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Creating a Learning Space in Problem-based Learning

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Abstract

An important aspect of PBL problems is the affordances that they hold for engaging students in discussion of important content knowledge. In this paper, I argue that one can analyze a problem in terms of a deep problem space and a broader learning space to identify the conceptual ideas for potential engagement. The problem space refers to the specific ideas and concepts that are part of the goals of the problem at hand. The learning space includes those aspects of the problem space and also includes the broader space of related conceptual ideas such as the anatomy and physiology related to a particular disorder or the pathology and clinical medicine of other disorders that might be considered as part of a differential diagnosis. This idea is tested in an exploratory analysis of a PBL tutorial conducted by Howard Barrows. The results demonstrate that much of students' talk is focused in these related conceptual spaces and a substantial amount of the overall learning space is engaged in the group discussion. These results have implications for understanding the affordances of problems and providing another lens on how learning unfolds in a PBL problem. It also provides another means for evaluation of learning and assessment of discursive productivity in PBL groups.

Keywords: content analysis, conceptual knowledge, PBL tutorial

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Creating a Learning Space in Problem-based Learning

One of the important goals of problem-based learning is to help students develop flexible knowledge that they can apply to problems. A prerequisite for flexible knowledge is getting learners engaged with a breadth of conceptual ideas during PBL tutorials (Jonassen, 2011). Having students engage with a range of conceptual ideas is important in helping learners develop the integrated and flexible knowledge that they will need for their future practice (Diemers, van de Wiel, Scherpbier, Heineman, & Dolmans, 2011; Feltovich, Coulson, Spiro, & Dawson-Saunders, 1992; Hmelo-Silver, 2004; Teasley & Roschelle, 1993). The goal of this paper is to examine the extent to which students cover the related conceptual space (RC) afforded by a PBL problem through a content analysis of group discourse and learning issues. This paper re-analyzes data from similar fine grained analyses of Howard Barrows as a tutor and knowledge building within PBL groups (Hmelo-Silver & Barrows 2006; 2008). The end result is not only a complementary perspective to prior work and good fit for the special issue but a critical extension that incorporates the nature of the problems and associated learning issues.

Comparisons have been made between PBL and traditional students on the content they have learned (e.g., Dochy, Segers, Van den Bossche, & Gijbels, 2003; Vernon & Blake, 1993; Walker & Leary, 2009) as well as examination of the learning issues that were produced (Dolmans & Schmidt, 2000; Hmelo-Silver, 2000). Other studies have examined ideas discussed in a tutorial (Diemers et al., 2011; Hmelo-Silver & Barrows, 2008) but there has been little fine-grained analysis of the extent to which students cover the related conceptual space a problem affords. The notion of a problem space refers to the features, knowledge and goals that are needed to solve a problem-at-hand (Teasley & Roschelle, 1993). Concepts within a problem space include both clinical and basic biomedical concepts. Teasley and Roschelle (1993) have argued that maintenance of a shared problem space is essential for collaborative learning. This is particularly relevant for PBL groups, but part of the power of PBL is consideration of the clinical and basic biomedical concepts that are part of a bigger related conceptual space, which encapsulates the problem space.

Purpose of this Research

In this article, I introduce the idea of a problem's learning space consisting of both a related conceptual space, and, within that space, a problem space leading to the correct diagnosis. I argue that this broader shared learning space provides learners opportunities to engage with many important ideas while addressing a given problem (though it is hard to guarantee any particular concept is engaged in a single problem). In the research reported here, I examine the extent to which students cover this space in a PBL tutorial led by an expert facilitator.

An important aspect of what accounts for the power of PBL is the opportunity for a problem to engage learners in productive discourse about conceptual ideas (Engle & Conant, 2002; Zhang, Lundeberg, & Eberhardt, 2011). The notion of a problem affording productive discourse is echoed by Jonassen (2011), writing that "The problem to be solved should be engaging, but should also address the curricular issues required by the curriculum. The problem provides the purpose for learning" (p. 101). I argue here it is the learning space that includes both a problem space and the related conceptual space that shows how these curricular issues are addressed.

