03	26	0.02	23	0.04	73	0.03
journal/paper/article	6	0.01	10	0.01	14	0.02	30	0.01
	135	0.16	111	0.1	92	0.16	338	0.13

Most common functions of textual communication words: Table 5 shows that the textual words were used to organize questions, differential diagnoses, and disease mechanisms on the whiteboard. These words were also used to discuss learning issues and describe data visualization tools, library materials, and lecture notes used during the self-study period.

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Conjunction Words

Frequency of conjunction words: Fifteen frequent conjunction word types were extracted from the corpus data (Table 6). We retrieved 72.8% of the 22,842 connective words using the Wmatrix 3 program. The coordinating connectives included additive ("and"), alternative ("or"), and adversative ("but") connectives. The subordinating connectives included cause-effect ("because," "so"), temporal ("before," "when"), and concession or comparative ("though," "like") connectives. These connectives had the highest overall frequency in the third PBL session but were least prevalent in the first session. Overall, "and," "so," "but," "because," "that," and "or" were the most prevalent connective words.

Table 5: Common functions of textual communication words.

Function	Example
Information Organization	F2: "We have got that on our list of questions."; M1: "…. do we have a list of causes of heart failure….?"; M1: "Shall we write mechanism up here."
Learning issues	M4: "I am going to look_it_up."; M3: "Can we look_ up what the main differences are?"
Data visualization	F3: "This diagram here…."; F3: "From what it shows on your chart, …
	M1: "… you have a graph of end-diastolic volume…"
Self-study/ Library materials	M2: "Have you seen the formulary ......?"; M4: "The dictionary says it is due to damaged heart valves…"; M4: "I checked out a few vascular books …"; M1: "… I have just looked at his lecture notes….."; M3: "I found a paper......"; F3: "I was looking_it_up …"

Table 6: Raw and normalized frequency per 100 frequently used conjunction text words across the PBL tutorial sessions: This table shows the conjunction words used in PBL sessions 1, 2, and 3, as measured from the semantic grammatical domain (Z5) of the Wmatrix 3 program.

Word	PBL 1		PBL 2		PBL 3		Total	
	RF	NF	RF	NF	RF	NF	RF	NF
and	1499	1.73	2423	2.23	1143	1.97	5065	2
But	528	0.61	736	0.68	461	0.79	1725	0.68
or	466	0.54	513	0.47	216	0.37	1195	0.47
So	587	0.68	880	0.81	574	0.99	2041	0.81
because	493	0.57	631	0.58	375	0.65	1499	0.59
that	408	0.47	619	0.57	324	0.56	1351	0.53
that_is	285	0.33	349	0.32	342	0.59	976	0.39
like	330	0.38	352	0.32	207	0.36	889	0.35
when	223	0.26	381	0.35	144	0.25	748	0.3
As	167	0.19	207	0.19	76	0.13	450	0.18
though	59	0.07	45	0.04	40	0.07	144	0.06
whether	49	0.06	46	0.04	42	0.07	137	0.05
before	43	0.05	64	0.06	36	0.06	143	0.06
than	39	0.05	74	0.07	36	0.06	149	0.06
after	30	0.03	58	0.05	29	0.05	117	0.05
	5206	6.02	7378	6.79	4045	6.96	16629	6.57

Most common functions of conjunction words: Table 7 describes the most common functions of connective words. The connective words were used to elaborate knowledge through commenting, clarification, and exemplification; extend learning by adding, alternating, and contrasting ideas; and enhance knowledge through reasoning and temporal sequencing of information. They were also used to preface questions and recount previous learning and clinical experience.

Conversation Interactional Words

Frequency of Conversation Interactional Words: Table 8 shows the frequent CIWs. We analyzed 73% of the 6,807 interactional words extracted using the Wmatrix 3 program. The data in the table show that affirmative ("yes"/"yeah") words had the highest overall frequencies, and the negation word ("No") occurred moderately, while others occurred relatively less frequently. Generally, the interactional words were most prevalent in the first tutorial session and least prevalent in the second session.

Most common functions of conversation interactional words: The most common functions of the conversational interactional words were acknowledgment, agreement, and disagreement, as well as knowledge elaboration through clarifying and repair, extension through addition, and contrast and enhancement through reasoning (Table 9 below). At other times, they were used to ask clarifying and confirmatory questions and appraise peers' contributions.

