Rich environments for active learning

in action: problem-based learning

Scott Grabinger,* Joanna C. Dunlap** and Judith A. Duffield*

*University of Colorado at Denver, USA
**Regis University, USA

Rich Environments for Active Learning (REALs) are comprehensive instructional systems that are consistent with constructivist theories. They promote study and investigation within authentic contexts; encourage the growth of student responsibility, initiative, decision making and intentional learning; cultivate collaboration among students and teachers; utilize dynamic, interdisciplinary, generative learning activities that promote higher-order thinking processes to help students develop rich and complex knowledge structures; and assess student progress in content and learning-to-learn within authentic contexts using realistic tasks and performances. Problem-Based Learning (PBL) is an instructional methodology that can be used to create REALs. PBL's student-centred approach engages students in a continuous collaborative process of building and reshaping understanding as a natural consequence of their experiences and interactions within learning environments that authentically reflect the world around them. In this way, PBL and REALs are a response to teacher-centred educational practices that promote the development of inert knowledge, such as conventional teacher-to-student knowledge dissemination activities. In this article, we compare existing assumptions underlying teacher-directed educational practice with new assumptions that promote problem solving and higher-level thinking by putting students at the centre of learning activities. We also examine the theoretical foundation that supports these new assumptions and the need for REALs. Finally, we describe each REAL characteristic and provide supporting examples of REALs in action using PBL.

In 1995, ALT-J published an article titled 'Rich Environments for Active Learning: a definition' (Grabinger and Dunlap, 1995). This present contribution builds on the concepts discussed in that initial article by using PBL as an example of REALs. Though REALs are defined briefly here, readers are encouraged to consult the first article for a more thorough defining discussion.

Changing educational needs

Learning and the information explosion

In today's complex world of rapid change, of increasing innovation and of proliferating knowledge, employers and employees must be able to apply tools and knowledge to new situations with increasing frequency to remain productive and competitive (see Nash, 1994). Because we face an environment in which knowledge and skills become rapidly obsolete, people need to know how to be involved in a continual process of 'retooling' their knowledge

and skill base (see Swanson *et al*, 1993). Consequently, learning to think critically, to analyse and synthesize information to solve technical, social, economic, political, and scientific problems, and to engage in lifelong learning, are crucial for successful and fulfilling participation in our competitive society. Learning environments which prepare learners for the complexities of the professional world utilize instructional activities reflecting the problem-solving and challenge-meeting process professionals use on their jobs. Learners need to:

- determine for themselves what issues need to be addressed when facing a new problem;
- identify knowledge and skills they already possess that can be applied to the situation;
- determine which skill and knowledge areas are deficient, and create learning plans to address those deficiencies;
- create timelines, manage resources, and monitor their progress;
- apply what they know to problems that may change substantially from one moment to another; and
- assess their performance and make changes in personal processes for use to meet subsequent challenges.

The instructional activities in which learners need to be engaged require them to take personal and active roles in all aspects of the knowledge construction and problem-solving processes. A learning environment that places students in the driver's seat of the learning process – involving them in the planning, controlling, and directing of learning activities and the application and assessment of learning processes and outcomes – is the essence of a REAL – a Rich Environment for Active Learning (Grabinger and Dunlap, 1995). See Figure 1.

