A Problem-Based Learning Approach to Integrating Foreign Language Into Engineering

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Abstract: *Problem-based learning (PBL) is an instructional methodology placing primary emphasis on students solving realistic problems in a team-oriented environment. Here we discuss using PBL to integrate a language for specific purposes (LSP) track into an undergraduate biological engineering curriculum as a way to prepare students for an engineering career requiring job-specific foreign language skills. In Part I we review PBL theory and anticipate problems that may arise when merging it with an LSP track. In Part II we detail the development of a PBL/LSP module, including module performance objectives and assessment instruments. Areas of potential future research also are highlighted.*

Key words: *engineering, language for specific purposes, problem-based learning*

Language: *Relevant to all languages*

A Case for Using Problem-Based Learning to Integrate a Language for Specific Purposes

In an effort to put a halt to declining foreign language enrollments, which Welles (2004) notes have dropped from 16.1 per 100 institutional enrollments in 1960 to 8.6 per 100 institutional enrollments in 2002, foreign language departments nationwide have begun to initiate language for specific purposes (LSP) courses. Von Reinhart (2001), for example, reports that since the inception of the International Engineering Program at the University of Rhode Island, the number of German majors at the university has increased from 5 in 1987 to 91 in 2000. This has allowed the German program to offer more upper-division courses in German culture and literature, graduate more students with context-specific language skills and cross-cultural competence, and cultivate relations with international companies seeking graduate students with highly demanded skills.

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Engineering programs, also seeking ways to prepare students for real-world engineering scenarios, usually run problem-based learning (PBL) courses alongside traditionally taught engineering courses (see Cawley, 1989). A logical pedagogical approach, beneficial to foreign language and engineering departments alike, would combine both PBL and LSP tracks into one course. However, this is not always practical, and we advocate here construction of PBL/LSP modules that can be introduced into existing engineering courses. Moreover, only the students in the courses who choose the LSP track in their engineering major need complete these modules. This modularity also may allow multiple language tracks to be offered in parallel. Offering students a choice of languages would appeal to a greater number of students and could be implemented by developing several language-specific modules to complement each engineering assignment. Practical implementation might best be achieved through digital materials developed jointly by the engineering and languages programs and delivered via a campus course management system such as Blackboard Learning System or Moodle. As with existing LSP programs, these materials would be developed with the aim of preparing students for a professional internship where the specific language skills are put to practice alongside the engineering skills. Most important, however, is that the use of a course management system for delivery of PBL/LSP modules would allow for collaboration between several universities and colleges in the development and management of these modules and possibly the creation of PBL/LSP distance education courses, ensuring that student enrollment across participating universities and colleges is sufficiently large to justify offering the course every semester.

The current global economy demands engineering professionals who, in addition to being flexible and adaptive, are well versed in the languages and cultures of foreign countries. Never before has the need been greater for people who have competitive skills in technical or scientific areas *and* who also can successfully negotiate international boundaries. Accordingly, the time is ripe for language instructors and departments to reach out to university engineering departments, which currently are seeking ways to implement the curricular changes outlined by the National Academy of Engineering Committee on Engineering Education project, the Engineer of 2020 (http://www.nae.edu/nae/engeducom.nsf). The PBL/LSP approach outlined here aims to contribute to these curricular changes by producing graduates with the self-reliance, fundamental skill sets, and real-world experience to compete successfully in increasingly competitive and global markets. Since the program outlined in these pages is designed to be rigorous and demanding, we suggest that participating students have at least an intermediate to advanced proficiency in the target foreign language (e.g., advanced grammar and composition courses, a strong background in literature and reading, and strong verbal communication skills) and at least two years of engineering background (see Table 1).

Foreign language departments wishing to implement PBL/LSP modules as a means of widening their academic offerings and increasing student enrollment will, as described in the following discussion, need to adapt PBL theory so that the linguistic as well as the engineering aspects of these modules can be addressed adequately. These departments also will need to demonstrate creative thinking in terms of module development and management, technological innovation, student preparedness, faculty and tutor development, material creation and accessibility, problem scaffolding, student assessment, intercollegiate cooperation, and networking both in industry and academia. Since the development of such an ambitious program involves considerable time and resources, support from tenured faculty and university administration is a must. We feel, however, that the potential rewards of a PBL/LSP program far outweigh

TABLE 1

Learner and Context Analysis

	Area	Target Population Characteristics
Learner analysis	Entry behaviors	**German:** Four semesters of undergraduate German; intermediate to early advanced knowledge of German grammar and syntax; intermediate speaking and listening skills, possibly low reading and writing skills
		Biological Engineering: Introductory physics, chemistry, biology, calculus
	Prior knowledge	**German:** Minimal familiarity with German business environments, may have taken a Business German course
		Biological Engineering: Uncertain prior knowledge of hemodialysis and possible misconceptions that must be corrected
	Attitude toward instructional format	**German:** Possible hesitation that an online format is conducive to learning German communicatively; students may have the attitude that online learning is no substitute for face-to-face communication
		Biological Engineering: Engineering lends itself to PBL and students are familiar with popular culture depicting engineers as problem solvers having to construct solutions in short times with minimal resources; however, if this is their first PBL course, additional scaffolding may be needed
	Group characteristics	**German:** Some students may possess greater German competency or have spent more time in German-speaking countries than other students
		Biological Engineering: Students have all taken the same prerequisite courses; some students may have prior work or internship experience
Context analysis of learning environment	Adaptability of module to simulate the workplace	**Biological Engineering:** Dependent upon the selected problem space; the hemodialysis module is appropriate for most major universities in terms of required facilities, tools, and equipment
		German: Replicating the German workplace environment will be difficult as complete language immersion is not possible
	Learning site constraints	**Both:** Students will meet in main German section 2 times a week, in main biological engineering section 3 times a week Students will meet in tutorial sessions twice a week for 90 minutes, once for German and once for biological engineering
Context analysis of performance setting	Physical aspects	**Both:** Adaptability is key here, as students must train for a variety of potential employers in a broad field such as biological engineering Fundamental skills and knowledge of commonly encountered equipment and instrumentation are core
	Social aspects	**Both:** Employers will clearly look for both individual and team skills as employees must be self-reliant yet capable of contributing to and interacting with the larger group
	Relevance of skills to workplace	**Both:** The aim of university educators is to prepare students for a variety of careers within their field of study, thus fundamental concepts must be embedded in all the context-specific PBL modules so students can transfer this knowledge to potentially new settings PBL in engineering and languages is not vocational training for a predefined or foreseen task

the difficulties universities may have in developing it.

