Core-periphery assessment of collaboration for knowledge building and translation in continuing medical education

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Abstract

Collaborative assessments have potential to support sociocognitive interactions that foster a shift from traditional educational models toward collective knowledge innovation networks. This study illuminates relationships between pre/posttest assessment and social network core-periphery analytics, verified by content analysis, and demonstrates changes in positions/roles and the co-creation of ideas for translation to practice. Core-periphery analytics extends Freeman's concept of centralization to shared leadership and is well-aligned with Knowledge Building theory. Family physicians in the End-of-Life Care Distance Education Program, a 5-month, online continuing medical education course, participated in this study. Core-periphery analysis of Knowledge Forum® build-on measures were correlated with individual pre/posttests results to provide structural visualizations of collaboration, across 5 modules. In both groups, participants with strong prior knowledge

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and pre/posttest gains shared core position/leadership roles with the facilitator. Thematic analysis of discourse identified numerous emergent ideas and Knowledge Building trajectories, beyond module objectives – evidence of participant metadesign. This study provides a model of new possibilities for collaborative assessment and educational design to facilitate a shift from learning, as an exclusively individual enterprise with external assessment, to the creation of a community with participants assuming agency for the emergence of relevant issues and authentic, meaningful problems, scaffolded by transformative assessments – integral to Knowledge Building and creation.

Keywords: collaboration, assessment, knowledge building, core-periphery analysis, continuing medical education

Exponential growth of scientific knowledge makes improvable expertise (Bereiter, & Scardamalia, 1993; Frenk et al., 2010) and continuing medical education (CME) an imperative (Dauphinee, 2011). However, concerns about the effectiveness of CME permeate the literature along with identified deficiencies in assessment and formative feedback to support knowledge improvement, particularly in relation to web-based learning that relies on an outdated model of individual knowledge acquisition and didactic transmission of facts (Cook, Levinson, Garside, Dupras, Erwin, & Montori, 2008; Curran, Lockyer, Sargeant, & Fleet, 2006; Davis, Thompson O'Brien, Freemantle, Wolf, Mazmanian, & Taylor-Vaisey, 1999; Dorman, & Miller, 2011). Few CME courses offer opportunities for collaborative Knowledge Building (KB) combining belief and design-mode knowledge work (Bereiter, & Scardamalia, 2003; Scardamalia, & Bereiter, 2006). The End-of-Life Care Distance Education (EoL Care) Program was created in Knowledge Forum® (KF®) to enable sustained, collective, cognitive work beyond learning facts, to promote idea advancement and knowledge translation to practice in palliative care (Lax, Singh, Scardamalia, & Librach, 2015/2006). This 5-month online CME course for family physicians is accredited by the College of Family Physicians of Canada, sponsored by the Ontario Ministry of Health and Long-Term Care, and offered through Continuing Professional Development at the Faculty of Medicine, University of Toronto.

This research study was conducted in the context of the EoL Care Program, which provided opportunities to explore and evaluate new

designs and combinations of individual and collaborative assessment to foster knowledge improvement (Lax, 2012). Relationships between individual pre/posttest assessment and social network (SN) core-periphery centrality analytics were verified by content analysis, to demonstrate physicians' prior knowledge and knowledge gains, temporal variance in position/role (i.e. shared leadership), and knowledge co-creation outcomes. The combination of individual and collective assessment tools used in this research study is recommended for future educational programs pedagogically designed for students and teachers to employ concurrent, embedded, transformative assessment to scaffold KB.

1. Theoretical foundations

Foundations of this study are based on Scardamalia and Bereiter's theory of KB (2003), focusing on the principle of concurrent, embedded, transformative assessment (Scardamalia, 2002) and the Royal College of Physician and Surgeons of Canada medical competency framework (2015) for education, training, and CME. Bereiter (2002a) describes the creative drive of KB, as developing a *relational* concept of understanding that is closely tied to intelligent action and adds value to conceptual artifacts. This essential linkage between KB and knowledge translation is also evident in Whitehead's concerns about inert knowledge (1929), Schön's ideas on reflection-on-action for professional practice (1987), and Thagard's concept of coherence in thought and action (2000). This connectionist view of mind is implicit to CME and inherently challenges us to determine what competencies are required for knowledge work to cultivate relational understanding and innovation capacity, and what kinds of educational designs and transformative assessments are necessary to scaffold KB and translation (Graham, Logan, Harrison, Strauss, Tetroe, Casell, & Robinson, 2006).

1.1. Concurrent, embedded, transformative assessment

Traditional summative assessment of individual learning, as is common in education, has been criticized as promoting competition and

inadequately addressing collaboration, lacking in opportunities for formative feedback, and engaging students in a process of memorization and regurgitation of facts - studying for the test, instead of working deeply to make sense of things and intentionally KB to improve ideas (Scardamalia, 2002; Scardamalia, Bransford, Kozma, & Quellmalz, 2012; van Aalst, 2013).

Formative assessment embedded within a collaborative process of belief and design-mode knowledge work is uncommon in education. However some models can be found in the design disciplines, such as Schön's (1987) student/coach dialogue from the architectural studio, Cross' (2007, 2011) designerly ways of thinking and knowing through design research, Seitamaa-Hakkarainen, Viilo, & Hakkarainen (2010) formative feedback process inherent to collaborative KB in her university craft studio courses, and Lax's use of KF® to support and document KB sociocognitive dynamics of improvability of ideas and artifacts for belief- and design-mode work and student collaborative online critiques in her medical legal visualization course in the master's program in Biomedical Communications (Lax, Taylor, Wilson-Pauwels, & Scardamalia, 2004; Lax, Scardamalia, & La Rosa, 2012).