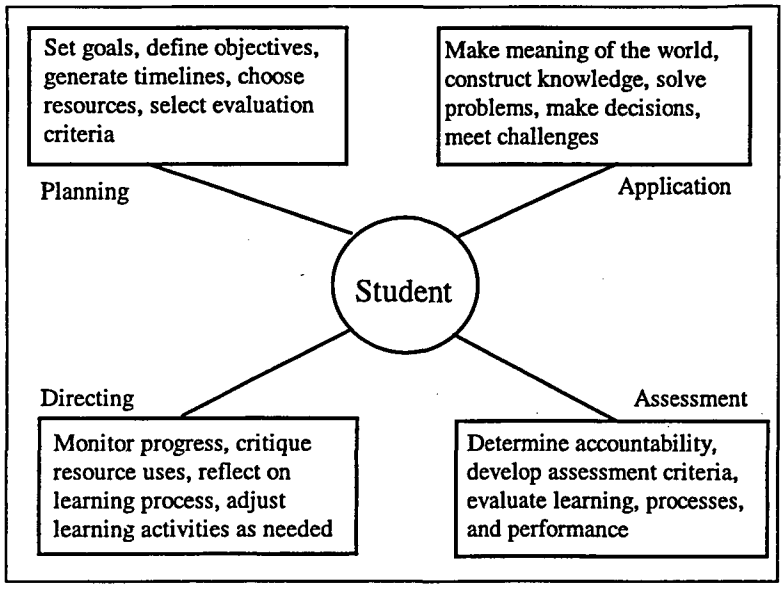

Figure 1: Preparing students for the workplace – a student-centred model

The purpose of this article is to use Problem-Based Learning (PBL) to describe the criterial elements of REALs, including the theoretical foundations and instructional strategies. We shall

begin with definitions of REALs and PBL, then move on to a description of the attributes of REALs and how PBL uses those attributes.

Rich Environments for Active Learning

Purpose of REALs

Conventional instruction often utilizes simplified, decontextualized examples and problems (Collins *et al*, 1991) leading to an inadequate understanding of and ability to apply the understandings developed. Bransford *et al* (1990) state that 'the basic problem is that traditional instruction often fails to produce the kinds of transfer to new problem-solving situations that most educators would like to see'. Because the information presented to students has no relevance or meaning for them, they tend to treat new information as facts to be memorized and recited rather than as tools to solve problems relevant to their own needs. This type of teacher-centred instructional practice, unfortunately, leads to inert knowledge (Whitehead, 1929) – knowledge and skills that cannot be applied to real problems, situations, and challenges.

If we intend to avoid the production of inert knowledge and to prepare our students to stay current in their fields once they have left the classroom environment, we must engage them in the types of knowledge-construction and problem-solving activities and thinking and learning processes they will be expected to engage in once they are on the job. The learning environment needs to involve them in activities that allow them to plan, control, drive, and assess their own learning activities and apply what they have learned to new challenges.

Characteristics of REALs

REALs are based on the constructivist values and student-centred strategies of 'collaboration, personal autonomy, generativity, reflectivity, active engagement, personal relevance, and pluralism' (Lebow, 1993, p. 5) – values and strategies that purposefully place students in active and directive roles over their own learning activities. The constructivist view of learning assumes that knowledge acquisition is a continuous personal process of building, interpreting, and modifying understanding as a natural consequence of experience in the world (Goodman, 1984; Bednar *et al*, 1991; Jonassen, 1994; Savery and Duffy, 1995); learning is not about the *acquisition* of new knowledge, but the constant *reconstruction* and refinement of what someone already knows (Forman and Pufall, 1988; Fosnot, 1989). To address the problem of inert knowledge, the constructivist view of learning promotes the development of learning activities that are embedded in a variety of authentic contexts, creating 'a rich web of memorable associations between them [concepts and facts] and problem-solving concepts' (Collins, Brown, and Newman, 1989, p. 457). Rather than starting the learning process with abstractions (a characteristic of traditional education), REALs develop abstractions from authentic experiences (Duffy and Grabinger, 1997) to create a rich understandings. Thus REALs possess a specific set of characteristics that need a specific set of instructional strategies and tactics to have the desired cognitive effects on learning. These characteristics are outlined below (for a more detailed discussion of them see Grabinger and Dunlap, 1995, and Grabinger, 1996).

- *Student responsibility.* Using self-directed learning activities, students are encouraged to identify their own deficiencies, to ask questions about their knowledge base, and to select and manage their learning activities.
- *Dynamic, generative learning.* Learning is essentially an act of active construction on the part of the student (Resnick, 1989) using authentic cognitive and physical processes.

- *Authentic contexts*. Students acquire content and skills through the resolution of realistic problems. Understandings that are developed in their realistic and complex situations are more easily retrieved when needed (Brown *et al*, 1989).
- *Collaboration*. Through collaborative group work and the accessing of a variety of resources, students experience and develop an appreciation for multiple perspectives, and learn important co-operative skills for functioning in society.
- *Reflection*. Thinking about learning experiences in terms of what one understands and how one learns is a critical feature of all instruction. Students must be able to analyse personal knowledge-construction processes and articulate why and how a learning task was completed or a problem was solved (Honebein, 1996).