PBL theory, outlined in Part I of this article, will be the pedagogical approach underpinning the PBL/LSP modules. The purpose of Part I is to (1) outline the basic components that these modules should possess, (2) anticipate where potential concerns and sticking points may arise, (3) articulate potential solutions for these problems, and (4) highlight areas for possible interdepartmental and intercollegiate cooperation. Part II provides a sample blueprint for practical implementation of the theory outlined in Part I. A representative PBL/LSP module, introducing hemodialysis and associated subtopics to undergraduate engineering students, illustrates salient points in both Parts I and II. Although the topic of hemodialysis is extremely specialized, it is hoped that the approach outlined here will serve as a developmental model for other, perhaps more general, engineering topics, as well as a catalyst for interdepartmental collaboration.

Part I: Problem-Based Learning and Foreign Languages

Problem-based learning, of which an excellent overview is provided by Savery (2006), is a pedagogical methodology requiring learners to take an active role in the construction of knowledge by developing metacognitive learning strategies, working in small groups, and solving realistic ill-structured problems. The bulk of empirical research on PBL is in the field of medical education, where the type of problems most frequently encountered can be classified as diagnosis-solution problems according to the Jonassen typology (Jonassen, 2000). Yet as the use of PBL has recently extended beyond the field of medical education, other problem types have begun to find application in PBL curricula (see Savery, 2006). Despite efforts strictly to define the constitution of problem-based learning, it is perhaps the open-endedness of the method itself that contributes to the difficulty interpreting it. A brief perusal of scholarly literature on the subject reveals numerous PBL avatars, each with different interpretations and implementations of the method (cf. Albanese & Mitchell, 1993; Boud & Feletti, 1997; Maudsley, 1999; Vernon & Blake, 1993).

Since the definition of a typical PBL environment is loose, and since there are numerous flavors of PBL depending on educational context and curriculum goals, we feel it is important to establish the basic and fundamental pedagogical features of a PBL/LSP module. These features are based on the basic definition of PBL articulated by Neufeld and Barrows (1974), Barrows (1996), and Gijbels, Dochy, Van den Bossche, and Segers (2005). Areas that may prove difficult to implement, potential ways to overcome problems, and future research opportunities also are identified.

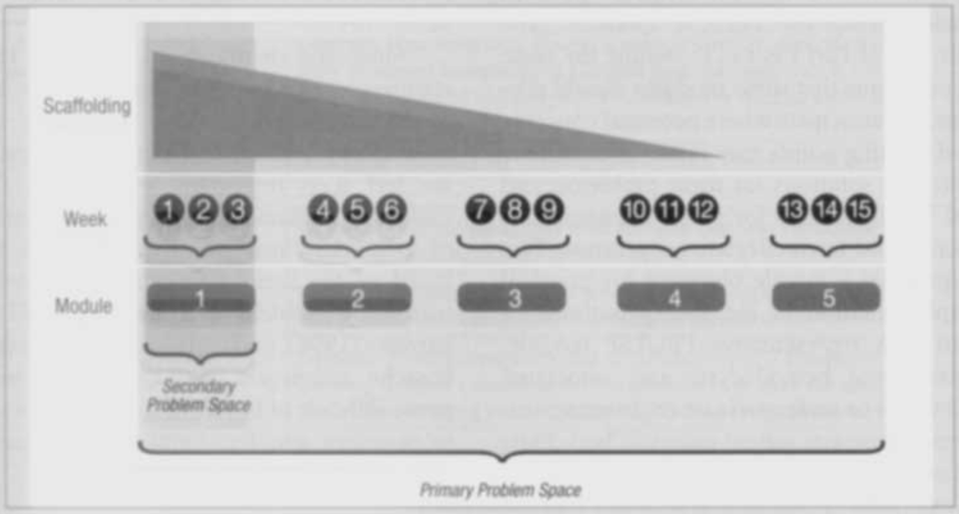
Student-Centered Learning

Instead of promoting a teacher-centered learning environment, PBL places students in the center of the instructional paradigm. This shift in pedagogical focus requires students to take control of their own learning by "identifying what they need to know to better understand and manage the problem on which they are working and determining where they will get that information" (Barrows, 1996, p. 5). The primary aim of the student-centered learning environment is the creation of effective problem-solving strategies. These strategies foster the ability of students to recognize patterns in related problem structures and to come up with universal approaches for the solution of these problems (Mestre, Dufresne, Gerace, Hardiman, & Touger, 1993). For undergraduates preparing for a competitive job market, the development of problem-solving strategies and deep linguistic competence in a specific field would be extremely beneficial.

The question emerges, however, as to whether the majority of undergraduates have sufficiently developed linguistic backgrounds to manage PBL/LSP modules. The technical and scientific demands of a problem-based scenario, coupled with the lin-

FIGURE 1

A Sample PBL/LSP Course with Faded Scaffolding



guistic complexities of an unfamiliar foreign language, may lead to cognitive overload (Chandler & Sweller, 1991; Sweller, 1988, 1994). As Table 1 indicates, students using a PBL/LSP module will come from disparate educational backgrounds and experiences. It may be desirable, therefore, that PBL/LSP modules be scaffolded with an eye to managing student cognitive load, thereby allowing the development of topic-specific proficiency gradually over the course of one semester instead of rapidly during one module. As the semester progresses, this scaffolding gradually would be withdrawn until students are able to function completely autonomously (see Figure 1).

The primary concern with this approach is problem appearance and legitimacy. If too much scaffolding is provided, the problem space becomes less realistic and students run the risk of being led to a solution rather than developing their own. On the other hand, too little scaffolding may simply overwhelm students with problem intricacies and prevent them from developing a solution at all. An instructional design model such as van Merriënboer's four-component instructional design model (4C/ID) would be a useful resource in the development of PBL/LSP modules by providing guidelines for structuring an effective scaffolded curriculum (Van Merriënboer, 1997; Van Merriënboer, Clark, & deCroock, 2002; Van Merriënboer, Kirschner, & Kester, 2003; Van Merriënboer & Sweller, 2005). The final PBL/LSP module should be a capstone experience in which scaffolding is totally absent and students are required to employ all the problem-solving strategies they learned over the course of the semester toward the solution of a closely related problem. As Dunlop (2005) notes, a PBL capstone experience is effective in increasing student perceptions of preparedness, self-efficacy, and personal ability, and serves as an excellent bridge between the academic and professional worlds.

Should scaffolding be based on the 4C/ID model, three primary areas would need to be developed: (1) supportive information that assists in the performance of nonrecurrent module tasks, (2) part-task practice items derived from recurrent aspects of module activity, and (3) just-in-time instruction providing students with the step-by-step knowledge needed to perform recurrent tasks (e.g., job aids in the form of quick-start manuals).

