EFFECTIVE DESIGN PRINCIPLES FOR ACTIVITY-BASED LEARNING: THE CRUCIAL ROLE OF 'LEARNING OBJECTS' IN SCIENCE AND ENGINEERING EDUCATION

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Before we ask what a learning object is, it is more appropriate to ask what learning is. From different perspectives, according to Jonassen (2003, in press), learning is biochemical activity in the brain; a relatively permanent change in behavior; information processing; awakening, remembering and recalling; social negotiation; critical thinking; knowledge construction; conceptual change; meaning making; activity; turning perceptions to environmental affordances; and learning is chaos. These are merely alternative conceptions of learning. None of them is completely correct; all are descriptions of different aspects of learning. What all of these conceptions assume is that learning is an activity which creates unity of learning, doing and thinking. Learning, especially meaningful learning, engages activity (Jonassen and Churchill, 2003). I assert that the goal of learning is construction of advanced knowledge representations in a form of mental models. In this paper, I argue that an active interaction with a learning object in activity-driven or activity-based learning enables construction of learners’ mental models.

The goal of activity-based learning is for learners to construct mental models that allow for 'higher-order' performance such as applied problem solving and transfer of information and skills. New information and communication technologies make it possible to develop and deliver multimedia learning objects for activity-based learning. This paper focuses on the crucial role of learning objects in activity-based learning. As will be discussed, learning objects should be approached not just in terms of learning “content” but also the following: the nature of the learning activities that they can support; the knowledge states that may result from learning; the nature of the dialog or conversation supported by these objects; the nature of the thinking processes supported by these objects; and the learning artifacts that might result from learning. Learning objects will be discussed as a basis for outlining a framework for designing, developing and integrating these objects into active e-learning environments.

From Engineering in the Mind to Learning Objects

One of the gifts of nature that makes us human superior to other creatures is that we have ability to build machines which we can use to solve problems and accommodate our environment to our needs. Ability to transfer science into technology, that is, to engineer, is perhaps the crowning achievement in the development of the human intellect. Before we build or understand the “machines of the world” we build some “machines of the mind” – let’s say we do “cognitive engineering”. We can “run” these “machines” in the minds to test our theories and to predict behavior of devices or systems (Norman, 1983). We can construct in the mind models of simple concepts and propositions such as “a triangle has
three angles”, to relationships such as “effect of machining feed rate on machining time”, to very complex theories and processes such as architectural and engineering designs. When we plan lessons we also use our models to think about and predict outcomes of the lessons. These models exist in our mind; they are our Mental Models.

We have many mental models, but the thing is, we do not think about our mind in this way. This is to say that we are not aware of our mental models. Mental models are tacit (Mevorach, 1995) and usually incomplete (Norman, 1983), thus we are not aware of our own power of cognitive engineering. When we teach, typically we have already finished running our mental models; essentially we just serve the results to the students - we share “what” we know but not “how” we know that. Outcomes without a process are usually ambiguous. It is hard to understand reasoning behind the results; therefore an individual just wants to remember information – perhaps for the sake of passing an examination. Let’s pull back for a moment and consider a possibility of sharing your mental model with the students, instead of giving them results, we give them “mechanisms” which they can re-construct and use to get to their own results.

Mental models are more than declarative or procedural knowledge, they are advanced knowledge representations (Jonassen, 1999). Their descriptive and predictive power (Rouse and Morris, 1989) allows individuals to transfer learning and to examine and solve complex, ill-structured and authentic problems. Allowing learners to develop and use their own mental models goes well beyond teaching of concepts, principles and procedures. It includes that we provide learners with tools and opportunity to develop their own mental models. This is not straightforward as it might seem to be – we cannot just “take out” and pass our mental models to learners. Our mental models are not simply copied into learners’ mind. By examining, articulating and externalizing our mental models, we essentially create an external version of what is seen by our own “mind’s eye”. This external model is usually called by literature as a Conceptual Model (Mayer, 1989; Norman 1983). Conceptual model that we design is for learners, to help them to construct their own mental models. The driving goal is to design a conceptual model which is at least near congruent with learners’ mental models. I refer to this as “approximation”.

Previous research on design and use of conceptual models produced promising results (Mayer, 1989). However, it appeared to me that limitation of traditional non-interactive technologies and tools made these conceptual models not much different from print-based diagram, images, drawing and charts. Now, for the first time ever, we have powerful multimedia technologies at our disposal. These tools enable us to add critical dimensions to design of conceptual models – the interactivity and dynamic data visualization.