In the following section, we will use PBL to illustrate how each of these instructional characteristics come into play in a REAL to meet our new educational goals.

Problem-based learning

PBL is a student-centred instructional methodology that teaches content and skills within a knowledge domain by using substantive, carefully-crafted authentic problems or challenges (Boud, 1985; Savery and Duffy, 1995) as the stimulus and focus for collaborative and self-directed student activity (Boud and Feletti, 1991). This differs from conventional classroom situations in which problems are used as culminating activities *after* the teacher has presented content. In a PBL environment, the teacher presents students with authentic, ill-structured problems *before* they receive any instruction. Students engaged in PBL investigate issues looking for appropriate connections across disciplines, grapple with the complexity of the problem, and use newly acquired and existing knowledge to generate solutions. During the process, students build substantial knowledge bases through increasingly self-directed study. Through collaboration with classmates, students refine and enhance what they know. When a solution is at hand, they present, justify, and debate solutions, looking for the best possible resolution to the problem.

We shall briefly describe the PBL process using the Network Use Problem shown in Figure 2.

Situation
GandD is a rapidly growing satellite TV company. It considers itself an enlightened company, encouraging an entrepreneurial spirit among its employees. It has a decentralized management style and manages by consensus.

You are a member of a special task force charged with developing policies for information use in the electronic age. Your main task for the last four months has been to review how people in the company use new information technologies, and to develop ethical and fair guidelines for their use. For example, you are going to examine use of copy machines, cell phones, fax machines, and the company network (intranet and Internet). The task force's first issue is the company network use including such things as email and Web surfing.

Challenge
Your task force is to develop a set of ethical and fair guidelines to govern the use of the network by employees and for monitoring of the network use by GandD. These guidelines will be sent to all company employees and administrators. You must present your guidelines in a five-minute oral report in two and one-half hours to the Vice President in charge of Human Resources.

Figure 2: The Network Use Problem

In the PBL process, the teacher is a tutor of the learning process. He/she designs problems or challenges that students use to direct their learning and thinking (read the *Challenge* in Figure 2). After presenting the problem in a way that encourages student ownership (read the *Situation* Figure 2), the team 'thinks through' the problem with the guidance of the tutor. In 'thinking through' the problem, students propose ideas and hypotheses for meeting the challenge. They test these ideas with each other and record them. For each idea the students generate, they develop one or more learning issues (what they need to know) that will help them refine, eliminate, or add to their ideas. The tutor stimulates these discussions by asking 'why' and 'how' questions to encourage students to think critically about their ideas. The tutor encourages students to restate, to summarize, and to ask for clarifications. After developing a set of ideas and learning issues, the team develops a plan for investigating each of the learning issues. There follows a period of self-directed learning where each member of the team selects and investigates the learning issues. Though each student may investigate only a portion of the learning issues, the team is responsible for ensuring that all students learn enough about all issues to be able to justify and defend the resulting solution to the challenge. After a period of self-directed learning, the team reassembles and again thinks through the problem bringing their new understandings to bear on their ideas. They evaluate their initial ideas, revise them, eliminate them, generate new ones, and generate new learning issues. The cycle repeats itself until a sound solution to the challenge is developed and presented.

Content learning and skills development in the domain occur as natural consequences of solving the problem. In fact, in a PBL environment students take on the roles of scientists, doctors, historians, programmers, engineers, advertising executives, mechanics, or any others which have a stake in the problem. Therefore, the students work with problems in an authentic manner that fosters reasoning, knowledge application, and lifelong learning skills.

PBL's application of REAL characteristics

Student responsibility and initiative

Creating autonomous, lifelong learners, REALs in general (and PBL specifically) teach students to manage their own learning: identify their learning needs, set learning objectives, select and employ learning strategies, identify and use appropriate resources, and assess their overall process. In a PBL environment, students build their own knowledge bases founded on personal learning needs and interests. To do this, students set goals, create action plans to achieve those goals, set milestones and deadlines, and identify and evaluate appropriate learning strategies. Palincsar (1990) and Scardamalia and Bereiter (1991) refer to this as 'intentional learning'. Students engaged in intentional learning are purposeful, effortful, self-regulated, and active learners (Palincsar and Klenk, 1992). To teach for intentional learning means to cultivate those general abilities that make it possible to become lifelong learners (Palincsar, 1990).