Supportive information scaffolding may assume the form of bibliographic references for scientific journals, flowcharts depicting cognitive strategies for navigating the problem space, and readings on best practices in engineering. Depending upon available resources, this material, which will be in both the target foreign language and English, could be presented in the content module either as printable PDF files, PowerPoint presentations, Adobe Flash movies, streaming video, digital images, or some combination of these media. Part-task practice scaffolding may be focused exercises specifically targeting the automation of learner interaction with engineering equipment, the completion of appropriate target language business and governmental forms, the proper usage of advanced target language grammatical structures most frequently found in scientific writings and business correspondence, and the memorization of topic-specific target language vocabulary. Finally, the just-in-time instructional scaffolding could be job aids in PDF format instructing students how to operate project-specific instrumentation and background information highlighting prerequisite knowledge. To encourage the development of topic-specific vocabulary and cross-disciplinary competence, all job aids should be in the target language.

Areas of potential research on PBL/LSP learning environments include the deployment and effectiveness of other scaffolding methodologies, the measurement and management of student cognitive load, the use of current and emerging digital technologies as scaffolding support, and types of capstone experiences with associated learning outcomes.

Small-Group Learning

As defined by Barrows (1996), PBL groups consist of "five to eight or nine students" (p. 5), although the exact size, structuring, makeup, and interaction of groups varies from setting to setting. Rangachari (1996), for example, prefers "floating groups of three to five students" that shift around and loosely collaborate with each other to obtain the information necessary for the solving of the problem (p. 66). Cawley (1989) favors groups of three to four engineering students. Graham and Misanchuk (2004) conclude that group size is largely determined by the context in which the group is working, although larger groups have the increased overhead of team member coordination.

The primary goals of small-group learning are to simulate a realistic team-based working environment and to foster a community of practice that will provide the members of the group with (1) an opportunity for mutual engagement, (2) a joint enterprise, and (3) a shared repertoire (Wenger, 1998). Mutual engagement presupposes the interaction of all community members and no peripheral participation. In this sense, PBL groups are more collaborative than cooperative: Collaborative learning manifests characteristics of participation, interaction, and synthesis, whereas cooperative learning is characterized by a divide-and-conquer mentality (Ingram & Hathorn, 2004; McInnerney & Roberts, 2004). The joint enterprise with which community members occupy themselves is not a stable problem or a stated goal, but rather an emergent question whose parameters are "defined by the participants in the very process of pursuing it" (Wenger, 1998, p. 77). Finally, participation in a joint enterprise develops the shared repertoire and skills of the community, including "the discourse by which members create meaningful statements about the world, as well as the styles by which they express their forms of membership and their identities as members" (Wenger, 1998, p. 83).

On the question of whether student groups should be heterogeneous or homogeneous, Graham and Misanchuk (2004) note:

> The differences existing in heterogeneous groups are more likely to lead to controversies within the group, which increases the time required to come to a consensus and complete

> tasks. However, the dissonance created by controversies can be constructive and promote more effective group learning. (p. 192)

McInnerney and Roberts (2004), on the other hand, suggest that groups should be homogeneous because research shows this composition to be most conducive to group collaboration.

The points outlined here address several core issues in the development of a PBL/LSP module, namely the size of student groups, the composition of these groups, and the facilitation of group communication. Although it is desirable to have larger heterogeneous student groups, since it is this type of group–with its widely divergent problem interpretations and interpersonal dynamics–that students will most likely encounter in the workplace, it is unlikely that a sufficient number of students will participate in the initial phase of module deployment. As a result, the quality of group communication and collaboration may suffer. A potential way around this problem, as modules will be distributed online, is to widen the delivery scope to include departments at other universities and colleges. A distributed problem-based learning (dPBL) format would allow students with unique specialization areas, who may otherwise not be able to pursue a PBL/LSP track due to low institutional enrollment, to collaborate with students pursuing a similar field of study at another institution (cf. Barrows, 2002; Orrill, 2002).

A dPBL/LSP module brings with it, however, an entirely different set of concerns. As this type of module is the collaborative product of faculty and students at different colleges and universities, solutions to problems of grading, course equivalency, delivery method, communication, and scheduling will have to be agreed upon before modules can be developed and implemented. In addition, Wertsch (2002) cautions that

> it may be important to take into consideration the possibility that one cannot simply add asynchronous communication tools into an existing mix of social and psychological processes without changing them in fundamental, unintended ways and that this may be one of the most interesting aspects to consider in computer-mediated PBL. (p. 106)

Research conducted by McConnell (2002), for instance, suggests that dPBL groups manifest more flexible stages of group formation and accordingly "may need to use time in different ways in order to carry out their work" (p. 79). This concern is especially valid given that there is very little research on the use of dPBL in foreign language pedagogy and it is unclear what impact this environment may have on how students learn a foreign language. On the other hand, Ronteltap and Eurelings (2002) find that the use of synchronous and asynchronous communication tools central to a dPBL course has strong positive effects on collaborative learning and may lead to a deeper level of information processing and increased opportunity for tutor interaction and feedback.

Keeping these points in mind, a PBL/LSP module should accommodate larger heterogeneous groups of students (five to eight, for example) that, in addition to meeting face-to-face, also make extensive use of synchronous and asynchronous communication tools in order to extend group participation, ease coordination problems, and foster higher degrees of tutor and instructor interaction. The use of digital communication tools also will allow for the participation of smaller foreign language departments, which may not be able to support a PBL/LSP program on their own. Similar to an actual working environment, students remain with a group for the duration of the semester and do not switch groups with the completion of a module.

Future research on PBL/LSP small-group learning could address student learning outcomes in a distributed versus onsite format, the efficacy of current communication and collaboration tools in supporting a communication-intensive PBL/LSP environment, the effect of a dPBL environment on foreign language acquisition, and the use of synchronous and asynchronous communication tools to develop metacognitive strategies in students.

Tutor as Facilitator or Guide

In problem-based learning, a tutor is present to lead students in the appropriate direction without prescribing instruction. Barrows (1996) describes the role of the tutor in terms of what he or she *does not* do:

> it was someone who did not give students a lecture or factual information, did not tell the students whether they were right or wrong in their thinking, and did not tell them what they ought to study or to read. (p. 5)

Moust, de Grave, and Gijselaers (1990) are more explicit in their description of the role of the tutor, depicting it as a person who monitors and criticizes the reasoning skills of the students, facilitates the cognitive processes of the students through probing questions, indirectly stimulates deeper analysis of the topic, and acts as an intermediary between faculty and students. Who the tutor is, however, is open to some debate. Berkson (1993) describes the tutor as a nonexpert in the field who simply facilitates the learning process and does not provide specific content information; it comes as no surprise, therefore, that she criticizes these tutors as ultimately undermining the educational effectiveness of PBL instruction. Others have expanded the role of the tutor to include faculty instructors or even advanced students in the field of study (Distlehorst & Robbs, 1998; Moust, de Grave, & Gijselaers, 1990).