Assessment in these examples is intrinsically linked to the tacit nature of cognitive and material artifacts made available and examined over time and throughout the process of KB and creation (Bereiter, & Scardamalia, 2014). Designerly assessments are intentionally transformative, embedded in the process, and concurrent; they are differentiated by interaction, iteration, and constructive feedback, driven by an internal motivation and a commitment to the improvability of ideas and artifacts. Creative work is aimed at uniqueness, if not innovation; replication and regurgitation, the cornerstones of traditional assessment, do not suffice. KF® supports designerly assessments by providing a record of collective visual thinking, reasoning, reflections, information, explanations and decisions; these cognitive artifacts are embodied within the material artifacts and can be analyzed concurrently with each iteration.

The KB principle of concurrent, embedded, transformative assessment extends our understanding (beyond summative purposes of assessment) to acknowledge that assessment is part of the effort to ad-

vance knowledge (Scardamalia, 2002) – that it is used to both examine and scaffold knowledge creation. Chan (2013) explains, assessments are "concurrent" in that they provide instantaneous feedback; are "embedded" into the pedagogy; and are "transformative" in that they can change the process. Traditional individual assessments may have an important place but do not address the full scope of knowledge work, particularly the co-creation of knowledge and ideas and the relationship between individual effort and collaboration. Collaborative assessment methods lag far behind and are notably missing from current CME guidelines (Moore, Greene, & Gallis, 2009; Schuwirth, & van der Vleuten, 2004), yet collaboration is an essential component of the Canada medical competency framework.

1.2. CanMEDS physician framework and collaborator competence

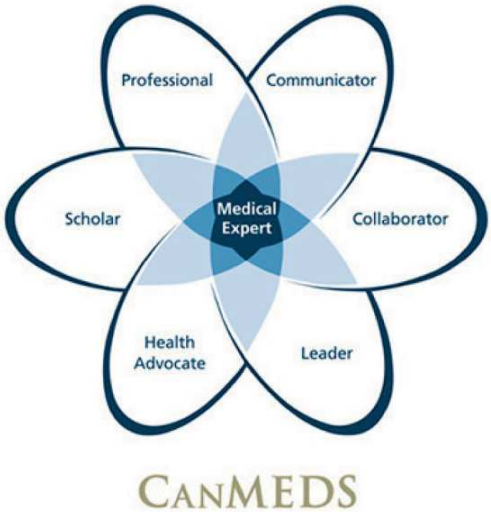
The Canadian Medical Education Directives for Specialists (CanMEDS) Framework (Fig. 1) developed by the Royal College of Physicians and Surgeons of Canada identifies 7 competencies, one of which is "Collaborator" (Royal College of Physicians and Surgeons of Canada, 2015; Frank, 2005). The College of Family Physicians of Canada (2016), responsible for CME accreditation, has adopted the CanMEDS Framework and narrowly defines collaborator competence as participation in team-based and interprofessional care.

An examination of the literature reveals that little exists on assessment of collaborator competence, other than one tool for resident training (Curran, Hollett, Casimiro, Mccarty, Banfield, Hall, Lackie; Oandasan, Simmons, & Wagner, 2011) that is not applicable to CME. Reports point to suboptimal assessment of collaboration and the need for development of innovative methods (Berger, Chan, Kuper, Albert, Jenkins, Harrison, & Harris, 2012; Puddester, MacDonald, Clement, Gaffney, & Wisenfeld, 2015). No publications or tools were found that focus on sociocognitive aspects of collaboration in CME.

2. Educational Design

The EoL Care Program is designed for sustained online collaborative KB in KF®. The balance between structured and unstructured

Figure 1. CanMEDS Competency Framework (2015)



pedagogic design is key to this CME environment. Authentic clinical case scenarios, related objectives/competencies, and embedded transformative assessments in KF® are used as scaffolds for KB. The open-ended, unstructured, online collective discourse in KF® is facilitated by a palliative care specialist and takes place over a one-month period for each of the 5 modules. Two 3-hour face-to-face sessions are held: one at the beginning of the program to introduce concepts of palliative care, KB theory, and hands-on training in KF®, and another midway through the program on symptoms other than pain.

Novel individual assessment design with formative feedback to participants was part of the initial development of the EoL Care Program (Lax et al., 2015/2006). Academic assessment typically uses a series of within course and post-course summative tests; pretests are rarely used to establish students' prior knowledge and analysis of individual pre/posttest knowledge gains are rarely conducted, and even if so, results are rarely shared with students. However, in edu-

cational research, pre/posttest assessments are typically conducted to answer these types of questions. We decided that this research strategy could be used as an effective educational strategy and we re-designed participant test assessment in the EoL Care Program for concurrent, embedded, transformative feedback. Thus, custom designed pretests and posttests submitted online through KF® are automatically scored by question and by module objectives, related to palliative care competencies. Participants are provided with feedback by question and with a Pretest Scorecard and a comparative Pre/Posttest Scorecard. The Pretest Scorecard enables participants to identify areas of strength, weakness, and knowledge gaps, as a baseline for reflective goal setting and intentional contributions to higher-level collective KB.

The EoL Care Program is composed of 5 palliative care clinical case scenarios that unfold via text and video vignettes within KF® notes. Three modules focus on pain assessment and management and two on the patient's last days of life. Module case-based objectives related to palliative care competencies for practice are pre-identified in KF® along with KB prompts, to provide initial scaffolding for KB discourse.