Student responsibility occurs throughout PBL. In the initial phase of the PBL process – referred to by Barrows (1985, p. 62) as 'reasoning through the problem and identifying educational needs in counterpoint' – students reason aloud through the presented problem, defining what they know and do not know, formulating hypotheses, clarifying understanding through negotiation, critiquing peers' comments about the problem, setting educational goals, and creating action plans to meet those goals. With tutor-coaching and scaffolding, these activities

help students develop the self-monitoring skills necessary to relate learning needs to their ideas and hypotheses.

During the self-directed study phase of a PBL activity, students carry out their action plans by engaging in self-study. They work out how long it will take to address an action plan item, create a timeline, determine the required resources, then implement the plan. They learn to assess the effectiveness of their plans and alter those plans when necessary. They learn to evaluate critically information sources and the information they are learning. They are able to stand aside and take a look at *how* they are learning in addition to *what* they are learning.

During the reflection and review PBL phase, students reflect on and summarize what they have learned, and discuss how it will be used during future problems. They work out contingencies, explore alternatives to their solutions, and determine ways to improve both the solutions and the process used to arrive at them. Students consciously recall and reflect on the learning that occurred while they were solving the problem, elaborate on that learning, and integrate it into their existing knowledge structures (Barrows, 1985). Because PBL focuses students' attention on their learning processes, this activity further builds the metacognitive skills needed for lifelong learning.

Dynamic generative learning activities

Students cannot construct or evolve their own learning without generating something through dynamic, meaningful learning activities. People who learn through active involvement create an 'increasingly rich implicit understanding of the world' (Brown *et al*, 1989, p. 33) and are more likely to use that learning (Adams *et al*, 1988; Lockhart, Lamon and Gick, 1988). Dynamic generative learning requires that students 'engage in argumentation and reflection as they try to use and then refine their existing knowledge as they attempt to make sense of alternate points of view' (CTGV, 1993, p. 16). Argumentation and discussion form the skeleton of PBL. Students are taught and encouraged to test their ideas with each other, to look for flaws in reasoning, and to marshal supporting facts for their ideas.

Dynamic generative learning requires a shift in the traditional roles of students and instructors. Teachers become facilitators and tutors of the learning process rather than presenters of knowledge. Students in REALs and PBL become active investigators, seekers, and problem-solvers working purposefully on a challenge. In generative learning, students apply the information they learn to authentic problems.

Generating ideas and materials is a necessary component of a PBL challenge. For example, students meet frequently in their teams to bring their self-directed learning to bear on the challenge. Their learning, listening, and discussion usually generate changes in how they think about the challenge and potential solutions. They must present their new understandings and learning to their team-mates clearly and concisely. This may require the generation of documents or displays. The final solution to a challenge is a product consistent with the context of the problem, for example a presentation before a Board, a new product for distribution, or a marketing plan for a business. PBL activities require students to generate overt representations of their learning and thinking from start to finish.

Authentic learning contexts

Another characteristic of REALs is that learning takes place within a context that requires use of authentic cognitive, psychomotor, and affective skills. An authentic context, such as a PBL

challenge or problem, incorporates as much fidelity as possible to what students will encounter outside the education system in terms of tools, complexity, cognitive functioning, and interactions with people (Williams and Dodge, 1992). Therefore, creating an authentic learning context means that students must be involved in contextualized, realistic activities that require realistic thinking, movement, and emotions.

Authenticity is an important part of a PBL for three reasons. First, realistic problems hold more relevance to students' needs and experiences because the students can relate what they are learning to problems and goals they see every day (Blumenfeld *et al*, 1993). Second, because the situations students encounter during learning are authentic and reflect the true nature of problems in the real world, they develop deeper and richer (indexicalized and conditioned) knowledge structures (Albanese and Mitchell, 1993), leading to a higher likelihood of transfer to novel situations. Finally, because complex problems require a team approach that provides natural opportunities for learners to test and refine their ideas and to help each other understand the content, PBL encourages collaboration and negotiation (Johnson and Johnson, 1979; Lowry and Johnson, 1981).