Components of a Learning Space

The learning space has two parts: the problem space and related conceptual space. The related conceptual (RC) space is a broad set of issues that are considered in the context of a problem. For example, in the medical PBL described here, developing a causal explanation of the patient's problems (The Case of Ann George, in this particular instance) as the outer circle in Figure 1 shows.

The RC space consists of alternative hypotheses and basic science concepts. Embedded in this is the much more detailed problem space, which includes all the causal mechanisms that account for the patient's signs and symptoms. Consider this overall learning space as a key to understanding the affordances of problems for guiding self-directed learning in problem-based learning groups. Affordances refer to the opportunities that a problem provides to engage with particular ideas (Greeno, Collins, & Resnick, 1996; Kafai

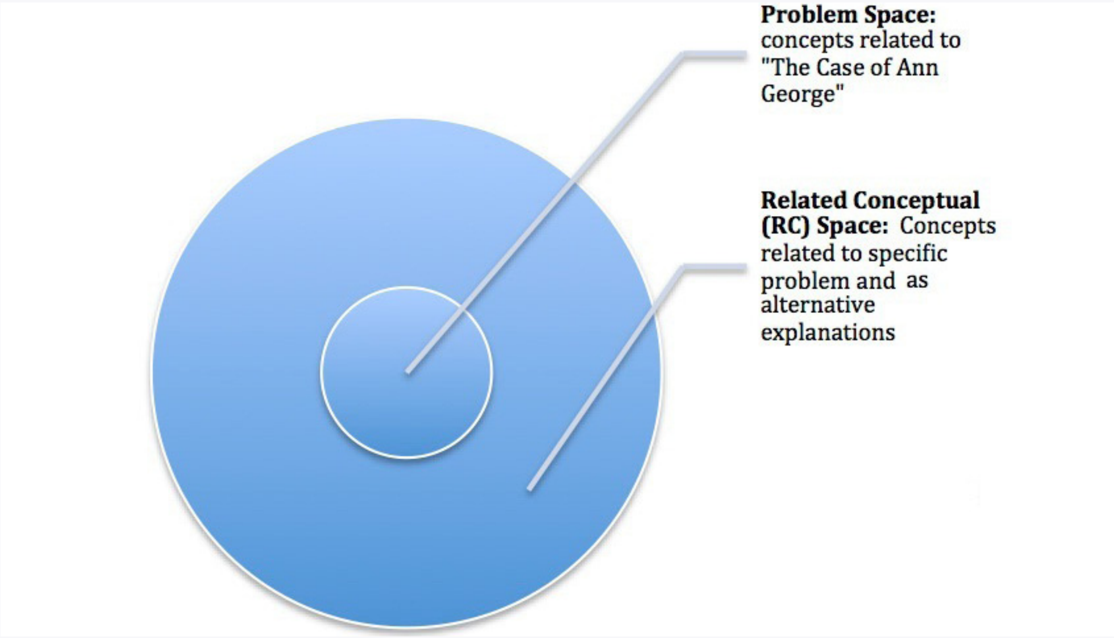

Figure 1. Overall learning space includes both the problem space and a larger related concept space (see Appendix for specifics).

& Ching, 2001). PBL designers and facilitators can only expect students to explore and understand those concepts that students have engaged in their discussions, self-directed learning, and solutions.

A key contribution to thinking about this has been research that examines the learning issues generated in a PBL session. In a medical school context, Dolmans & Schmidt (2000) found that both problem discussion and course objectives had the greatest influence on what students studied in their self-directed learning. However, they did not directly examine what topics students engaged with during the PBL tutorial itself. In a study that examined student-generated learning issues, Dolmans and colleagues found that students tended to cover about 64% of the learning issues that the faculty anticipated in designing problems (Dolmans, Schmidt, & Gijselaers, 1995). Using PBL in an educational psychology course, Hmelo-Silver (2000) found that sharing student learning issues in a relatively large class lead to knowledge diffusion among other groups that might have originally overlooked topics. An analysis of whiteboards and group papers showed that students covered much of the related conceptual space that the course was designed to cover. This analysis demonstrated that, at a group level at least, use of conceptual ideas deepened over successive engagement with key ideas on subsequent problems. Similarly, Hmelo-Silver et al. (2009) showed that student learning about a particular concept in a PBL course was related to the depth to which they engaged with that concept during the PBL sessions. None of these studies, however, has used discourse to look at the extent to which the conceptual terrain of a problem is traversed over time, as is important for developing a flexible knowledge base (Diemers et al., 2011; Feltovich, Spiro, & Coulson, 1993).