The process of Collaborative Knowledge Construction

Problem-Based Learning Session 1: Text sample 1 is a segment of a long talk on how a diagnosis was constructed and co-constructed between the tutorial participants and the simulated patient (also a student). The simulated patient provided information from which the students constructed the likely diagnosis. The salient features of the exchanges are that the simulated patient responded to the question in fragments, and the group members elaborated on the answers through restating and paraphrasing. The students converted the layperson pieces of information provided by the simulated patient to medical concepts, which were synthesized to arrive at an overarching atopic disorder occurring in the family. It is noteworthy that the question in this excerpt relates to the presence of asthma in the extended family. However, the simulated patient (M2) continued to talk about his father and mother. Interestingly, the extended family's history was never revisited in the following exchanges.

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Table 7: Common functions of conjunction words.

Function	Example
Elaboration	M5: "...... people are .... aware of their heartbeats, and it is ... normal."; M2: "No .... but I mean .... who started it?"; M2: "In COPD like bronchitis......"
Extension	F2: ".... a left bundle branch and a right bundle branch."; M2: "On the top or the anterior?"; M2: "... the atrioventricular is myogenic conduction or myocyte conduction."; M3: "She could have asthma or COPD."; M2: "...., but it might also mean a build-up...."; F2: "We do not know whether it is left or right..."
Enhancement	M1: ".... you get the depolarization before muscle contraction."; M3: "...... it goes onto the esophagus and then ...."; M1: ".... it does the same thing as steroids..."; M4: "......it is an umbrella term like COPD."; F1: "I will think of that as heart failure."; M1: "It is better than lung cancer."; F3: "...... with ... heart block, you have decreased output......, so it can lead to dizziness...."; M4: ".... you have heart failure because you have had an MI ...."; M2: "De Musset's sign is head nodding when your heart beats...."
Question	M2: "...... but how do you treat that?"; F3: "It would not make it edematous though, would it?"
Recount	M1: "...... the hygiene theory ...... says that....."; M3: "...... physiologists believe that ..."; F2: "......, Ben thought that ..."; "......the risk calculator is a tool that GPs use..."

Table 8: Raw and normalized frequency per 100 text words of the CIWs used as indicators of collaborative knowledge across the PBL tutorial sessions.

Word	PBL 1		PBL 2		PBL 3		Total	
	RF	NF	RF	NF	RF	NF	RF	NF
yeah	617	0.71	579	0.53	526	0.91	1722	0.68
yes	552	0.64	438	0.4	174	0.3	1164	0.46
No-negation	248	0.29	273	0.25	177	0.3	698	0.28
Oh	118	0.14	79	0.07	66	0.11	263	0.1
sorry	85	0.1	108	0.1	50	0.09	243	0.1
right	81	0.09	112	0.1	70	0.12	263	0.1
i_think	72	0.08	66	0.06	45	0.08	183	0.07
you_know	67	0.08	82	0.08	64	0.11	213	0.08
i_mean	61	0.07	73	0.07	40	0.07	174	0.07
thank_you	16	0.02	17	0.02	13	0.02	46	0.02
	1917	2.22	1827	1.68	1225	2.11	4969	1.96

Note: This table shows CIWs used as indicators of collaborative knowledge in PBL sessions1, 2, and 3, as measured from the semantic discourse domain (Z4) of the Wmatrix 3 program.

Table 9: Common functions of the CIWs.

Function	Example
Acknowledgment	M2: "Yeah."; F1: "Oh, ECG thing."
Agreement	M4: "Yeah, I .... agree with you...."; M3: "It is not 100%." F3: "No, it is not."; M4: "Oh, I get it..."
Disagreement	M1: "No, P and T are waves."; M1: "Is that blood...?" F3: "No, it is protein."; M1: "No, I disagree totally..."
Elaboration	M2: "sorry, that is acute bronchitis."; M1: "No, I_mean just as you are now..."; F3: "Sorry, say that again."
Extension	M4: "Yeah, and they are leaky."; F3: "Yes, but you get double signal..."; M1: "No, but it was implied by part of it."; M3: "It is dry, I_think."
Enhancement	M3: "Yes, because it's internalized..."
Questions	M4: "Yeah, but what does out of shape mean?"; M5: "Is that right?"; M2: "Yeah, is this stage one?"
Appreciation	F3: "Thank_you."