The program begins in KF® with introductions and asks participants to identify their personal and local health care system barriers to practice. The ultimate goal is to improve knowledge, to overcome health systems barriers and potentially to create new knowledge to improve patient care. Palliative care is complex and nuanced by psychosocial dimensions according to different patient and family expectations, end-of-life situations, culture, religion, communication, etc. Specific knowledge and skills are required to practice palliative care and it is straightforward to teach some aspects such as titration of opioids to relieve pain. But many other aspects do not have one correct answer or pose challenges within systems constraints and therefore provide opportunities for intentional, collaborative KB discourse, involving ethical debate, situated problem-solving, critical examination of evidence, translation of knowledge to practice, and importantly the continual advancement of ideas to improve patient care, particularly around issues near the end-of-life.

3. Methods

The research ethics protocol for this study was approved by the Health Sciences Research Ethics Board, University of Toronto. This case study was guided by the following research question: What are the relationships between individual knowledge improvement, KB sociocognitive dynamics, and social network core-periphery positions/roles and do these relationships contribute to democratization/shared leadership and co-creation of knowledge in the EoL Care CME program? A design research methodology (Bereiter, 2002b; Collins, Joseph, Bielaczyc, 2004) was used, employing mixed methods of quantitative, qualitative analyses (Creswell, 2009; Chi, 1997) and social network centrality analysis (Scott, & Carrington, 2011; Scott, 2009; Wasserman, & Faust, 1994), specifically core-periphery measures (Everett, & Borgatti, 2005).

3.1. Participants

Nineteen family physicians and 2 palliative experts participated in this study. The family physicians were in practice in the Toronto area and elected to register in the EoL Care Program. All participants consented to the research component. Participants were randomly distributed into 2 KF® groups; Group 1 was composed of 10 family physicians and a facilitator/expert in palliative care and Group 2 was composed of 9 participants and a different facilitator/expert in palliative care. Data from the strongest knowledge improvement year, 2008-09, were selected for this study.

3.2. Materials and Measures

Research materials and measures include: (1) pre/post knowledge tests, (2) KF® analytic toolkit (ATK) KB measures, as well as social network (SN) density measures, (3) core-periphery collaboration measures, and (4) KB/KF® discourse notes for comparative content analysis of emergent themes. We provide details about the core-periphery measures below to highlight this novel analysis of collaborative KB.

Core-periphery measures

Core-periphery analysis extends Freeman's concept of centralization to multiple participants (Everett, & Borgatti, 2005) and therefore was specifically selected for use in this study since it is well-aligned with KB theory. Everett and Borgatti (2005) indicate that SN "centralization measures the extent to which a network revolves around a single highly central actor. However, what if there are two or more actors occupying the same central position and playing that same structural role?" (p.75). The centralization measure with one actor at the centre gets a lowers score. In contrast, Everett and Borgatti's core-periphery measures yield a high score regardless of how many people are in the core. Since we hypothesize that collaborative KB will result in democratization and shared leadership, core-periphery measures of extended centrality are a better fit for the intended analysis. Everett and Borgatti use the term "concentration" at the core, as opposed to the singular notion of centrality. This is an important difference between core-periphery analytics and other SN centrality analyses.

Procedures

Participants were asked to contribute to the discourse weekly in KF®, over 1-month period of time, in each of the 5 modules, for a total time period of 5-months. All contribution measures were automatically collected online in KF®. Family physician participants completed an online Pain Pretest before the 2nd module and a Pain Posttest after the 4th module. Correct/incorrect answers, explanations, associated references and novel Pain Pretest Scorecard and a Pain Pre/Posttest Comparative Scorecard were provided to participants as embedded, concurrent, transformative feedback to scaffold their KB.

4. Analyses

Pre/Posttest data collected online was downloaded to Excel and analyzed in SPSS in aggregate according to the 4 objectives/related competencies pre-identified for these modules, which are assessment and management of: (1) pain, (2) opioids, (3) neuropathic

pain and (4) bone pain. *T*-test for significant difference from pre to posttest, as well as Cohen's *d* effect size were performed. A 2-way ANOVA was used to analyze difference between groups. The KF® ATK was employed to determine contributions to reading, writing and building-on notes, across all 5 modules in Groups 1 and 2 and the KF® SN analysis tool was used to visualize density of read and build-on contributions. SN analysis software (NetMiner 3) was used to determine core-periphery measures and to construct visual analytics (Aviv, Erlick, Ravid, & Geva, 2003; Everett, & Borgatti, 2005; Philip, 2010; Wang, 2010). Eigenvector core-periphery measures were viewed relationally, in correlation with individual students pre/posttest outcomes. Content of KB/KF® discourse notes in the final module of each group were thematically analyzed and then compared to module objectives and categorized as an emergent idea or objective. Exemplars of shared leadership within the discourse confirmed positional roles and identities.

5. Results

Results of analyses conducted and presented herein are: (1) pre/post knowledge tests, (2) KF® analytic toolkit (ATK) KB measures, as well as a summary of KF® SN density with visualization examples, (3) core-periphery collaboration measures related to pre/posttest results, and (4) content analysis of KB/KF® discourse notes for thematic comparison and verification of emergent ideas with modules objectives, along with exemplars of shared leadership and the evolution of prominent ideas.

Knowledge pretest and posttest

Seventeen of the total 19 family physician participants complete both the Pain Pretest & Posttest. Matched results of Groups 1 and 2 Pain Pre/Posttests, in aggregate, was statistical significant and showed a 14% knowledge gain (on paired t-test = 4.30, $p < 0.001$), from 67% on pretest to 81% on posttest (Table 1). Cohen's *d* effect size (*d)* was 1.15, which is considered very strong.