Understanding the Conceptual Terrain in PBL

One approach to studying this conceptual terrain is interactive ethnography (Castanheira, Green, & Yeager, 2009). In this approach, Bridges, Botelho, Green, and Chau (2012) opened the black box to see how a PBL group in dental education constructed knowledge. Like Hmelo-Silver and Barrows (2008), this approach studied how learning unfolds in PBL. The focus in Bridges et al. was not the related conceptual space itself, but how the RC was mediated across contexts with the use of multimodal tools. They accomplished this through tracing back the knowledge of one student in a group as they identified key events in the problem cycle both within and across contexts, including self-directed learning activity. The results show how the use of multimodal texts and ideas drawn from them lead to a shift in discourse. This inductive approach provides an extremely rich way of tracing learning *in situ* as they studied the themes that emerged in the tutorial data. It allows researchers to study the paths students take, regardless of how those paths fit with the specific affordances and goals of problem designers. It provides a lens on students' initial conceptions of biomedical and clinical issues and how they evolve. In contrast, Diemers et al. (2011) took a deductive approach to study a PBL tutorial with real patients and examined the extent to which students integrated biomedical (i.e., basic science) and clinical concepts in their discussion. They started with predefined coding schemes for several categories of clinical knowledge, biomedical knowledge as well as some additional categories of interest. They found that both clinical and biomedical knowledge were discussed, and that the biomedical knowledge was used to explain signs and symptoms. This top-down deductive approach has the strength of examining how well the problem design and facilitation goals are achieved, but may miss catching alternative paths that the group might take.

Understanding the range of concepts discussed in a case is important because it predicts student achievement (Yew & Schmidt, 2012). Yew and Schmidt coded relevant conceptual contributions in PBL tutorial group discussions as well as obtaining a learning outcome measure. Using a structural equation modeling approach, they demonstrated a significant positive relationship between concepts articulated and learning, arguing that the PBL tutorial provides opportunities for learners to engage in constructive processing of these conceptual ideas. This study demonstrated the importance of discussing concepts in the tutorial but did not examine the depth of discussion in relation to the overall problem and learning spaces anticipated when the problem was designed.

The study presented here takes a deductive approach at a finer level of specificity than Diemers et al. (2011). I examine how students discussed the conceptual terrain of a problem in terms of both a learning space and problem space. To develop the coding scheme, I conducted a cognitive analysis of the problem itself along with the additional objectives listed in the tutor guide.

Methods

Data Sources

The participants in this study were five second-year medical students who were experienced in PBL, and a master facilitator, Howard Barrows. Barrows is a physician with a specialty in neurology as well as a medical educator. He is an experienced PBL facilitator (Barrows, 2000). Students worked as a group on a medical problem during five hours spread over two sessions. These students all knew each other but had not previously worked together as a group. The sessions were videotaped and transcribed. In addition, the group whiteboards were available for analysis.

Instruction

The instruction in this study followed the Barrows model as described in Hmelo-Silver & Barrows (2006; 2008). The students worked on the case of a female patient, Ann George, with a vitamin B-12 deficiency caused by inability to absorb the vitamin in the gastrointestinal tract. The patient presented with numbness in her extremities. The students worked on this over two sessions.

Coding and Analysis

We were interested in the extent to which students covered the learning space afforded by the problem. To examine how productive the discourse was, all utterances were coded as to their content to describe how the students traversed these two spaces: the RC space and the problem space.

To examine this, a hierarchical concept map was created that included all 123 nodes that were relevant to the learning space. This was constructed using standard medical textbooks and was checked by an expert physician (Dr. Barrows). In addition, this was crosschecked against the learning objectives for the problem from the tutor guide. Any additional objectives were incorporated into the concept map. All utterances were coded as to where they fit into this concept map that included both the problem space and RC space. The unit of analysis was an idea unit, which generally coincided with the conversational turn. When a turn contained multiple ideas or functions, it was parsed into separate units (see Hmelo-Silver & Barrows, 2008 for details).