We can create illustrations, animations and simulation of our mental model by creating interactive conceptual models – illusions and replicas of what we see and run with our mind. The remaining essential for activity-based learning is to plan an activity (e.g. problem-based, inquiry based), either for a classroom or for an e-learning environment. The activity is to bring thinking, doing and learning together through interaction with a learning object (a conceptual model) towards a solution or solutions to a problem. The activity must drive learners to explore relationships and relationships within relationships, apply knowledge, and innovate. The learners might develop their own thinking principles - this level of critical thinking is underlined by Fisher and Scriven (1997) as even higher than metacognition or metathinking. All of these should lead to “accidental” construction of learners’ own models in mind. A conceptual model is therefore the true Learning Object.
Example of Learning Objects in Action

In this example from a precision engineering course at a technical training institute, I intend to illustrate how learning objects were used to facilitate construction of mental models through an activity-based e-learning. After the example, I will provide further discussion and definition of a learning object.

The first important step in design of any learning, whether it is e-learning or classroom-based, is to identify suitable topic for a particular approach. The topic of machining parameters was selected as it is an important concept to practicing precision engineers and turning machines operators. It is also a theoretical topic with clear links to application. The productivity of machining operations in turning process depends on efficiency of “metal removal”. This efficiency is dependant upon the type of tool and the combination of machining parameters employed in operation. Without a mental model that cognitively integrates these parameters, an engineer risks to incorrectly estimate clients requirements, to excessively use a machine, to increase failure and decrease quality of machined components, to waste tools and inserts, to increase production cost, and so on. The current instructivist-based teaching approach to machining parameters usually results in limited understanding by learners. Learners usually learn about machining parameters by practicing how to calculate various parameters without in-depth understanding of relationships that exists between these parameters. The machining parameters are usually taught independently of each other and separately from actual machining practice. When learners do not develop a mental model of machining parameters, they are likely to experience difficulties once they shift to a workshop and transfer learning. Thus, without mental models, learners might learn about engineering rather that learn about how to be engineers.

The Activity

Learning process started with an activity in a problem form of “What’s the Client Looking For?” (see Figure 1). The problem was authentic and ill-structured - with multiple solutions and paths, and with minimum parameters to build upon. Authentic and ill-structured problems, according to Jonassen (2000), “are kind of problems that are encountered in everyday practice, so they are typically emergent” (p.7). A certain degree of simplicity (although difficult for ill-structured problems) was needed to allow learners’ to focus on the process of meaning making towards a solution. Process of problem-solving and meaning making rather than a solution, are in the center of problem solving. Traditionally, teaching is driven by curriculum structure. Activity-based learning begins by examination of learning requirements and what learners must do to think to solve a problem rather than by what we will tell them. Content is dispersed and distributed around the problem and used with the purpose of solving that problem. The learners are not to learn about the content but about the process of making meanings and using information to solve the problem. Accidentally as they go towards the solution, they will also learn about the content. At the beginning of learning, learners were presented with a problem in a form of client’s job requisition - a short video clip of a client outlining his request for proposal and a technical drawing of a part to be machined. That is how it happens in a professional context. E-learning environment enables us to deliver “digital requests” of the client’s jobs to the learners (e.g. emails, audio or video messages, technical drawings). There were three different requests by the client. The learners had to choose one to follow-up with. It might
be important to provide the learners with these options. The possibilities to choose their own job provides learner with the sense that they may be in control of their own learning.

Learners understood the problem by interpreting the data from the job specifications and articulating what they were required to deliver by completing separated activity sheet or template. The activity sheet scaffolds learners to interpret the client’s requirements and drives their attention to consideration of details which otherwise might remain unnoticed. This activity enables a learner to construct a mental representation of a problem or a problem space (Jonassen, 2000). Jonassen also wrote about unity of consciousness and activity which enables a learner to manipulate this problem space. The learners are required to identify job quantity requested by a client, work-piece material, surface finish quality, tolerances, and accordingly to identify machining-process sequence and bring forward some pre-conceptions about an importance of these to a solution.

Figure 1: Home Page of the Machining Parameters E-learning

There are a number of activity sheets which learners have to complete towards the solution. The learners were working on the activities in pair. Activity sheets were organized and downloadable from the learning environment (under “What are Your Tasks?” in the Figure 1). Activity sheets were completed electronically and kept in a learner’s “digital portfolio”. As the final step towards the solution of the problem, the portfolio is to be summarized into “a quotation proposal” to the client. The proposal synthesizes the learners’ decisions into a single value of “total machining time”. The total machining time is used to calculate a “production cost”. However, this value is not a single fixed value. This means that there are multiple solutions to this problem what demands from a learner to provide additional arguments supporting their proposed values in the quotation proposal. For the next try-out we are planning to require learners to document their argumentative justification in “a case library”. Case libraries, based on the principles of case-based reasoning, represent a very powerful form of support for ill-structured problem solving (Jonassen & Hernandez-Serrano, in press). This is also important, as according to Jonassen (2000), in solution to ill-structured problems, learners should be encouraged to make judgment and to express personal opinion about the problem. The
quotation proposal and portfolio are artifacts of learners’ learning. They should expose any misconception constructed by learners and lead to qualitative actions by a facilitator. At the same time the portfolio enables learners to reflect back at the learning and problem solving experience.