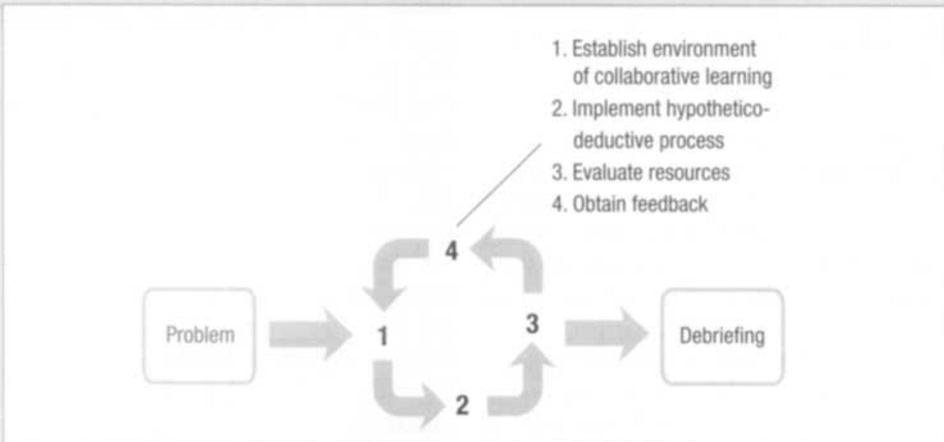
Ideally, given that the role of the tutor in a PBL setting is radically different from other types of teacher-centered instructional paradigms, tutors should undergo a training session prior to participation as group moderators. Moust, de Grave, and Gijselaers (1990) outline a two-stage workshop that occurs several times a year. The first stage is an introduction to the principles of problem-based learning and the pedagogical role of tutors. Three weeks later the tutors participate in another workshop in which they play the role of students and personally experience problem-based learning. Distlehorst and Robbs (1998) describe a one-week intensive workshop in which tutors first learn about PBL, then participate as students, and finally function as tutors in training.

The tutorial session itself can take many forms but is primarily directed at inculcating in learners the reasoning processes and skills of experts in the field. In this sense, the tutor acts as a more capable peer who assists the learner in negotiating his or her zone of proximal development and fosters capabilities in the learner that are in the process of maturation (Vygotsky, 1978). Distlehorst and Robbs (1998) outline a four-step tutorial process that first establishes an environment of colearning; implements a hypothetico-deductive process to reason through the presented problem; identifies and evaluates potential resources that can be used by the learners; and finally feeds the knowledge and information gained through the self-directed learning back into the problem for further analysis or to achieve integration, abstraction, and transfer (see Figure 2). This feedback loop can occur for several iterations or only once. To determine the efficiency and success of the instruction, tutors generally assess student performance against preestablished criteria identified in the instructional design process (Jones, Bieber, Echt, Scheifley, & Ways, 1984).

The role of tutor and the operation of the tutorial session in a PBL/LSP module require further examination, specifically the competency of the tutors and instructors. Von Reinhart (2001) notes that many of the faculty involved in teaching specialized language classes hold advanced degrees in either literature or linguistics, and accordingly feel uncomfortable when teaching language courses with a heavy emphasis on science and technology. Because language instructors generally will be unable to devel-

FIGURE 2

PBL/LSP Small-Group Tutorial Cycle



op scientific and technological instruction on their own, and engineering instructors most likely will be unable to do the same in the target foreign language, close collaboration between the two areas is a prerequisite for a successful PBL/LSP module. The second point to consider is how this collaboration will be expressed in the tutorial session. Unlike traditional PBL courses that have a single topic, a PBL/LSP module will have two: the target foreign language *and* engineering. This essentially doubles the amount of tutor training that needs to be conducted and raises the question of how the problem space will be parceled and managed so that both its linguistic and engineering aspects receive sufficient attention.

A possible way to overcome this problem is simply to divide the problem space into two tracks. The first track deals primarily with the technical skills required for a successful solution of the engineering problem (e.g., hypothesis generation, application of formulas, experiments, data collection), while the second track develops the linguistic skills necessary for the successful management of the problem (e.g., division of labor, forms and papers, research documents, team communication skills, reporting, specialized vocabulary). If the module is divided in this manner, tutors can focus on areas in which they have pedagogical expertise or academic background, although collaboration between tutors will be necessary to ensure smooth operation. Points of interaction between the linguistic and engineering tracks most certainly will occur and must be handled on a case-by-case basis (see Figure 3).

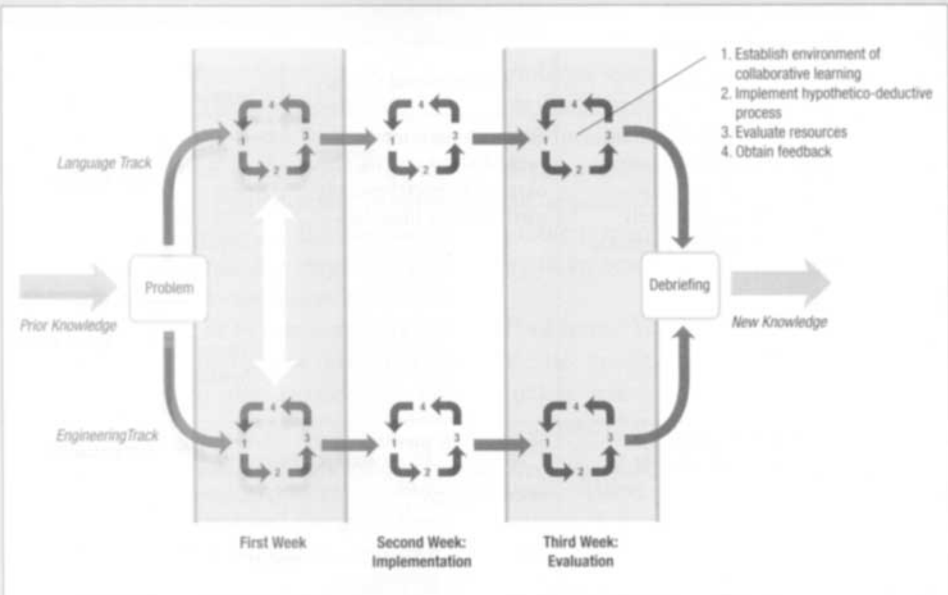
Areas of potential research on the role of the PBL/LSP tutor include the format, length, and frequency of tutor training; the development of pedagogical materials for use by the tutors during instruction; strategies for facilitating collaboration and contact between tutors; alternative divisions of the problem space between tutors; and the pedagogical approach to foreign language acquisition (e.g., communicative) used by the tutors.