To make the analysis tractable, the 123 nodes that were initially coded were collapsed into the 64 nodes shown in the Appendix. All nodes of this condensed space were classified as to whether they were in the broader RC or the deeper problem space. Twenty-five nodes were in the RC space. These included items such as general anatomy and physiology of the nervous system and various spinal and neurological disorders, including both biomedical knowledge and clinical knowledge. The problem space contained 39 nodes. These were specific to the patient's diagnosis and included items such as Vitamin B-12 deficiency, symptoms related to this disease, and biochemical pathways involving B-12 utilization. Some examples of these are shown in Table 1. Examples 1 and 2 show student discourse focused around the RC part of the learning space. Example 1 is part of a discussion on anatomy and physiology and nervous system issues that might result. Example 2 is one of several discussions of spinal cord pathology that could result in signs and symptoms that the patient exhibited. Examples 3 and 4 are problem space examples from the first and second PBL session respectively. The first is a fairly simple correlational comment about pernicious anemia and its association with patients of that age. The second is about a test that gets more into causal mechanisms.

To check coding reliability, two independent raters coded 15 percent of the discourse; interrater agreement was 90%. The data were analyzed descriptively through frequency distributions of the codes by speaker (facilitator or student). In addition, we examined how the discourse differed across the two sessions.

Another source of data was the group whiteboard. The learning issues and ideas from the first tutorial session were coded and counted. The relevant columns of the whiteboard are reconstructed in Table 2.

Example	Discourse Example	Content Code	Learning Space
1	"Well, sort of a catchall was like the vascular disorders like, like vasculitis or deepening thrombosis, like vascular damage from diabetes. Because any of those things can . . ."	Anatomy and Physiology	RC Space
2	S1: "Are there any more proximal lesions that could cause this? I mean . . ." S2: "I know it's bilateral. I think the spinal cord. I think a spinal cord lesion could easily . . ."	Pathology of Spinal Cord Note: These were coded as 2 units	RC space
3	". . . We could probably rule out malnutrition but leave pernicious anemia because um, as people age they tend to not to make much intrinsic factor so . . ."	Pernicious anemia (Day 1)	Problem space
4	"And the Shilling's test, there's like three ways you can do it and . . . it'll tell you where the problem is . . . the first way you can do is just give them free vitamin B-12. It's not bound to the protein. So that you can see um, that if they do take that in . . . that they do have intrinsic factor."	Pernicious anemia/ Schilling test (Day 2)	Problem Space

Table 1. Examples of learning space coding.

Results

Analysis of the Learning Issues from Table 2 demonstrates that there were 20 hypotheses and 17 learning issues considered. All of the learning issues were in the RC space and none were in the detailed problem space. The major hypothesis related to the problem space, pernicious anemia (Hypothesis 16), had been crossed off the list. To deepen our understanding of the concepts the students engaged with, further analyses were needed.

A total of 7793 idea units were coded for content. The students covered a total 56% (36 out of the 64) of possible nodes in the problem and learning spaces. The nodes they did not discuss were either very general, such as review of anatomy and physiology of nerves, or related to symptoms that the patient did not exhibit. The material covered by some of the very general nodes was often covered at a greater level of detail and was thus coded at the most specific node possible. The students discussed 25 nodes during session 1 and

Ideas	Learning Issues
1. Diabetic neuropathy	1. Guidelines for hypertension
2. Multiple sclerosis	2. Diabetic neuropathy
3. ~~Alcoholic neuropathy~~	3. Multiple sclerosis
4. ~~Malnutrition~~	4. Peripheral neuritis
5. Afferent neuropathy	5. Innervation of foot and blood supply
6. Peripheral neuritis	6. Pathophysiology of numbness
7. ~~Guillain Barré syndrome~~	7. Guillain Barré
8. Spinal cord lesion	8. Paresthesia
9. Spinal cord tumor	9. Paralysis
10. Compression fracture	10. Afferent tracts
11. Herniated disc	11. Arcus senilus
12. ~~Hypothyroidism~~	12. Broad based gait
13. Toxicity	13. Romberg
14. Arsenic	14. Cerebellar function
15. Lead	15. Muscle tone resistance
16. ~~Anemia~~ Pernicious	16. Olivopontocerebellar atrophy
17. ~~Scleroderma~~	17. CSF studies
18. Electrolyte problem	
19. ~~Psychiatric disorder~~	
20. CNS tumor	
21. CNS infection	

Table 2. Hypotheses and learning issues from session one (from Hmelo-Silver & Barrows, 2008). Numbering added here.