PBL challenges come from real situations: today's headlines, business and community problems, and student interests. The following examples describe two ways to present authentic activities using the PBL methodology (Savery and Duffy, 1995). Example 1 describes the 'grand problem' way of presenting a challenge to students. The 'grand problem' is presented in a summarized, problem-statement format that gives students the information they need to begin investigating and solving the problem (see also Figure 2). Example 2 describes a way of presenting PBL problems using authentic materials. The authentic materials present students with clues to the problem; students must determine what the problem is by examining the information from a number of different sources in much the same way as people gather clues from a variety of sources when they are on the job. These sources can be memos, interviews, statements of work, notes from meetings with clients, sketches and diagrams, and so forth. The power of this type of PBL problem presentation is that it engages students in authentic activity from problem identification to problem solution and implementation, allowing them to practise the types of problem-identification activities they will be expected to do on the job.

Example 1

The challenge statement: *many school district decision makers do not believe that instructional technologies play an important role in education today. In fact, the school Board is preparing a policy to prevent the expenditure of any more money for technology for 12 months. They will be voting on the policy next month. Your team of faculty from the district must create a 15-minute presentation that argues for or against their proposed policy.*

This particular example came from an article in a local paper in which a local school district was proposing just such a policy. The class members working on the challenge were teachers in a Master's degree program in information and learning technologies. The possibility of being confronted by such a proposal was authentic to them. The nature of the presentation included a time limit because the school Board limited arguments. In preparing the presentation, students had to look into how technology was used in their districts, define instructional technologies, and prepare an argument supporting or refuting the Board's proposed policy.

Example 2

For an undergraduate computer-programming course in which the course objectives were to

develop an understanding of the C++ language syntax and object-oriented design and programming techniques, PBL was used to structure student activity (Dunlap, 1996). Following PBL methodology, the course was designed to engage students in four different programming problems in which students met course objectives by solving problems. Spanning three to five weeks, each project required students to learn specific content and skills in order to develop viable solutions. Students were immediately placed in the role of C++ programmers for a contracting company. In this role, students were assigned client-based projects for which they were required to develop solutions. Each project was presented via authentic materials documenting the nature and requirements of the project. For example, in the second project students had to develop an electronic card catalogue system for a library that would allow searches to be conducted on the information in the library's main database. All of the project's requirements and constraints were contained in office memos, transcripts of interviews with library personnel, and newspaper clippings – emulating the way in which programmers in the business world often get their information from clients.

Each had four phases, reflecting Barrow's (1985) phases of the PBL process. The first phase – Problem Analysis – began with students examining the authentic materials. After students had had an opportunity to examine the authentic materials, the instructor created four columns on the whiteboard with the following headings: Ideas, Facts, Learning Issues, and Action Plan. Using these columns as a guide, the instructor helped students examine the authentic materials in such a way as to draw out the client's requirements. Students quickly generated ideas on what the solution might look like ('We will want to create classes for books, periodicals, films, and videos.') and factual information from the authentic materials ('The e-mail from "aschwartz" says the files will be pipe delimited.'). As the session progressed, learning issues were identified that would require additional study ('How does a list work?'). Finally, an action plan was developed to guide the students' activities so they could begin to solve the client's problem.

The second phases of each project – Project Design – involved students working together in groups of three to design a solution for the client while adhering to the requirements and constraints identified in the first phase. During the next two weeks, the class broke into their project teams to design an on-paper solution to the problem identified during Problem Analysis. Students worked together using a variety of resources, including books, online help, experts, instructor, Internet resources, and sample code. Towards the end of the two weeks, project teams shared their designs with each other to test their ideas, generate additional ideas, and verify or modify their understandings. At the end of each class period, the class reconvened to discuss previous learning issues, generate new learning issues, and update the action plan. These modifications to learning issues and action plan were made to the original four columns used in Phase 1.