Problems Precede the Learning Sequence

Instead of equipping students with the necessary information required to solve the problem before entering the problem space, PBL enters the problem space at the outset and then works toward a synthesis of problem-solving knowledge. Barrows (1996) describes PBL problems as being very similar to what students will encounter in real-world practice and, in an earlier article

FIGURE 3

The Division of the Problem Space Into Language and Engineering Tracks



(1986), describes two types of problem spaces as being appropriate for problem-based learning: the case history or vignette and a type of diagnosis-solution problem (cf. Benitez, 1996).

Because a PBL/LSP module must prepare students for employment in engineering fields in which team research and cooperation play a primary role and outcomes are generally unpredictable, the types of problems more suitable for these environments would be those that Jonassen (2000) classifies as design problems and dilemmas. Design problems are characterized "as ill-structured because they have ambiguous specifications of goals, no determined solution path, and the need to integrate multiple knowledge domains" (p. 80); dilemmas, on the other hand, are "the most ill-structured and unpredictable type [of problem] because often there is no solution that is satisfying or acceptable to most people, and there are compromises implicit in every solution" (p. 80). Although, in the strictest interpretation of Jonassen, one could argue that PBL/LSP students are not "designing" anything since no physical artifact is produced, this interpretation is too narrow. The design and application of abstract solution paths also can be included under the rubric; very often these solution paths will be the product of complex negotiation between groups of people with conflicting interests and diverging interpretations of the problem set (see Jonassen, 1997). Problem-based learning scenarios can include both types of problem spaces and frequently blend the two.

A PBL/LSP module is shaped by essentially two problem spaces: the primary, or larger, space that gives structure to the semester and provides the story connecting all the modules, and the secondary, or smaller, space that is obtained by deconstructing the primary space into constituent components that can be handled within the framework of a three-week module (see Figure 1). The primary problem space would generally be presented on the first day of the semester and assumes the form of an introductory narrative that sets the stage for the semester, allows students to organize themselves into groups, and gives students a general direction in which to proceed. The secondary problem space would be a task or problem

TABLE 2

Overview of a Sample PBL/LSP Semester

(cf. Figure 1)

Module	Subject	Instructional Goals	Artifacts and Supplemental Activities
1.	Introduction to hemodialysis and related human physiology; articulation of problem space and development of potential solutions	Historical development of hemodialysis and its physiological impact; research methods and materials	8- to 10-page team design brief in German; 3- to 5-page student paper in German on the history of hemodialysis and its physiological impact; student and team journals; biological engineering and German quizzes; module debriefing
2.	Short- and long-term hemodialysis complications	Sterilization methods, bacteria, biocompatibility, and microbiology	3- to 5-page student paper in German on bacteria and sterilization methods; student and team journals; biological engineering and German quizzes; module debriefing
3.	2D membranes and 3D hollow fibers	Modeling and optimization of design; material science, mass transport, ultrafiltration, and surface chemistry	3- to 5-page student paper in German on ultrafiltration and surface chemistry; student and team journals; site visit or virtual tour of Fresenius Medical Care North America; biological engineering and German quizzes; module debriefing
4.	FDA; economics and health care; future of hemodialysis and regenerative medicine; intellectual property and patents	Macrolevel analysis and economic feasibility; cell cultures	8- to 10-page team project summary in German; 3- to 5-page student paper in German on German health care system; student and team journals; video; biological engineering and German quizzes; module debriefing
5.	Capstone experience	Synthesis of prior knowledge	8- to 10-page team capstone summary in German; student and team journals; semester debriefing

that must be immediately addressed by the team. Table 2 details the primary problem space and its subdivision into five three-week modules dealing with key elements of a core biological engineering course and hemodialysis.

Upon entering the classroom for the first time, students are given a copy of the introductory narrative, preferably in the target language, outlining the primary problem space and a description of the secondary problem space that will be explored during the course of the three-week module. The assignment could be on company letterhead with other corporate materials to lend authenticity to the experience. For example:

> Recently having graduated from college with a double major in biological engineering and German, you have landed a position as research colleague and project coordinator at Fresenius AG, an international medical research company based in Bad Homburg, Germany, and a provider of dialysis products and services for patients with End-Stage Renal Disease (ESRD). You will be a member of a team that liaises between the Ogden, Utah, manufacturing site and the main office in Bad Homburg. The Ogden site develops and produces peritoneal dialysis solutions and dialyzers, including the Optiflux dialyzer family, a new class of dialyzers with an exceptional clearance performance that remove toxic substances from the blood during dialysis treatment.
>
> In addition to organizing the team that will research the feasibility of new dialysis membranes, your other short-term goals will be to put this research into a historical and physiological framework, evaluate potential resources in the development of these membranes, and report on experiment results. Your first design brief is expected in Bad Homburg in three weeks. In addition, you will be competing with other design teams for approval of limited company research and development resources.

Areas of potential research on PBL/LSP learning sequences include the type of problem space most amenable to PBL/LSP, methods of collaboration between industry and foreign language programs in order to develop realistic instruction, and pedagogical approaches to structuring the primary problem space to foster a sense of authenticity in an academic environment.