Table 1. Matched Results of Pain Pre/Posttests

		(*n* = 17)					
Objective	Pre *M (SD)*	95% CI	Post *M (SD)*	95% CI	*t* (16)	*p*	*d*
1. Pain Management	0.78 (0.20)	[0.68, 0.89]	0.80 (0.19)	[0.71, 0.90]	0.49	.632	0.10
2. Opioid Use	0.63 (0.16)	[0.54, 0.71]	0.79 (0.15)	[0.72, 0.87]	3.17	.006	1.00
3. Neuropathic Pain	0.69 (0.13)	[0.63, 0.76]	0.77 (0.08)	[0.73, 0.81]	2.28	.037	0.61
4. Bone Pain	0.69 (0.18)	[0.59, 0.78]	0.87 (0.08)	[0.83, 0.91]	4.10	.001	1.42
Total	0.67 (0.12)	[0.61, 0.73]	0.81 (0.10)	[0.76, 0.86]	4.30	.001	1.15

Results of a 2-way ANOVA demonstrated significant difference between pre/posttest mean over group, $F(1,15) = 17.94$, $p < .001$ (Table 2). Group 1 demonstrated a larger pre/posttest knowledge gain of 16%, in comparison to the Group 2 gain of 12%, and a higher posttest mean outcome of 84%, as opposed to 78% in Group 2.

Table 2. Results of 2-way ANOVA Groups 1 and 2

	Pre		Post			
Group	*M (SD)*	95% CI	*M (SD)*	95% CI	Difference	*d*
1 (*n=8)*	0.68 (0.14)	[0.59, 0.77]	0.84 (0.12)	[0.59, 0.76]	0.16	1.11
2 (*n=9)*	0.66 (0.11)	[0.76, 0.92]	0.78 (0.09)	[0.71, 0.86]	0.12	1.12

KB/KF® Performance

Activity and interactivity.

ATK results overall showed high levels of KB activity in KF®, (i.e. notes created/written and notes read) and interactivity, (i.e. building-on each other's notes) (Table 3).

Table 3. KB/KF® Activity and Interactivity Results

	Number of notes created		Percentage of notes read		Number of build-on notes	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Mr. Singh's Pain, Part 1	96	69	79.4	92.5	80	58
Mr. Singh's Pain, Part 2	101	60	78.6	91.0	77	48
Mary's Misery	78	55	86.9	92.8	60	43
Judy's Last Days, Part 1	65	36	78.2	74.1	47	28
Judy's Last Days, Part 2	65	31	73.6	78.1	45	20
Total number	405	251			309	197
Average/ participant	36.8	25.1			28.1	19.7
M			79.3	85.7		
(*SD*)			(4.8)	(8.9)		

Note. Group 1 (n = 11); Group 2 (n = 10)

Group 1 writes more and reads less that Group 2. On average Group 1 participants wrote 36.8 notes in comparison to Group 2 who wrote 25.1. Mean notes read in Group 2 is 85.7% as compared to 79.3% in Group 1. The average number of build-on notes per participant in Group 1 is 28, which is substantially higher than 19 per participant in Group 2. The number of notes created/written and number of notes built-on generally decreased over each module. The number of notes read stayed relatively consistent or increased in the first three modules and then decreased in the last two. Temporal changes are further described and verified by results of KF® SN density analysis.

SN density.

Results of KF® SN density analysis were used in the next level of exploration to compare notes built-on and notes read performance measures across modules and groups. All KF® SN density visualization results of Groups 1 and 2 are presented with detailed interpretations elsewhere

(Lax, 2012). In summary, Groups 1 and 2 build-on notes, over 5 modules, during 5 months, became more distributed across participants and less focused on the facilitator after Module 1. Corresponding to ATK results, the SN of notes built-on also became less dense over time with each module. Percentage of notes read decreased over 5 months but not to the same extent as build-on performance. Examples of SN density results are shown in the visualization of Group 1, Modules 1 and 5 (figs. 2 and 3).

Number of Notes Built-on Percentage of Notes Read

Figure 2. Group 1, Module 1, Mr. Singh's Pain, part 1

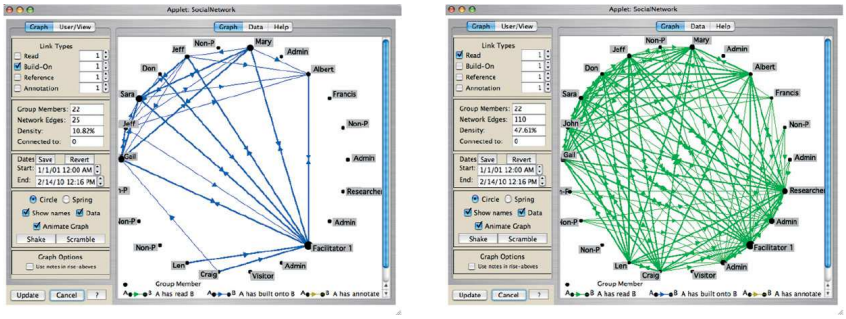
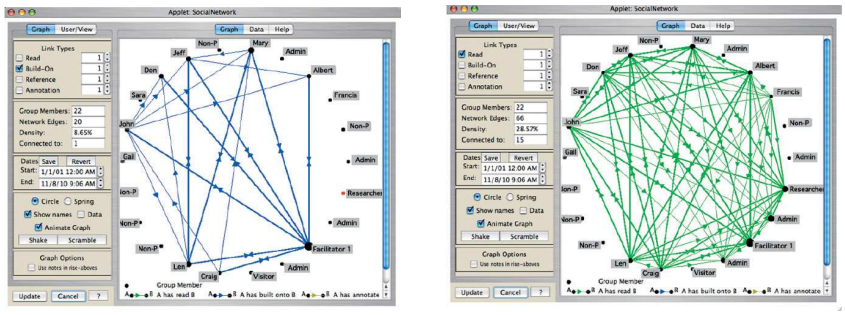