28 nodes during session 2. Figure 2 shows the number of idea units coded in the RC space and problem space each day. This coding shows that for 82% of the 7793 idea units coded, the discussion was in either the problem space or the RC space, demonstrating that the students' talk was productive and that they covered most of the learning issues that the problem designers anticipated. Students were content-focused throughout the duration of the tutorial. They started out broad in the first session discussing both the RC space and problem space at length, and they engaged deeply into the problem space content in the second session (despite having removed pernicious anemia from their candidate hypothesis list during the first session). As Figure 2 indicates, most of the content talk was by the students (S). The facilitator (F) used his questioning strategies to focus the students deeply into the problem space in the second session but did not completely ignore the RC space (see Hmelo-Silver & Barrows, 2008 for a description of the questioning strategies).

Discussion

Elsewhere, Hmelo-Silver & Barrows (2008) provided an in-depth analysis of how students refined their ideas about the main diagnostic hypothesis. This analysis complements that work by showing that there is also a breadth to the group discussion that allows the problems of PBL to do their jobs in providing opportunities for a learning space beyond the immediate problem space. The problem analysis shown in the appendix demonstrates the overall learning space that learners might be engaged in discussing. It is clear from this analysis that

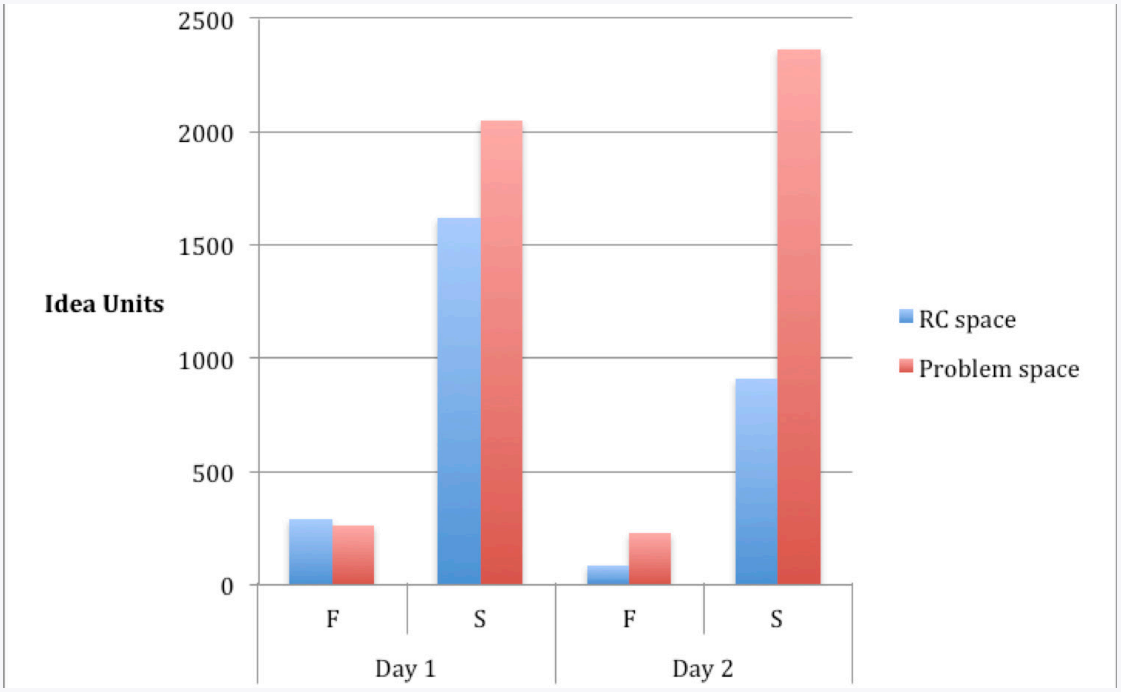

Figure 2. Content coding for overall learning space, consisting of RC and problem spaces.

a focus only on the learning issues to understand the learning space that students traverse may be a gross underestimate (though clearly one that is more practical for routine evaluation). They may be a starting point, but it is clear that other factors influence the concepts that students engage with. Moreover, it suggests that individual problems can afford broad learning (but of course cannot guarantee that all the space is covered).