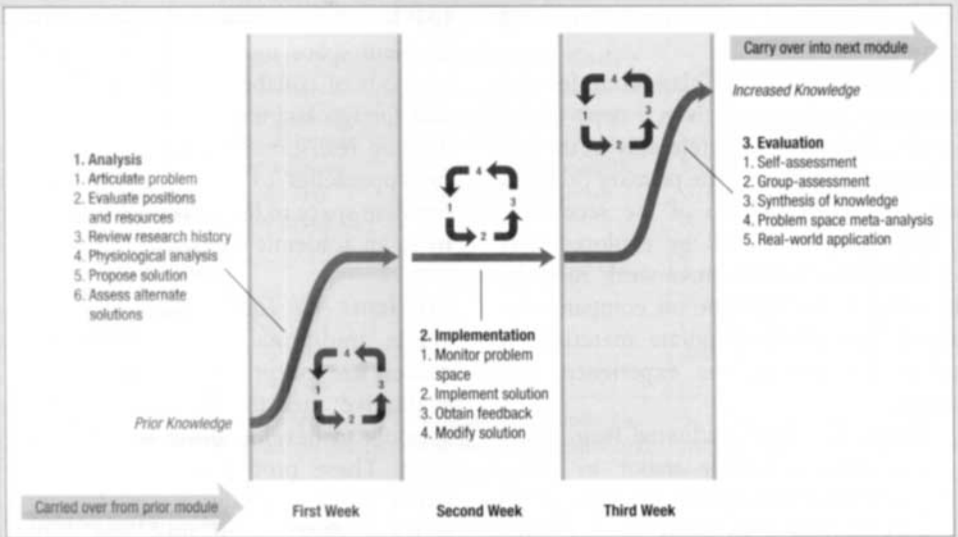
Problems Are Tools

While traditional classroom instruction makes use of problems primarily as an evaluative measure, PBL uses problems as tools to develop problem-solving schemata. These problems can be structured either as a stand-alone scenario or as a series of interrelated problems requiring the repeated application of the same mental schema to reach a solution. Byrnes (2001) notes that the latter type of problem structure encourages the decontextualization of student knowledge, enabling more ready transfer to related problem spaces.

Although ill-structured problems very rarely have a single best solution on account of numerous solution paths that can be explored, Jonassen (1997) outlines seven steps that facilitate the development of metacognitive strategies. These steps include: (1) the articulation of the problem space, which will by nature be highly contextualized and emergent, and the identification of primary problem components; (2) the identification of alternate opinions, positions, and perspectives of stakeholders; (3) the generation of possible solutions, including their logical outcomes, and the construction of mental models of the problem that can undergo preliminary testing; (4) the assessment of alternative solutions and the construction of arguments for and against the proposed solution; (5) the continual monitoring of the problem space and the defined solution options in order to determine if the proposed solutions remain valid; (6) the implementation and monitoring of the solution;

FIGURE 4

The Analysis-Implementation-Evaluation Cycle of a PBL/LSP Module, Including the Four-Step Tutorial Process



and (7) obtaining feedback and adapting the solution.

A PBL/LSP module could distribute this model over Weeks 1 and 2, with Week 3 being devoted primarily to the synthesis of metacognitive strategies and knowledge that can be carried over into the next module. Synthesis would be fostered through module debriefing sessions (Steinwachs, 1992; Thiagarajan, 1993). Weeks 1 and 3, the analysis and evaluation periods of the module, rapidly build student knowledge and metacognitive strategies, while Week 2, the implementation period, provides students the opportunity to test whether their knowledge and metacognitive strategies are accurate. Small-group interaction for all module weeks is modeled on the four-step tutorial process described by Distlehorst and Robbs (1998), resulting in a nested metacognitive architecture that is both reiterative and ascending in nature (see Figure 4).

Because PBL problems are used primarily as a learning tool and not for assessment, a PBL/LSP module also has to provide a means whereby student progress and learning can be measured. Both quantitative and qualitative evaluation measures should be included. A quantitative evaluation lends itself to easy statistical interpretation and can be used to provide a quick overview of general course trends such as mastery of topic-specific vocabulary, relevant grammar structures, and necessary engineering equations. In order to assess how well students understand a topic and can transfer knowledge to new situations, a qualitative evaluation should be administered. Mayer (2001) outlines several qualitative evaluation strategies that could be adapted for use in a PBL/LSP module: the use of conceptual questions, which require the learner to uncover an underlying principle of the problem space; redesign questions, which require the learner to redesign the problem space in order to accomplish a given function; troubleshooting questions, in which the learner must determine why failure is present in a problem space; and prediction questions, in which a learner must determine what will happen in a problem space given certain circumstances. In addition to these qualitative evaluation strategies, PBL/LSP instructors must learn to rely on student journals or instructional artifacts to uncover the thought process of students during the problem-solving stages.

Areas of potential research on PBL/LSP problem-solving schemata include alternative pedagogical architectures to foster the development of metacognitive strategies, as well as the use of different qualitative and quantitative assessment procedures to measure their effectiveness.

Self-Directed Student Learning

The final facet of PBL, self-directed student learning, can be considered the additive of the points outlined above. Because learning is student-centered and occurs in small groups, and because the role of teacher is replaced by tutors who direct students in the development of their own metacognitive strategies, this approach leads students to become independent thinkers, capable of assessing a problem and discovering on their own the resources that can be used in its solution. In this sense, PBL can be closely aligned with theoretical tenets of higher-order thinking, namely the capability of a subject-matter expert to recognize the fundamental characteristics of the problem at hand, reflect on solution options, implement the best option, evaluate the outcome of the implementation, and avoid reasoning biases (Byrnes, 2001). The self-directed learning fostered by PBL also has been observed to continue beyond the classroom setting, and it has been noted that students who participate in PBL curricula frequently remain better lifelong learners than students who participate in a traditional curriculum (Barrows & Tamblyn, 1980; Doucet, Purdy, Kaufman, & Langille, 1998; Schmidt, 1993.).

In order to assess the long-term efficacy of PBL/LSP modules, instructors and administrators must develop a sense of responsibility for students that extends beyond the academic environment. Although admittedly difficult to implement due to administrative concerns, a PBL/LSP course should not conclude with the termination of the semester but rather naturally progress into an internship with a company. Fostering long-term relationships with industry will not only determine how well interns and graduates of a PBL/LSP program do in a realistic setting, which will provide needed data for the continued success and legitimacy of the program, but may also provide needed sources of funding for the program in addition to external grant monies. PBL/LSP instructors and administrators must be savvy and entrepreneurial enough to seek these opportunities on their own and leverage the university Industrial Advisory Board, or a similar unit, for the purpose of providing internships and company tours.

Part II: PBL/LSP Module Development

Part II of this article outlines the development of an introductory PBL/LSP module that teaches hemodialysis and associated subtopics to undergraduate biological engineering and German language students. This scenario, which was introduced in Part I, is presented under the context of designing, preparing, and characterizing hemodialysis membranes for a parent company in Germany, thus requiring project-specific German language proficiency in addition to the necessary biological engineering and science skills. Space limitations prevent full articulation of the development model, although the steps outlined below are detailed enough to apply to other areas of module development. Again, although the topic of hemodialysis is extremely specialized, it is hoped that this approach serves as a developmental model for other, perhaps more general, engineering topics and a catalyst for interdepartmental collaboration.