Figure 3. Group 1, Module 5, Judy's Last Days, part 2



The typical fan-shape distribution pattern with the facilitator at the apex, is indicative of a high level of facilitator interactivity building-on participant notes in the KF® discourse in Module 1 (Fig. 2). In comparison visual representation of the last module shows a change

in SN build-on pattern demonstrating more even distribution of interactivity and a decrease in density (Fig. 3). Results of Module 1, SN density analysis of percentage of notes read shows near circular patterns that are relatively dense across all 5 modules, indicative of strongly distributed activity.

Comparison of SN density measures in Groups 1 and 2 demonstrate differences and changes across modules that are instantly recognizable and quickly understood, more easily through the visualizations that metrics. However, usefulness of these visual analytics and numerical measures is limited by definition and interpretation of discourse density. How does density correlate to KB since more doesn't necessarily mean better? These results raise questions that require additional analyses about sociocognitive dynamics of collaboration.

5.1. Core-periphery assessment of collaboration in relationship to pre/posttests

Results of core-periphery SN centrality analysis, presented herein, helps us understand relationships and sociocognitive dynamics of KB from new perspectives. Focusing on assessment of position/role, sociocognitive *relationships* and *transformations between and across* modules, over time, is substantively different from traditional summative assessments. Core-periphery analysis is well-aligned with KB and the aim of concurrent, embedded, transformative assessments to inform the process of knowledge creation.

Core-periphery relationships were demonstrated through SN structural analysis of change and transformation in participant positions/roles. Extended centrality measures were employed (Everett, & Borgatti, 2005) using data from KF® ATK build-on notes. The visual analytic field was divided into core-mid-periphery measures that were correlated with individual pre/posttest scores. Trajectories of individuals that participated in all 5 modules were tracked. Results of analysis for Group 1 are reported in this paper, along with a summary of Group 2 results. Additional details are reported elsewhere (Lax, 2012).

Participants, with a high level of prior knowledge that scored well on Pretest (80% or higher) were identified as 'incoming stars' (star

graphic) and those that achieved the largest pretest to posttest gain in score were identified as a 'greatest gainer' (plus sign graphic). Individuals that completed both the pretest and posttest and participated in KF® discourse in all 5 modules were eligible for these designations (Table 4). In the core-periphery visual analytics the facilitator position is shown by a blue square and student participants are indicated by red dots. In the corresponding core-periphery metrics individuals that did not contribute to module discourse in KF® were designated a non-participant (np) (grey dots).

Findings based on interpretation of visual analytic relationships stem from 3 key dimensions: (1) facilitator/student & student/student interactions within modules (2) who is at the core – the power position with the most influence on ideas, and (3) what changes in position – shifts in role and movement in knowledge and ideas, occurs across modules?

Table 4. Group1 Pre/Posttest Scores

Student	Pretest score	Posttest score	Difference
Albert	0.58	0.90	0.32
Craig	0.87	0.87	0.00
Don	0.56	0.59	0.03
Francis	0.63	n/a	n/a
Gail	0.59	0.95	0.36
John	0.69	0.73	0.04
Jeff	0.83	n/a	n/a
Len	0.80	0.88	0.08
Mary	0.85	0.85	0.00
Sara	0.51	0.93	0.41

☆ = incoming star (pretest score=80% or higher)
✚ = greatest gainer

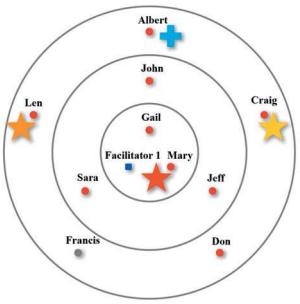
In Group 1, three 'incoming stars' are identified with pretest scores of 80% (Len/orange star), 85% (Mary/red star), and 87% (Craig/yellow star) and one 'greatest gainer' with a 32% increase in pre/posttest score (Albert/blue plus sign) (Table 4). Results of Group 1 core-periphery analysis (Figs. 4-8) shows that the facilitator worked with ideas in the core in all 5 modules and at times

shared this position with others. In 4 of 5 modules Mary/red star shared the core position and leadership role with the facilitator. Mary began in the core and remained at the center building-on ideas and moved to the midfield in Module 4 and them back to the core. Lowest scoring of the 'incoming stars' (Len/orange star) began in the periphery and then in the second module worked with build-on notes in the midfield and remained in that position for the next 3 modules. The highest scoring 'incoming star' (Craig/yellow star) worked in the periphery for 2 modules, skipped the third module and then worked in the periphery and moved to the midfield for the final module.

It is noteworthy that core-periphery analytics demonstrated shared core position between the facilitator and numerous student participants. In Group 1, Module 1 the facilitator shared leadership with Gail (Fig. 4) and in Module 5 with three students, John, Jeff and Mary (Fig. 8).

The next core-periphery trajectory examined was that of the 'greatest gainer', the student that completed all 5 modules and achieved the greatest gain from pretest to posttest. In Group 1, Albert/turquoise plus sign, had a pre/posttest gain of 32%. Albert moves from working at the periphery, to the midfield, and then to the core to share leadership at the centre with the facilitator in Module 4 (Fig. 7).