After Project Design came the Project Development phase. The Project Development phase required each student to program the solution using the design created by the project team as a blueprint. Students spent time in class coding a solution to meet the client's requirements. Class meetings were used as an opportunity for students to discuss problems they encountered while coding, and to share the solutions they had developed to solve those problems. Periodically, the class as a whole was reconvened to address issues that the class was encountering and to update the action plan.

The final phase – Post Project Review – happened once students finished coding a solution.

This review was used to discuss the C++ and object-oriented techniques students used, share solutions and discuss possible alternatives, and to answer any lingering questions. It was also used as a time for students to reflect on the process itself, discussing what learning strategies they employed, what strategies worked and did not work, and what they would do differently when solving future programming problems.

In addition to the review that occurred during these four phases, an additional review component was incorporated. These were referred to as 'in-progress reviews'. At several points during the course of a project, the instructor would bring the class together as a whole to discuss issues related to project status, design and programming problems, and possible solutions. The in-progress reviews also encouraged students to reflect on the strategies they were employing and the effectiveness of those strategies, to reassess their status regarding personal learning issues, and to adjust their personal action plans if needed.

In the context of working on the problem, students often take on roles that lead to authentic decision making, such as those of engineer, policy maker, school Board member, or executive Boards. These roles help lend more authenticity to the problem, for learners must not only solve the problem, but also act consistently within the role they play. By engaging in authentic activities that reflect the work environment for which they are being prepared, students have an opportunity to practise applying knowledge and skills to new problems, improving their ability to transfer their knowledge and skills to future challenges.

Collaboration

Collaboration acknowledges the social nature of knowledge construction (Roth, 1990). 'All co-operative learning methods share the idea that students work together to learn and are responsible for one another's learning as well as their ownÓ (Slavin, 1991, p. 73). Working in peer groups helps students refine their knowledge through argumentation, structured controversy, and the sharing and testing of ideas and perspectives.

Collaboration plays several important roles in PBL. First, PBL employs collaboration to provide students with opportunities to see and hear how other students approach and solve problems. During the problem-analysis phase of PBL, students describe what they know and do not know about a problem and what they need to learn. Being able to determine learning needs and to plan a method of attack are important metacognitive skills for lifelong learners. Because students are working collaboratively during problem solving, their thinking processes – or metacognitive skills – are observable and therefore open for personal and peer assessment and refinement. Students test ideas, identify misconceptions, and challenge each others' thinking. Group participation means that the members must understand many different roles and viewpoints to gain additional insights to the problem.

Second, PBL problems are complex. Students may not be used to or able to tackle a realistic problem on their own. Students working together collaboratively can often successfully tackle problems that individual students working alone would not be able to handle; collaborative learning can 'give rise synergistically to insights and solutions that would not come about without them [the members of the collaborative group]' (Brown *et al*, 1989, p. 40).

Finally, collaboration develops important collaborative work skills. Students learn to work together in a give-and-take interaction rather than just dividing the workload. They learn to work in a team framework that emphasizes discussion, testing ideas, and revising ideas.

Reflection and review

If there one defining feature of REALs can be said to be more important than the others, it is reflection. Reflection activities are embedded into instructional activities to support both understanding and the development of metacognitive skills. Dewey (1933) described the value of reflection as a component of educated thinking. By reflecting on their activities, students abstract and summarize what they learn in terms of content and skills, and review how they solved a problem. Students need to move from the specific instance that the problem provides and abstract what is generalizable to other situations. They also need to examine the strategies, processes, tools, and resources they used, making personal recommendations for future use.

The final phase of a PBL activity is summary and integration of learning. If this phase is skipped or cut short, the full impact of students' PBL experience is lost. During this phase, students reflect on and summarize what they have learned and discuss how it will be used during future problems. They look for generalizable principles and understandings and discuss other scenarios and domains in which they may apply. In addition, the reflective activities that take place during PBL's review phase encourage students to make tacit cognitive and metacognitive activities overt so that they can assess and improve the activities. Having opportunities to reflect on metacognitive skill utilization is necessary if students are expected to develop these skills to the point of using them without prompting or guidance.