Adapting Dick, Carey, and Carey (2001) as the instructional system design model for the PBL/LSP module, we focus on the development of six essential areas: (1) the articulation of an instructional goal for the module; (2) an in-depth analysis of the instructional goal, including the required steps and substeps that a subject-matter expert in the field would be expected to take for successful resolution of the problem; (3)

an identification of the prerequisite subordinate skills and knowledge that a subject-matter expert would need in order to undertake these steps; (4) an analysis of the learners and contexts in which the instruction will be applied, including the abilities of the learners prior to instruction and encompassing the professional area in which the skills eventually will be applied; (5) a description of the module performance objectives; and (6) the development of assessment instruments to measure knowledge retention and transfer.

Instructional Goal

Instructional goals, according to Dick, Carey, and Carey (2001), are "clear statements of behaviors that learners are to demonstrate as a result of instruction" (p. 30). Although we can prescribe these goals during the initial design process, the freedom characteristic of a PBL environment allows students to pursue tangential or alternative problem solution paths. Therefore, instructional goals, at best, can provide only a nonbinding pedagogical framework. These goals, however, are absolutely critical because they clearly delineate the range of possible student activity and offer a measurement against which to assess student performance. Since the knowledge that students develop in a PBL/LSP module may manifest itself only in latent mental schemata–and not observable behavior–it is important to adjust assessment strategies accordingly. Assessment instruments based on a strict behaviorist interpretation of the instructional goals may incorrectly indicate a lack of effective learning.

While the development of biological engineering skills forms the technical backbone of this PBL/LSP module, the linguistic and interpersonal skills necessary for drafting the design brief help create the dramatic backdrop that can flesh out the module and situate it in a real-world context. Keeping in mind that we are dealing with two disparate skill tracks that will have to be developed, we formulated the following instructional goal for the module:

> Having conducted research on the historical development of hemodialysis and the physiological impact it has on the human biological system, students will evaluate hemodialysis membranes and then prepare a design brief in German.

Analysis of the Instructional Goal

The analysis of the instructional goal is a more thorough description of the steps that a subject-matter expert would follow in order to solve the problem successfully. For the hemodialysis module, these steps are: (1) conduct research on the historical development of hemodialysis, (2) conduct research on the physiological impact of hemodialysis, (3) evaluate hemodialysis membranes, and (4) prepare a design brief (see Figure 5).

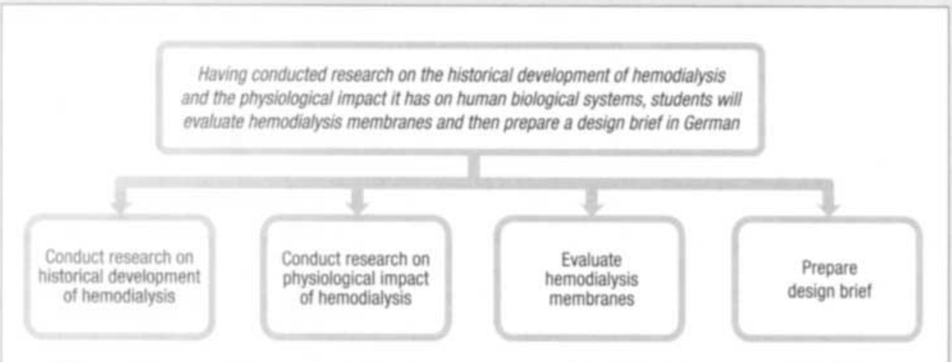
It cannot be emphasized enough that although these steps represent one solution path that a subject-matter expert could pursue, it is by no means the only solution path; students may very well decide, based on their (mis)interpretation of the presented problem space, to follow these steps in a different order or to pursue entirely different solution paths. From the viewpoint of the instructors, however, the analysis of the instructional goal is important for five primary reasons: (1) it develops a standardized rubric against which student performance can be measured and evaluated, (2) it targets possible assessment areas (e.g., criterion-referenced assessment, schema construction and transfer), (3) it outlines topics for potential tutorial sessions, (4) it identifies areas of instruction that may be handled better through the application of behaviorist instructional strategies (e.g., the rote memorization of topic-specific vocabulary), and (5) its suggests how the problem space can be subdivided in order to fit within the three-week time period.

Identification of Subordinate Skills and Knowledge

The next step in the instructional design process is the identification of the subor-

FIGURE 5

Goal Analysis of Hemodialysis Module



dinate skills and knowledge necessary to accomplish the steps identified in the analysis of the instructional goal. A hierarchical analysis of these steps deconstructs them to the point that no further subordinate skills and knowledge can be identified.

Normally, after conducting the hierarchical analysis and eliminating superfluous tasks, the instructional designer determines which skills are entry behaviors for the problem space and which will become final components of the instruction. A PBL/LSP module, however, makes no distinction between these types of skills since the problem space, by necessity, is ill-structured and ill-defined. Although the educational context of the module instruction obviously entails some type of course prerequisites, students themselves are solely responsible for determining the necessary subordinate skills and prerequisite knowledge. Students also should be allowed to cull excess module information on their own as this filtering process is necessary for students to experience as they develop their own metacognitve problem-solving strategies. Figure 6 depicts a suggested hierarchical analysis of the historical development of hemodialysis; other components of the instructional goal will not be shown for the sake of brevity. Steps in Figure 6 with hatched shading suggest areas that are covered both in English and German in the tutorial sessions, whereas the fully shaded steps are those that are covered only in German.