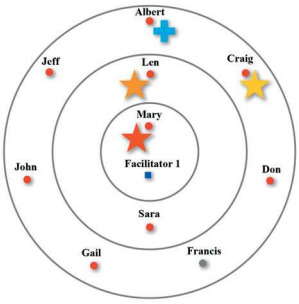
Figure 4. Core-periphery position/power of ideas map, Group 1, Mr. Singh part 1, Build-on notes



Mr. Singh's Pain Part 1, build-on notes

Group 1	Participant	Eigenvector	Centrality map position		
	Albert	0.107			periphery
	Craig	0.06			periphery
	Don	0.046			periphery
	Francis	0			n/p
	Gail	0.44	core		
	John	0.199		mid	
	Jeff	0.217		mid	
	Len	0.034			periphery
	Mary	0.446	core		
	Sara	0.387		mid	
Facilitator	1	0.591	core		
Distribution			3	3	4 + 1 n/p

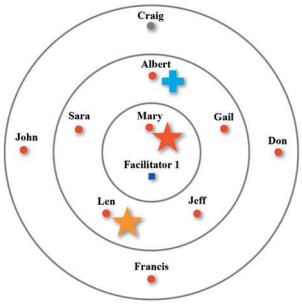
Figure 5. Core-periphery position/power of ideas map, Group 1, Mr. Singh part 2, Build-on notes



Mr. Singh's Pain Part 2, build-on notes

Group 1	Participant	Eigenvector	Centrality map position		
	Albert	0.205			periphery
	Craig	0.107			periphery
	Don	0.087			periphery
	Francis	0			n/p
	Gail	0.196			periphery
	John	0.175			periphery
	Jeff	0.176			periphery
	Len	0.33		mid	
	Mary	0.493	core		
	Sara	0.308		mid	
Facilitator	1	0.626	core		
Distribution			2	2	6 + 1 n/p

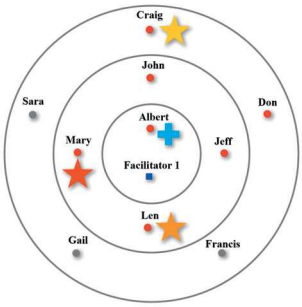
Figure 6. Core-periphery position/power of ideas map, Group 1, Mary's Misery, Build-on notes



Mary's Misery, build-on notes

Group 1	Participant	Eigenvector	Centrality map position		
	Albert	0.223		mid	
	Craig	0			n/p
	Don	0.111			periphery
	Francis	0.083			periphery
	Gail	0.239		mid	
	John	0.157			periphery
	Jeff	0.26		mid	
	Len	0.362		mid	
	Mary	0.483	core		
	Sara	0.287		mid	
Facilitator	1	0.578	core		
Distribution			2	5	3 + 1 n/p

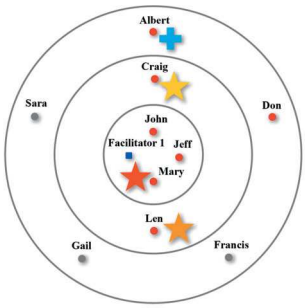
Figure 7. Core-periphery position/power of ideas map, Group 1, Last Days part 1, Build-on notes



Judy's Last Days Part 1, build-on notes

Group 1	Participant	Eigenvector	Centrality map position		
	Albert	0.5	core		
	Craig	0.062			periphery
	Don	0.062			periphery
	Francis	0			n/p
	Gail	0			n/p
	John	0.25		mid	
	Jeff	0.275		mid	
	Len	0.23		mid	
	Mary	0.399		mid	
	Sara	0			n/p
Facilitator	1	0.626	core		
Distribution			2	4	2 + 3 n/p

Figure 8. Core-periphery position/power of ideas map, Group 1, Last Days part 2, Build-on notes



Judy's Last Days Part 2, build-on notes

Group 1	Participant	Eigenvector	Centrality map position		
	Albert	0.142			periphery
	Craig	0.204		mid	
	Don	0.14			periphery
	Francis	0			n/p
	Gail	0			n/p
	John	0.413	core		
	Jeff	0.375	core		
	Len	0.361		mid	
	Mary	0.406	core		
	Sara	0			n/p
Facilitator	1	0.56	core		
Distribution			4	2	2 + 3 n/p

In Group 2, one 'incoming star' was identified (Jenn) with a pretest score of 80% and a posttest score of 85%. This 'incoming star' shared the core position with the facilitator in Modules 2 and 4; otherwise worked in the midfield. In Group 2, Brenda was identified as the 'greatest gainer' with a 25% difference from prettest (57%) to posttest (85%). Brenda did not work with build-on notes at the center with facilitator 2 in any module but worked instead in the periphery and midfield throughout.

In both Groups 1 and 2, participants shared the core position/leadership role with the content expert/facilitator at various times. As hypothesized shared leadership between students and facilitator can be related to a high level of prior knowledge; but not always related to those making the greatest knowledge gains. These results demonstrate that sociocognitive dynamics and interactions are context depend on other group members, the facilitator and relationships between students, and that students with respect to their prior knowledge of a subject will approach KB work in different ways. Trajectories and pathways to achieving competency in KB and creation may be highly individualized and contextualized; therefore the need for both individual and relational collaborative assessment provided temporally as formative feedback is essential. As demonstrated herein, core-periphery analytics can provide a strong visual and numerical tool for KB embedded, concurrent, transformative feedback and assessment.

5.2. Content analysis of emergent ideas

Results of core-periphery collaboration assessment and KB were verified through content analysis of the KF® discourse. Groups 1 and 2, Modules 2 and 4 build-on notes were thematically analyzed (40% of the dataset) using Zhang and colleagues (2009) method. Themes/threads were then compared and categorized according to pre-defined module objectives or as emergent ideas (Table 5).