Conclusion

The information age is placing a premium on educated people who can think creatively and flexibly, solve problems, and make decisions within complex, ill-structured environments. Given these changes, we must modify our traditional assumptions about learning and education. These new assumptions require student-centred methods, techniques and strategies that encourage the development of student responsibility and the use of dynamic, generative, and authentic learning activities. PBL is an excellent example of a student-centred instructional methodology based on a constructivist view of learning. Enabling content acquisition and the development of problem-solving and lifelong learning skills, PBL provides a way for educators to adhere to the principles of a constructivist view of learning in order to prepare students to meet the demands of a changing workplace and society. And PBL fulfils the educational outcomes of REALs by involving students in learning activities that focus on (Barrows, 1985; Bridges, 1992; Schmidt, 1993; Gijselaers, 1995, 1995b; Savery and Duffy, 1995):

- the acquisition of an essential body of transferable knowledge and skills;
- the development of critical reasoning and problem-solving skills needed to meet new and novel challenges; and
- the development lifelong learning skills to extend or improve their knowledge and skills in order to remain contemporary.

References

Adams, L., Kasserman, J., Yearwood, A., Perfetto, G., Bransford, J. and Franks, J. (1988), 'The effects of facts versus problem-oriented acquisition, *Memory and Cognition*, 16, 167–75.

Albanese, M.A. and Mitchell, S. (1993), 'Problem-based learning: a review of literature on its outcomes and implementation issues', *Academic Medicine*, 68 (1), 52–81.

Barrows, H.S. (1985), *How to Design a Problem-based Curriculum for the Preclinical* Years, New York: Springer.

Bednar, A.K., Cunningham, D., Duffy, T.M. and Perry, J. D. (1991), 'Theory into practice: how do we link?' in Anglin, G.J. (ed), *Instructional Technology: Past, Present, and Future,* Englewood CO: Libraries Unlimited, 88–101.

Blumenfeld, P.C., Soloway, E., Marx, R.W., Krajcik, J.S., Guzdial, M. and Palincsar, A. (1991), 'Motivating project-based learning: sustaining the doing, supporting the learning, *Educational Psychologist,* 26 (3/4), 369–98.

Boud, D. (1985), *Problem-based Learning in Education for the Professions,* Sydney, Australia: Higher Education Research and Development Society of Australia.

Boud, D. and Feletti, G. (eds) (1991), *The Challenge of Problem-based Learning.* London: St. Martin's Press.

Bransford, J.D., Sherwood, R., Hasselbring, T., Kinzer, C. and Williams, S. (1990), 'Anchored instruction: why we need it and how technology can help' in Nix, D. and Spiro, R. (eds), *Cognition, Education, and Multimedia: Exploring Ideas in High* Technology, Hillsdale NJ: Lawrence Erlbaum, 115–42.

Bridges, E.M. (1992), *Problem-based Learning for Administrators,* Eugene OR: ERIC Clearinghouse on Educational Management.

Brown, J.S., Collins, A. and Duguid, P. (1989), 'Situated cognition and the culture of learning', *Educational Researcher,* 18 (1), 32–42.

Cognition and Technology Group at Vanderbilt (CTGV) (1993), 'Designing learning environments that support thinking' in Duffy, T.M., Lowyck, J. and Jonassen, D.H. (eds), *Designing Environments for Constructive Learning,* New York: Springer-Verlag, 9–36.

Collins, A., Brown, J.S. and Holum, A. (1991), 'Cognitive apprenticeship: making thinking visible' *American Educator,* Winter (6–11), 38–46.

Collins, A., Brown, J.S. and Newman, S.E. (1989), 'Cognitive apprenticeship: teaching the crafts of reading, writing, and mathematics' in Resnick, L.B. (ed), *Knowing, Learning and Instruction: Essays in Honor of Robert Glaser,* Hillsdale NJ: Lawrence Erlbaum, 453–94.

Dewey, J. (1933), *How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Processes,* Lexington MA: D.C. Heath.

Duffy, T. and Grabinger, S. (1997), *An Introduction to Problem-based Learning* (presentation to Ferris University).

Dunlap, J.C. (1996), *The Relationship of Problem-based Learning to Life-long Learning* (unpublished manuscript).