Machining Parameters Learning Object

Engineering content can effectively be represented with learning objects (Churchill & Wong, 2002, Pitchian and Churchill, 2002). With technology learners can change one or more parameters while updated display can provide them with changes of other parameters. We do not have to tell learners what do we want them to know – we can allow them to experience and construct it by themselves. The Figure 2 shows one of the three learning objects used to facilitate learners’ problem solving and construction of a mental model of machining parameters. Repositioning of sliders on the Learning Objects in the middle of the Figure 2 initiates changes in calculation which are presented on the right and changes of animation in the top-left. The learning object in the Figure 2 by itself enables learners to explore large number of combinations of various parameters and to immediately view impact of controlling machining parameters on the other independent parameters – something that cannot be achieved easily and trouble-free even with the real machine.

Figure 2: Machining Parameters Learning Object

A product of interaction with elements in the learning object in the Figure 2 can be exhibited not only as numerical values but also as visual information in form of diagrams and animation (e.g. speed of rotation of the work-piece, number of passes, removal of material feed-rate movement of the tools) and in a form of auditory effects (e.g. a turning machine changes sound when rotation is increased). If a picture is worth thousands of words, a learning object might be worth thousands of pictures. Interpretation of data which is accessed through purposeful interaction with the learning object, engages learners in examination and discovery of relationships and relationships within relationships. This facilitates critical thinking and I suspect that it might results in generalization of critical propositions and articulation of these propositions into mental models. My intention is
investigate this assertion in further studies. This thinking is further extended as learners attempt to “run” their mental model in a problem which they are solving.

The three learning objects are interconnected within a problem solving activity in an e-learning environment (organized under “Your Tools” link in the Figure 1). Interpretation and decision which learners make through interaction with one of the learning object are validated or expanded through interaction with another learning object. These autonomous learning objects might contribute to construction of a mental model at the higher level. A research is needed to explore this assertion.

Activity and Learning Objects -The Two Essentials for Construction of Mental Models

To support the design of an activity for learning, any existing learning objects must be described not only in terms of information within it, but also in term of activities that it can support or in terms of learning artifacts that can result from these activities. If learning is an active, intentional and purposeful thinking activity, a learning object can serve as a catalyst and support for thinking, as well as a medium for constructing a learning artifact. Thus, learning objects should also be described by the thinking processes that it can support. In order to explain the complexity of learning and the utility of any learning object in supporting that a learning object must be described according to (see Jonassen and Churchill, 2003):

(i) the nature of the information included in the object;
(ii) the nature of the learning activities that it can support;
(iii) the knowledge states that may result;
(iv) the nature of the dialog or conversation supported by that object;
(v) the nature of the thinking processes supported by the object, and finally
(vi) the nature of the artifacts that can be created that represent learning.

Accordingly, rather than describing a learning object in only one dimension (information), learning objects must be described in several dimensions, as illustrated in Figure 3. There may indeed be other properties of learning objects necessary to conceptualizing meaningful learning. The form and substance of these objects would require collaboration with psychologists, philosophers, educators, designers, and software developers.

As a mental model might be composed of less complex and autonomous mental models (Williams, Hollan and Stevens, 1983), similarly, a set of learning objects can be positioned in a more complex system. Learning objects could dynamically interact with each other causing various manifests such as malfunctions of the larger system at random basis and present learners with whole range of problem solving situations. With a physical systems and structures, this can be delivered with high level of realism (such as wearing of components, weathering and corrosion, electrical malfunctioning, impact of microbiological and other life forms, poor maintenance and so on). To research and develop a prototype of such system (for example Tool-Making Machine used in engineering, or even a Sony video player not just for training of technicians and troubleshooter, but also for operators, design engineers, beyond formal learning for product support and continuous customer support) could serve as a model to developers developing complex systems. Once we understand how this applies to physical system, it would be possible to transfer the experience into systems such as leaving organisms, business structures and communities. Thus a learning object might range in complexity, from a model of a single proposition to a meta-model of complex and dynamic structures.
This view of a learning object for activity-based learning is fundamentally different from the approaches proposed by industry-driven initiatives that argue for structuring content into small reusable chunks of information. Our view of learning objects includes that:

(i) A learning object is not an explicit granular piece of information – information is not equal to instruction;
(ii) A learning object is not a practice or assessment object – ability to apply knowledge cannot be tracked, it must be reflected in learning artifact and examined qualitatively through reflection within a context;
(iii) Learning object is not a teaching object – instruction is not equal to learning; and last but not least
(iv) Learning object is not reusable by itself - it is reused within activities rather than by itself.