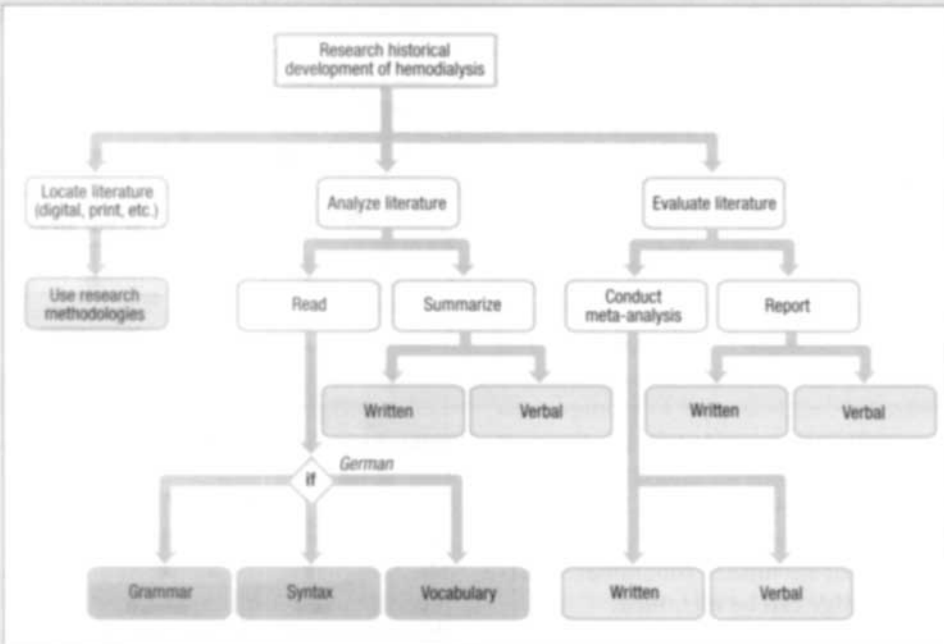
Analysis of Learners and Contexts

This step of the hemodialysis module design process tunes instruction more closely to the needs and capabilities of the students so that it has the greatest probability of being pedagogically effective. Students using the module, although they may have advanced in the same program and possess similar academic backgrounds, will be sufficiently dissimilar in terms of how they respond to the pedagogical environment, their motivation in the subject matter, and their knowledge of the topic area. The analysis of learners and contexts, therefore, serves as an instructional check and balance system, ensuring that the plans of the instructor do not outstrip the capabilities of the students or that the instruction is irrelevant for the workplace setting. If at all possible, test learners and students should be directly included in the design process itself from the very beginning.

For the sake of our PBL/LSP module development, we outline in Table 1 assumed learner and context characteristics that are loosely based on the learner and context analysis suggested by Dick, Carey, and Carey (2001). Many of these categories need to be further refined through data collection, learner surveys, and corporate collaboration.

FIGURE 6

Hierarchical Analysis of the Historical Development of Hemodialysis



Target population characteristics suggest that students participating in a model such as this will have intermediate competency in German, with low proficiency in reading and writing, and be skilled in fundamental chemistry, biology, physics, and calculus, as well as core engineering courses. Students may possess a rudimentary understanding of hemodialysis. It is assumed that all students will possess the same biological engineering background. Some students, due to prior experience living abroad, may be more fluent in German than other students. When organizing the PBL/LSP small groups, therefore, it is important that linguistic proficiency be spread out among the groups; pretests or surveys may have to be administered to determine student linguistic proficiency and time spent living abroad. In addition, instructional scaffolding (e.g., textual preorganizers, vocabulary self-assessments, organizational flowcharts for writing assignments) must be present to help students increase their proficiency in reading and writing German.

As tutorial sessions take place only biweekly, it is necessary to extend small-group interaction through digital communication technologies. It is anticipated that biological engineering students will be more comfortable working collaboratively in small groups than German language students. Some equipment, such as the spectrophotometer, will be similar to what students will use in the workplace; other features of the workplace, however, cannot be replicated easily in an academic setting. Therefore, it is very important to establish a sense of realism by providing PBL/LSP students with corporate realia such as official forms and documents. To simulate the team environment typical of the workplace, students should remain in their groups for the duration of the project.

Module Performance Objectives

Performance objectives are based on the description of the instructional goal with the added criteria of behavioral assessment, the conditions under which the behavior is performed, the parameters of correct performance, and the criterion used to measure this performance. For the hemodialysis module, performance objectives are subdivided into three areas: analysis (history of hemodialysis and its physiological impact), implementation (preparation and evaluation of hemodialysis membranes), and evaluation (design brief preparation). For the sake of space, only the analysis performance objectives are detailed here:

> Given appropriate training in research methodologies and five bibliographic references of biological engineering journals in the German language, students will locate five additional journal references and five articles dealing with the topic of hemodialysis. Working together in predefined small groups and using the resources they have located, students will write a 3- to 5-page paper in German on the history of hemodialysis and fundamentals of renal physiology. As determined by criteria formulated in advance by the PBL/LSP tutors, the paper will manifest correct use of German vocabulary and syntax as well as demonstrate an in-depth understanding of historical development of hemodialysis and its physiological operations. In addition, students will demonstrate mastery of basic biological engineering knowledge and German vocabulary and grammar through onsite and online quizzes with a score of B or higher.

Development of Assessment Instruments

The final step, the development of assessment instruments for the hemodialysis module, should include two elements: (1) PBL instruments that measure the transferability of knowledge and development of metacognitive strategies and (2) non-PBL instruments that measure how well recurrent or rote aspects of module activity have been automated. PBL assessment instruments focus primarily on qualitative measurements that must be subjectively evaluated by PBL/LSP instructors and tutors according to predefined parameters. For the hemodialysis module, students should demonstrate transferability of knowledge during the module debriefing by answering predefined conceptual, redesign, troubleshooting, and prediction questions in German and English; delivering a student journal at the conclusion of each module; and preparing a design brief that demonstrates meta-analytic and project management skills.

Non-PBL assessment instruments are more in line with traditional assessment instruments and normally include criterion-referenced quizzes and tests, for both the target foreign language and biological engineering; essays evaluated primarily for linguistic or factual accuracy; and homework assignments that focus on the automation of specific skill subsets and knowledge (e.g., dative prepositions in German, biological engineering equations). For the hemodialysis module, students take criterion-referenced quizzes on German and biological engineering, submit homework assignments on German grammar derived from the provided hemodialysis articles, write two short essays in German on the history of hemodialysis and its physiological impact on the human body and the mechanical operation of hemodialysis membranes, and prepare a design brief in German. The essays and design brief must manifest grammatical and syntactical correctness and demonstrate a solid grounding in the mechanical operation of hemodialysis membranes.

Finally, because the motivation level of the learners is essential in determining the success of the instruction, assessment instruments based on the ARCS model (attention, relevance, confidence, and satisfaction) should be used (see Keller, 1987). In the hemodialysis module, a short ARCS survey for students is administered during the debriefing session.

PBL/LSP Modules: Future Directions

PBL/LSP modules hold the potential to create an exciting and interesting course of study for foreign language students. Students who use these modules are presented with challenging and extended research scenarios that require them to synthesize their linguistic and academic skills into a cohesive whole and develop operational schemata that could be transferred from an academic to a professional setting. A problem-based LSP module is also excellent preparation for an academic or professional internship in countries where the target language is spoken. Areas of potential difficulty regarding the development and implementation of such modules include faculty training, cost, student preparedness, pedagogical integrity of the materials, and delivery method. Although the development of problem-based LSP materials may prove problematic at the individual level, current Web-based collaboration technologies offer the hope of developing and delivering these materials as a collaborative group effort. In this manner, the responsibilities and rewards of such development will be shared equally by foreign language departments nationwide and internationally, possibly turning the tide on declining enrollments and lagging student interest. Working together, foreign language departments and industry could devise a set of authentic problem-based LSP materials that would allow students to explore how their target foreign language and academic interests come together in a manner directly pertinent to the real world.

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