Text sample 1: From PBL session 1 transcript

M1: Do any other members of your extended family have asthma? (*Question*)

M2: Actually, yeah. My father has a history of nasal allergy. (*Giving information*)

M1: So he has got rhinitis, interesting. (*Paraphrase/elaboration*)

M2: My mother said that she was told she has got dry skin **and** nasal polyps. (*Addition/extension*)

M1: So he has got nasal polyps and rhinitis. (*Restating/elaboration*)

M3: **And** your mother has got dry skin, **and** she has got eczema **and** asthma, so bloody hell.... (*Restating/elaboration*)

M1: There's an atopic disorder running in the family. (*Reasoning/enhancement*)

Problem-Based Learning Session 2: The text below is an excerpt from exchanges about the periodicity of shortness of breath (SOB) in a patient with chronic obstructive airway disease (COPD). The meaning of construction and co-construction was triggered by M4 who wanted to know what F1 meant by "Is it worse in the afternoon." The students spontaneously voiced their conception of the worsening SOB in the afternoon. M1 conceived SOB in the afternoon as possibly due to short-term or long-term disease progression, F1 provided a mechanical cause, while M2 vaguely suggested a mechanistic cause for worsening SOB in the afternoon. The suggestion of M2 was elaborated by M1, who proposed that the worsening of SOB in the afternoon might be due to the progressive accumulation of carbon dioxide (acidosis). M2 explicitly agreed with M1 through affirmative token (exactly) and paraphrasing (acidosis).

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Text sample 2: From the PBL session 2 transcript

F1: Is it worse in the afternoon? (*Request confirmation*)

M1:Short-term or long-term progression. (*Co-construction:* paraphrase/*elaboration*)

F1: It might mean that because he is a builder, that is why it is worse by the afternoon. (*Co-construction: reasoning/ enhancement*)

M2: It could mean that, **but** it might also mean a build-up, some biochemical and metabolic build-up of a problem at the end of the day. (*Co-construction: addition/extension)*

M1: Like if he is slowly retaining more and more carbon dioxide, you mean? (*Request confirmation*)

M2: Exactly, or his acidosis or whatever. (*Agreement/ extension*)

Problem-Based Learning Session 3: Text sample 3 below is a discourse segment during an ECG demonstration. It presents an example of how students learn together. F2 has been discussing an ECG. M4 has mispresented the previous statement of F3 (not shown). This was promptly corrected by M1, and M4 repeated what M1 said to indicate correct understanding. In continuing, F2 talked about the PQ segment as a distance and demonstrated it on the ECG but noted that the ECG was of poor quality. F2 continued demonstrating with another diagram, and F3 indicated her understanding with "it makes sense." M1 asked a question to which F2 offered clarification. The salient features of the exchanges are understanding construction through paraphrasing, clarification and peer correction.

Text sample 3: From the PBL session 3 transcript

M4: So, P and T segment. (*Co-construction: Paraphrase/ elaboration*)

M1: No, P and T are waves. (*Co-construction: correction/ elaboration*)

M4: P and T are waves. (*Co-construction: restating/ elaboration*)

M3: Just say PQ segment or something, so it will be between here and here. (*Co-construction: paraphrase/ elaboration*)

F2: There is a better diagram there; so that is your bundle of His, branches into left and right; that is your anterior fascicle and Purkinje bits ... (*Co-construction:* addition/ *extension*)

F3: It makes sense. (*Agreement*)

M1: Which ones are these? (*Request clarification*)

F2: These are the Purkinje fibers. (*Clarification/ elaboration*)

The excerpts above show some interesting features. The first excerpt shows that the simulated patient did not answer the question. This could mean that the patient was not given sufficient time to complete a response to a previous question. Also, patient digression from the question asked is quite common in clinical practice, and the students need to repeat or rephrase their questions to the patients to get the desired response. The exchanges in excerpt two explicitly demonstrated how medical students jointly developed their initial fragmentary ideas to arrive at a more plausible causal mechanism of a simulated patient's symptom and how engaging critically with the patient's symptom and with each other in a team setting can provide a valuable solution to patient's problems. Excerpt 3 clearly demonstrates how students help each other to learn. As demonstrated in the excerpt, repetition is an important communication skill to indicate following a discourse and correctly understanding what is being said. The skill can be transferred to doctor-patient interaction.