Forman, G., and Pufall, P. (eds) (1988), *Constructivism in the Computer Age.* Hillsdale NJ: Lawrence Erlbaum.

Fosnot, C. (1989), *Inquiring Teachers, Inquiring Learners: A Constructivist Approach for Teaching,* New York: Teacher's College Press.

Gijselaers, W. (1995), Handout presented at the Educational Innovation in Economics and Business Administration (EDINEB) Conference, Ohio University, Athens OH.

Goodman, N. (1984), *Of Mind and Other Matters*, Cambridge MA: Harvard University Press.

Grabinger, R.S. (1996), 'Rich environments for active learning' in (no editor), *Handbook for Research in Instructional Technology*, New York: Macmillan.

Grabinger, R.S., and Dunlap, J.C. (1995), 'Rich environments for active learning: a definition', *Association for Learning Technology Journal*, 3 (2), 5–34.

Honebein, P.C. (1996), 'Seven goals for the design of constructivist learning environments' in Wilson, B.G. (ed), *Constructivist Learning Environments: Case Studies in Instructional Design*, Englewood Cliffs NJ: Educational Technology Publications, 11–24.

Johnson, D.W., and Johnson, R.T. (1979), 'Conflict in the classroom: controversy and learning', *Review of Educational Research*, 49, 51–69.

Jonassen, D.H. (1994), 'Thinking technology: toward a constructivist design model', *Educational Technology*, 34 (3), 34–37.

Lebow, D. (1993), 'Constructivist values for instructional systems design: five principles toward a new mindset', *Educational Technology Research and Development*, 41 (3), 4–16.

Lockhart, R.S., Lamon, M. and Gick, M.L. (1988), 'Conceptual transfer in simple insight problems', *Memory and Cognition*, 16, 34–6.

Lowry, N., and Johnson, D.W. (1981), 'Effects of controversy on epistemic curiosity, achievement and attitudes', *Journal of Social Psychology*, 115, 31–43.

Nash, D.A. (1994), 'The life-long learning imperative: ends and means', *Journal of Dental Education*, 58 (10), 785–90.

Palincsar, A.S. (1990), 'Providing the context for intentional learning', *Remedial and Special Education*, 11 (6), 36–9.

Palincsar, A.S., and Klenk, L. (1992), 'Fostering literacy learning in supportive contexts', *Journal of Learning Disabilities*, 25 (4), 211–25.

Resnick, L. (ed) (1989), *Knowing, Learning and Instruction: Essays in Honor of Robert Glaser*, Hillsdale NJ: Lawrence Erlbaum.

Roth, W.M. (1990), 'Collaboration and constructivism in the science classroom', *ERIC Document 318631*, 1–39.

Savery, J., and Duffy, T. (1995), 'Problem-based learning: an instructional model and its constructivist framework' in Wilson, B.G. (ed), *Constructivist Learning Environments: Case Studies in Instructional Design*, Englewood Cliffs NJ: Educational Technology Publications, 135–48.

Scardamalia, M., and Bereiter, C. (1991), 'Higher levels of agency for children in knowledge building: a challenge for the design of new knowledge media', *The Journal of the Learning Sciences*, 1 (1), 37–68.

Schmidt, H.G. (1993), 'Foundations of problem-based learning: some explanatory notes', *Medical Education*, 27 (5), 422–33.

Slavin, R.E. (1991), 'Synthesis of research on cooperative learning', *Educational Leadership*, 48 (5), 71–82.

Swanson, A.G., Anderson, M.B., Abrahamson, S., Beaty, H.N., Bryan, G.A., Carver, S., Friedman, C.P., Morahan, P.S., Reich, C., Rosse, C. and Seidel, H.M. (1993), 'Educating medical students: assessing change in medical education: the road to implementation (ACME-TRI)', *Academic Medicine*, 68 (6) (June Supplement), S7–S51.

Whitehead, A.N. (1929), *The Aims of Education and Other Essays*, New York: Macmillan.

Williams, M.D. and Dodge, B.J. (1992), *Tracking and Analyzing Learner-Computer Interaction*, paper presented at the 1992 National Conference of the Association for Educational Communications and Technology, New Orleans LA.