Limitations

This study clearly has limitations. It was conducted with a single problem and a single tutorial group. It was facilitated by an extraordinarily skilled facilitator in Dr. Barrows. Further research would need to be conducted to see if these results hold for a range of problems. It would also be important to understand to see how less experienced facilitators would cover such a learning space.

Implications

There are three potential uses for this sort of analysis. First, it might be used to evaluate the extent to which a particular problem has reached its potential, much in the way that Dolmans et al. (1995) did when examining the learning issues that arose for given problems. Second, it also suggests an approach to assessment, at least at a group level, of which concepts are engaged during discussions and how the conceptual landscape might be crisscrossed over a curriculum (Feltovich et al., 1993). This may serve to be useful in providing formative feedback to novice facilitators as they face the challenges of learning to facilitate. Focusing on the learning space of a problem could useful for professional development with video used to adapt lesson study types of approaches to training PBL facilitators (Lewis, 2002; Maher, Landis, & Palius, 2010). Third, it offers another lens on how learning unfolds in context, much like the research by Bridges et al. (2012), Yew and Schmidt (2012) and Hmelo-Silver and Barrows (2008). It provides way to see what students are focusing on and can help explain how they take conceptual ideas to new settings (Lobato, Rhodamel, & Hohensee, 2012). Where Hmelo-Silver and Barrows focused on the social processes involved in knowledge building, this offers the perspective of the important disciplinary content that practitioners must learn. Future work that looks at a collection of problems might focus on connections between the learning spaces of prior problems and how student exploration in prior work informs their new exploration of a subsequent problem space.

The groundwork for this study was developed by the opportunity to work with Dr. Barrows. As a skilled facilitator, Dr. Barrow's knowledge of neurology helped him in knowing when to push students and deploy particular strategies to help students traverse the learning space that the problem afforded. By pushing students not only when they proposed hypotheses in the problem space, he helped create a larger learning space. An important research question remains is how might such a learning space map support facilitators with less expertise in either facilitation or domain knowledge. Whether one defines learning as participation or as acquisition (Sfard, 1998), a key to that learning is engaging with conceptual ideas and disciplinary habits of mind. Here, those habits of mind include using conceptual knowledge as a tool for solving problems in the learning space created in problem-based learning.

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References

Castanheira, M. L., Green, J. L., & Yeager, E. (2009). Investigating inclusive practices: An interactional ethnographic approach. In K. Kumpalainen, C. E. Hmelo-Silver & M. César (Eds.), *Investigating classroom interaction: Methodologies in action* (pp. 145–178). Rotterdam: Sense Publishers.

Diemers, A. D., van de Wiel, M. W. J., Scherpbier, A. J. J. A., Heineman, H., & Dolmans, D. H. J. M. (2011). Pre-clinical patient contacts and the application of biomedical and clinical knowledge. *Medical Education, 45*(3), 280–288. http://dx.doi.org/10.1111/j.1365-2923.2010.03861.x

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*(5), 533–568. http://dx.doi.org/10.1016/S0959-4752(02)00025-7

Dolmans, D. H. J. M., & Schmidt, H. G. (2000). What directs self-directed learning in a problem-based curriculum? In D. H. Evensen & C. E. Hmelo (Eds.), *Problem-based learning: A research perspective on learning interactions* (pp. 251–262). Mahwah, NJ: Lawrence Erlbaum Associates.