Discussion

The present study described how graduate entry medical students in a PBL curriculum collaborated to construct medical knowledge from a sociocultural perspective using language. We used corpus analysis and the automatic semantic filters in the Wmatrix 3 program to identify markers of knowledge construction concepts rapidly and objectively. The knowledge construction process within the sociocultural framework involves activating prior knowledge and experience, forming relationships between new ideas and existing knowledge, using cultural tools, and developing each other's contributions [19]. The study results demonstrated how the medical students used language to reveal how to incorporate the voices of others into their knowledge-building processes, regulate their verbal behaviors, structure knowledge, and build knowledge on each other's contributions. It specifically revealed what happened during the students' self-study periods. The study further showed how the students used various visualization techniques to organize information and construct knowledge. Discursive activities in the tutorial sessions showed that their verbal exchanges often crystallized into common knowledge; they used specialized biomedical language to make sense of the world and each other. These medical students practiced the medical profession through language, which involved describing, analyzing, discussing, hypothesizing, reporting, writing, and questioning [23]. They created knowledge by connecting ideas and concepts through webs of relationships of biomedical meanings. Although several studies have explored knowledge construction in problem-based learning curricula [11, 29, 13, 14], the present study is unique in using the Wmatrix 3 program to lexicogrammatically analyze a larger PBL dataset within a sociocultural framework and show how the students used visualization devices to construct

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knowledge. We noted knowledge construction discourses throughout the PBL sessions, similar to the findings of other researchers. The present study has certain limitations. Not all the tutorial groups in the cohort participated in the research; the knowledge construction processes may differ in the unstudied tutorial groups. The study was conducted within a hybrid PBL curriculum with experienced students; results may not be generalized to other curricula with varied research subjects or centers with different institutional and cultural contexts. Most participants in the present study were British, with English as their first language. British culture promotes independence, outspokenness, and egalitarianism, with "speak up" culture being encouraged at the school level. Knowledge construction may differ in other contexts with different institutional and societal cultures and communication styles. As languages differ because they represent different worldviews and shape the world differently [30], knowledge construction may vary in contexts where other languages are spoken. In addition, the students may have behaved differently from usual because they were conscious of being recorded and were allowed to pause the recording to exclude what they did not want to record. However, the researchers were not present in the tutorials, and by viewing the videos, the students mostly appeared unaware of the recordings. The corpus methodology scans the corpus data to identify structural indicators of knowledge construction. Several structural markers of knowledge constructions were not evaluated in this study and will be the focus of future research. Besides, the functional analysis of knowledge co-construction was not examined in this study, which may be investigated in future studies through microanalytic techniques. The study provides an opportunity to use the sociocultural theory to understand medical students' use of language to construct knowledge, like medical experts, in their classrooms. The broader implications of the findings are that the PBL curriculum graduates could function well in a multidisciplinary setting and collaborate sufficiently with patients and their families. The study contributes to the current understanding of how medical students use cultural tools in actual practice to build biomedical knowledge. The study's relevance lies in providing evidence of collaborative knowledge construction as one way of inducting students into medical professional practice. In addition, the study establishes corpus-based techniques as viable approaches to open the black box of the PBL tutorials and describe students' verbal activities [31, 7]. Future research could apply sociocultural theory to link group inter-mental interactions with students' (intra-mental) achievements, as well as focus on other linguistic markers of knowledge construction that were not examined in this study. Corpus analysis can be used to investigate how facilitators guide students' group interactions and provide opportunities to research misconceptions that arise in the students' conversations. In conclusion, this study provides a window into the process of medical student's initiation into medical practice by using a sociocultural framework and corpus analysis methodology, to automatically identify knowledge construction. Through a sociocultural framework, the study provides a window to understand how medical students are initiated into medical practice. The PBL facilitator and student's understanding of the principles and processes of exploratory discourse is important for classroom discourse to align with education theory and policy. Future research is needed to connect the quality of verbal interactions with students' cognitive development. The study implies that corpus-based techniques are appropriate for analyzing complex PBL concepts, and PBL graduates may work well with patients and professional teams.

Conflict of Interest

No conflict of interest to declare.

Contributions of the Authors

The two authors were involved in the conception, design, and data acquisition study. All authors contributed to data analysis and interpretation, revised the article for important intellectual content and approved the final version for publication

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