Table 5. Content analysis of build-on note themes comparing objectives and emergent ideas

	Total *n* of notes	*n* of notes related to objectives (%)	*n* of notes beyond objectives/ emergent ideas (%)
Group 1			
Mr. Singh's Pain, Part 2	106	52 (49.07)	54 (50.94)
Judy's Last Days, Part 2	64	31 (48.44)	33 (51.56)
Group 2			
Mr. Singh's Pain, Part 2	59	34 (57.63)	25 (41.67)
Judy's Last Days, Part 2	30	22 (73.33)	8 (33.33)

Group 1 demonstrated nearly equal distribution of number of notes related to module objectives and number of notes with emergent ideas. In Mr. Singh's Pain part 2, 49% of notes related to pre-defined objectives and 50.9% related to emergent ideas. In Judy's Last Days part 2 48% of notes related to pre-defined objectives and 51.6% related to emergent ideas. Group 2 results were not as balanced. In Mr. Singh's Pain part 2, 57.6% of notes related to the pre-defined objectives and 41.7% related to emergent ideas; in Judy's Last Days part 2 73% of notes related to the objectives and 26.7% related to emergent ideas.

Within note content analysis necessarily complimented core-periphery analytics to identify emergent ideas, explicate trajectories of the most compelling knowledge work, and clarify relationships that advance knowledge, like democratization of KB and shared leadership. A variety of emergent ideas were identified by Group 1 and Group 2, beyond the pre-defined objectives (Table 6).

Table 6. Emergent Themes/Threads Beyond Learning Objectives

Learning Objectives	Emergent Themes/Threads Beyond Learning Objectives	
	Mr. Singh's Pain, Part 2	
	Group 1 (n of notes = 106)	Group 2 (n of notes = 59)
1. Pain management	Authentic practice	Authentic practice
2. Opioid use	Personal cases	Personal cases
3. Neuropathic pain	Drug cost	Support/Emotions
4. Bone pain	In-practice	Funerals
	Local access	Local Access
	Emotions	Coverage
	Communication	Communication
	Culture/Religion	Culture
	Self-care	Educate Family
		Self-Care
	Judy's Last Days, Part 2	
	Group 1 (n of notes = 64)	Group 2 (n of notes = 30)
1. Management of last hours of life	Authentic practice	Authentic practice
2. Family concerns and counselling	Personal cases	Personal case
3. Signs of imminent death	Culture/Religion	Funerals
4. Symptoms	Teamwork	Culture/Religion
	Homecare	Home visits
	Local Access	Death certificate
	Suffering	Billing/OHIP codes
	Communication	
	Death certificate	
	Self-care	
	Emotions	

Some themes overlapped and many differed across groups. It is evident that the open-ended collaborative discourse provided opportunities for participant identification of authentic practice problems and discussion of emergent patient and family issues and personal concerns, such as systems barriers to improving care, strategies for dealing with death, funerals, grieving, spirituality, and self-care – ideas that go beyond the original knowledge objectives of the EoL Care curriculum.

Examples of emergent themes and ideas and the evolution of those ideas through intentional KB were found in the discourse notes of participants that had been identified in the core-periphery analytics in the role of shared leadership with the facilitator. The power of Mary's ideas, her influence on others to become involved with those ideas, the diffusion, flow, and growth of the collective evolution is demonstrated below with quotes from within notes from Group 1, Module 5.

Core-periphery analysis of Group 1 showed Mary in a shared core position with the facilitator in 4 of 5 modules (figs. 4-8). Examination of the KF® discourse confirms Mary's position of leadership and influence; she shares a patient case, her reflections on how to balance office practice with home visits, and evokes abductive (breadth) and adductive (depth) of discourse engaging the facilitator and other participants on issues of dying at home (identified in the emergent theme of homecare).

Mary states, "I said in theory because the reality in my area and in my practice is I cannot always get to the patient's home as often as I should or want to. Some of my patients live quite a distance away and I have to maintain my day-to-day office practice as well". Mary then goes on to discuss a recent case about a 54-year old man, diagnosed with a large brain tumor. The neurosurgeon sent the man home with few days' supply of decadron. Mary indicates that the couple lives well over an hour away and it is difficult to provide advice and support over the phone when the patient is near end-of-life. "I have agreed to travel to them when the time comes, partly because I need the sense of closure as well as providing this last service for Lester... I realize that providing better palliative care for my patients is something I want to do for myself as well as for them".

The facilitator responds by thanking Mary for sharing a personal case and speaks to a medical dilemma she has experienced herself. She asks " Did you feel comfortable with the surgeon's directions to taper off the decadron? I have struggled with this decision in the past... Tapering the decadron can predictably lead to agitation and headaches... sometimes challenging to manage with opioids, neuroleptics and BZDs". The discourse continues to evolve.

Len, in the midfield, picks up on the second theme within Mary's note and comments "In retrospect I'm really grateful I was part of my dying patient's experience. Almost like delivering babies the role we play in people's lives are unforgettable to ourselves, and their families". John and Jeff, sharing leadership from the core with Mary and the facilitator, add poignant remarks about helping families to prepare for the funeral, spirituality, and religion. The discussion flows into ethical dilemmas around end-of-life decisions, issues around pronouncements, attending funerals, emotions and self-care.

The numerous emergent ideas and important themes that evolved through the sustained collaborative discourse exemplified above, solidified the community, enabled shared leadership, and expanded the curriculum. Participant co-creation or metadesign (Fischer, 2009) of curriculum through shared leadership and collective abductive and adductive (i.e. broader and deeper) discourse ensures relevant and flexible KB that is authentic and intentionally driven by investing in the advancement of knowledge and expertise – is well suited to CME.