Dolmans, D. H. J. M., Schmidt, H. G., & Gijselaers, W. H. (1995). The relationship between student-generated learning issues and self-study in problem-based learning. *Instructional Science, 22*(4), 251–267. http://dx.doi.org/10.1007/BF00891779

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a Community of Learners classroom. *Cognition and Instruction, 20*(4), 399–484. http://dx.doi.org/10.1207/S1532690XCI2004_1

Feltovich, P. J., Coulson, R. L., Spiro, R. J., & Dawson-Saunders, B. K. (1992). Knowledge application and transfer for complex tasks in ill-structured domains: Implications for instruction and testing in biomedicine. In D. Evans & V. L. Patel (Eds.), *Advanced models of cognition for medical training and practice* (pp. 213–244). Berlin: Springer-Verlag.

Feltovich, P. J., Spiro, R. J., & Coulsen, R. L. (1993). Learning, teaching, and testing for complex conceptual understanding. In N. Frederiksen, R. J. Mislevy & I. I. Bejar (Eds.), *Test theory for a new generation of tests* (pp. 181–217). Hillsdale, NJ: Erlbaum.

Greeno, J. G., Collins, A., & Resnick, L. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 15–46). New York, NY: MacMillan.

Hmelo-Silver, C. E. (2000). Knowledge recycling: Crisscrossing the landscape of educational psychology in a problem-based learning course for preservice teachers. *Journal on Excellence in College Teaching, 11*(2&3), 41–56.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266. http://dx.doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-based Learning, 1*(1), 21–39. http://dx.doi.org/10.7771/1541-5015.1004

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction, 26*(1), 48–94. http://dx.doi.org/10.1080/07370000701798495

Hmelo-Silver, C. E., Derry, S. J., Bitterman, A., & Hatrak, N. (2009). Targeting transfer in a STELLAR PBL course for pre-service teachers. *Interdisciplinary Journal of Problem-based Learning., 3*(2), 24–42. http://dx.doi.org/10.7771/1541-5015.1055

Jonassen, D. (2011). Supporting problem solving in PBL. *Interdisciplinary Journal of Problem-based Learning, 5*(2), 95–110. http://dx.doi.org/10.7771/1541-5015.1256

Kafai, Y. B., & Ching, C. C. (2001). Affordances of collaborative software design planning for elementary students' science talk. *Journal of the Learning Sciences, 10*(3), 323–363. http://dx.doi.org/10.1207/S15327809JLS1003_4

Lewis, C. C. (2002). *Lesson study: A handbook of teacher-led instructional change*. Philadelphia, PA: Research for Better Schools.

Lobato, J., Rhodehamel, B., & Hohensee, C. (2012). "Noticing" as an alternative transfer of learning process. *Journal of the Learning Sciences, 21*, 433–482. http://dx.doi.org/10.1080/10508406.2012.682189

Maher, C. A., Landis, J., & Palius, M. F. (2010). Teachers attending to student reasoning: Using videos as tools. *Journal of Mathematics Education, 3*(2), 1–24.

Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. *Educational Researcher, 27*(2), 4–13. http://dx.doi.org/10.3102/0013189X027002004

Teasley, S., & Roschelle, J. (1993). Constructing a joint problem space: The computer as a tool for sharing knowledge. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 229–258). Hillsdale, NJ: Erlbaum.

Vernon, D. T., & Blake, R. L. (1993). Does problem-based learning work?: A meta-analysis of evaluative research. *Academic Medicine, 68*(7), 550–563. http://dx.doi.org/10.1097/00001888-199307000-00015

Walker, A. E., & Leary, H. (2009). A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. *Interdisciplinary Journal of Problem-based Learning, 3*(1), 12–43. http://dx.doi.org/10.7771/1541-5015.1061

Yew, E. H. J., & Schmidt, H. G. (2012). What students learning in problem-based learning: A process analysis. *Instructional Science, 40*(2), 371–395. http://dx.doi.org/10.1007/s11251-011-9181-6

Zhang, M., Lundeberg, M., & Eberhardt, J. (2011). Strategic facilitation of problem-based discussion for teacher professional development. *Journal of the Learning Sciences, 20*(3), 342–394. http://dx.doi.org/10.1080/10508406.2011.553258