6. Discussion

Core-periphery analysis helps us understand the KB relationships through contextualized visualization of participation, temporal movement, shared/not shared core leadership, and shifting individual roles, identities relative to others and with perspective on individual and collective knowledge improvement. Core-periphery analysis in combination with content analysis provides opportunities for examination of influence, idea trajectories, and promisingness (Chen,

Scardamalia, & Bereiter, 2015). As indicated by Everett and Borgatti (2005) core-periphery analysis is an extended version of centrality analysis to be used when more than one participant may be expected to occupy the central position; this SN analysis is well-aligned with the theoretical foundations of KB. The combination of individual pre/posttest analysis, ATK activity and interactivity analysis including SN density measures and core-periphery analytics along with content analysis as used in this study provides new perspectives on collaborative assessment. 'Greatest gainers' can be strong individual learners but not necessarily strong collaborative knowledge builders or co-creators. As seen in this study, 'incoming stars' often share leadership roles and help drive KB. Further research is required to better understand how others drive knowledge improve from the core position and what core-periphery relationships, sociocognitive dynamics, and competencies support knowledge creation. Other SN tools such as Teplovs and Scardamalia's (2007) Knowledge Visualizer (Teplov, 2010), Law and colleagues (2011) coding visualization tool, van Aalst and colleagues (2013) Knowledge Connection Analyzer, and Oshima's (Oshima, Oshima, & Matsuzawa, 2012) KB Discourse Explorer have been developed to improve data mining and analysis. However none of these tools visually explicate relationships between participant position, role and centrality of ideas within collective and temporal changes as does core-periphery analytics. Core-periphery analytics in combination with content analysis used in this research study has strong potential for development and use as an embedded, concurrent, transformative feedback tool to participants. In future investigations it would be interesting to explore KB participant use of core-periphery analytics if designed and integrated in the EoL Care or other programs.

Intuitively understandable visual representation (Thagard, & Shelley, 1997) and graphical integrity (Tufte, 2009) are essential for embedded assessment to be effectively transformative. The visualizations of core-periphery analytics are easily understandable and can provide opportunistic feedback. Driven by participant metacognitive needs collaborative assessment analytics has the potential to scaffold KB and make individuals aware of their collaborative competence,

for internal and external assessments. This study suggests that core-periphery analysis may be purposefully used in CME and other KB contexts to make tacit and visible, the often invisible relational dynamics of collaboration.

This study was inspired by previous work by Aviv, & colleagues (2003) on cohesion, role, and power; by Cornelius and Herrenkohl (2004) on how power shapes relationships between students and ideas; by Tabak and Baumgartner's (2004) studies on teacher/student structures; by Ligorio's (2009) research on identity; and by Cacciamani and colleagues (Cacciamani, Cesareni, Martini; Ferrini, & Fujita, 2012) work on facilitator-student interactions.

Unlike scientists, most physicians do not see themselves as a KB community responsible for idea advancement, innovation (Punja, 2007; Mylopoulos, & Scardamalia, 2008) or knowledge creation (Nonaka, 1991; Hakkarainen, Paavola, Kangas, & Seitama-Hakkarainen, 2013). This study demonstrates potential of intentional KB for CME through emergent ideas, co-creation/metadesign of curriculum, and the importance of relational and temporal individual and collaborative assessments (Bereiter, & Scardamalia, 2003; Scardamalia, 2002) to support continuing professional development of expertise (Bereiter, & Scardamalia, 1993) and pathways to private and public advancement of justified true beliefs (Goldman, 2002) and design-mode knowledge advancement (Scardamalia, & Bereiter, 2006).

There are several limitations to this study. Participants were volunteers and had inherent biases, including an interest in palliative care and an affinity toward collaborative online learning, since they elected to enroll in the EoL Care Program. Therefore results may not be representative of all participants and it is not known whether a random sampling of participants would have similar results. In addition, we report only on two groups and a small number of participants. Therefore further research is required beyond this case study with additional groups. While the research context focused on palliative care, the EoL Care Program was created based on KB theory and according to agile design principles that are relevant and can be scaled to other populations and contexts.

7. Conclusions

In the 21st Century understanding and interpreting data is becoming part of our everyday lives (Mayer-Schonberger, & Cukier, 2013). Knowledge innovation is framed by the data we choose to collect, how we analyze it, represent it, and use it to inform idea improvement and our collaborative knowledge creation efforts. Outcomes of this study emphasize the purposefulness of core-periphery analysis and multiple assessments to scaffold interpretations of individual and collective relationships and collaborative competence. Core-periphery analysis provides us with visual analytics to better understand influence of position/role, promisingness of compelling ideas, and trajectories of sociocognitive engagement to support knowledge creating work. Core-periphery analytics extends Freeman's concept of centralization to shared leadership (Everett, & Borgatti (2005) and is well-aligned with KB theory. This analysis resonates within Scadamalia's (1999) continuing compelling notion of the essence of KB – of "putting ideas-at-the-centre".

To measure individual learning in a KB community is to measure only one facet of knowledge work. This research shows that measures of community work and sociocognitive engagement provide a more systematic approach – focused less on patterns of difference among individuals and more on the differences of patterns of relations among sociocognitive factors, as demonstrated through core-periphery analysis of the collective. Positive outcomes of this study provide strong incentives for cognitive collaboration assessment to elevate KB in CME for family physicians and to shift the educational paradigm from individual knowledge acquisition toward collective knowledge creation.

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