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Appendix

Overall Learning Space- Ann George

I. (3) Problem space

A. (3 1)Vitamin B12 deficiency[1]

1. (3 1 1) Poor diet

a. (3 1 1 1) Liver

(1) (3 1 1 1 1) Bone marrow

(a) (3 1 1 1 1 1) Defective DNA synthesis

(b) (3 1 1 1 1 2) Increase methly-malonate

(c) (3 1 1 1 1 3) Decrease Methionine

2. (3 1 2) Pernicious Anemia

a. (3 1 2 1) Stomach

(1) (3 1 2 1 1) No parietal cells

(a) (3 1 2 1 1 1) Partial or full removal of stomach

(b) (3 1 2 1 1 2) Corrosive poison

(2) (3 1 2 1 2) Atrophy of parietal cells

(a) (3 1 2 1 2 1) Age

(b) (3 1 2 1 2 2) Genetic (autosomal recessive)

(c) (3 1 2 1 2 3) Autoimmune disorder

i) (3 1 2 1 2 3 1) Ab's to IF

(d) (3 1 2 1 2 4) Loss of HCL acid and pepsin

i) (3 1 2 1 2 4 1) Indigestion

ii) (3 1 2 1 2 4 2) Nausea

iii) (3 1 2 1 2 4 3) Loss of appetite

iv) (3 1 2 1 2 4 4) Abdominal cramping or pain

(e) (3 1 2 1 2 5) Decrease B12

1 Numbers refer to nodes from qualitative data analysis software and show the hierarchical nature of the coding.

(3)(3 1 2 1 3) Schilling Test

b. (3 1 2 2) No B12-IF complex forms

3. (3 1 5) Bacteria-leads to include

4. (3 1 7) Anatomy physiology anticipated LI

a. (3 1 7 1) Review anatomy and physiology of

(1)(3 1 7 1 1) Spinal cord

(2)(3 1 7 1 2) Vascular supply

(3)(3 1 7 1 3) Ascending and descending systems

b. (3 1 7 2) Review anatomy and physiology of peripheral nerves

5. (3 1 8) Biochemistry anticipated LI

a. (3 1 8 1) The role of B12 and folate in biochemistry and physiology of the nervous system

Related Concept Space

6. (3 1 9) Clinical medicine

a. (3 1 9 1)Explain pathophysiology of all signs and symptoms

7. (3 1 10) Immunology anticipated LI

a. (3 1 10 1) Describe the autoimmune mechanism leading to

(1)(3 1 10 1 1) Atrophic gastritis

(2)(3 1 10 1 2) Achlorhydria

(3)(3 1 10 1 3) Loss of production of intrinsic factor

(4)(3 1 10 1 4) Vitamin B12 malabsorption

b. (3 1 10 2) Discuss familial disease incidence and any association with other autoimmune disease

c. (3 1 10 3) Discuss the relative roles of autoantibodies and autoreactive T cells in producing the immune damage to the stomach seen in pernicious anemia

8. (3 1 11) Pathology

a. (3 1 11 1) Differential pathophysiology and diagnosis of similar spinal cord problems

(1)(3 1 11 1 1) Ischemia

(2)(3 1 11 1 2) Compression

(3)(3 1 11 1 3) Demyelination

(4)(3 1 11 1 4) Injury to the spinal cord

(5) (3 1 11 1 5) Disc degeneration-protrusion

b. (3 1 11 2) Pathology of subacute combined degeneration

c. (3 1 11 3) Pathology of Neuropathies

d. (3 1 11 4) Pathology of Multiple Sclerosis

e. (3 1 11 5) Infection

f. (3 1 11 6) Tumor

9. (3 1 12) Pharmacology

a. (3 1 12 1) Detail the involvement of B12 and folic acid in DNA synthesis

b. (3 1 12 2) Describe the hematopoietic and neurological effects of Vit B12 deficiency

(1) (3 1 12 2 1) Explain the metabolic reasons for these effects

c. (3 1 12 3) Locus of interaction between Vi B12 and folate

(1) (3 1 12 3 1) Symptoms of B12 deficiency affected or not affected by treatment with folic acid

d. (3 1 12 4) Discuss if the oral treatment of pernicious anemia is rational

e. (3 1 12 5) What is the rational treatment of choice, route of administration and duration of treatment for pernicious anemia?