Design Recommendations for Activity-based E-learning
Design of constructivist learning has been a subject to many theoretical debates (see, Cooper, 1993; Merrill, 1991; Perkins, 1991; Wilson, Teslow and Osman–Jouchoux, 1995; Young, 1993). Scholars questioned whether traditional instructional design models are appropriate for design of constructivist learning environments (Cennamo, 1996). Even the term “instructional design” has been labeled as inappropriate terminology by some constructivist propagators. These models often approach design of instructions through content analysis and they are essentially about content rather than about context in which this content appears. The assumption about learning that is consistently applied by these standards is that information equals knowledge and instruction equals learning. In order to learn something, according to most of traditional instructional models, instructions must present information about the content, after which a learner practices remembering, recalling or understanding the content. This is a model for how to learn about the content. It supports declarative knowledge acquisition, not knowledge or understanding of how to do anything (Jonassen & Churchill, 2003).

Skilled performers and knowledge workers must learn how to do something (procedural knowledge) or learn by doing something. Learning about the content assumes that we must learn about something before we can apply what we learn. So to do something, all we have to do is to know something. This further means that knowledge is equal to mental models, which is not the case (Rouse and Morris, 1996). Knowledge and application are inseparable, according to most contemporary theories of learning. What combines knowledge and application is a meaningful and authentic activity that requires learners to construct their own mental models and build their own versions of that knowledge reflected in their learning artifacts. Additionally, most of the instructional design models assume that there is only one way of knowing something, which represents the most primitive form of epistemological beliefs, absolutism (Jonassen and Churchill, 2003). On the opposite, there are many ways of knowing things, and the research on expertise clearly and consistently shows that experts know what they know in many ways (declarative, conceptual, experiential, strategic, procedural, situational, and even tacit ways). Most learning, especially in everyday and professional world contexts, involves solutions to complex problems or the performance of complex tasks that require more than the individual components of that task to perform. Most instructional design models focus only on individual lesson models and provide little or no advice on how those individual chunks of content are arranged in order to fulfill any meaningful tasks.

Further problem with instructional design is that it separates design from the context of learning and teaching. From a study of a link of expert teacher thinking and instructional design process Moallem (1998) identified five major categories of knowledge and belief that underlines a teacher’s planning: knowledge of one self as a teacher, knowledge of content and curriculum, knowledge of pedagogy, knowledge of students and knowledge of context. Moallem understood that although a teacher does not engage in any formal analysis before planning (as instructional designers would do), his or her practical knowledge or experience-based knowledge and personal belief underlines her instructional decisions. Moallem emphasized that formal instructional design appears ignorant to this practical knowledge and personal beliefs that teachers-as-designers bring to the design situation. Context-free understanding about learners and learning strategies as a key source of decision making in instructional design is perceived as the significant short-fall of the formal approach to design of instructions (Moallem, 1998). In addition, a teacher as designer is also a subject matter expert, which means, that during the design process, a teacher’s practical knowledge and personal beliefs interact with his or her knowledge of content. On the other side, a formal instructional design is a content-free approach to design. Moallem also emphasizes importance of teacher’s critical perspectives (reflection)
through thinking about teaching, interaction with others, and self-monitoring of own practical knowledge and personal belief.

Rather than approaching a design as separated from the context of learning and a teacher, I articulated a design approach that considers teachers and learners, learning and technology at the same time. This approach to design of activity-based e-learning is summarized into four main stages (see Figure 4). The Construct stage is the most important stage in the design process. This is where a teacher-as-designer articulates his or her preconceptions about knowledge and learning, learners, technology and of self into design decisions. During the Construct stage, a teacher-as-designer identifies a topic suitable for e-learning, defines a learning outcome, constructs learning activity, identifies learning object(s), and articulates support strategy. In Produce stage, a teacher-as-designer converts his or her plan into digital pieces (alone or in collaboration with developers). In Assemble stage digital pieces are placed in the e-lesson within a learning-management system. In the final stage, a teacher-as-designer is to implement (facilitate learning), evaluate and re-design or update the e-lesson.

Figure 4: Activity-based E-learning design process

Learning is not organized by or driven by individual objectives. Some authors argued that it is inappropriate to use instructional design models to design constructivist learning materials as it is inappropriate to set learning objectives to students. A key problem with objectives is that most often this information only tells learners what knowledge they will pursue, not about how they will use this knowledge (Merril, 2000). Writing objectives is usually driven by the content analysis rather than learning task analysis. There is also a tendency amongst teachers to write a learning outcome as granular
objectives in terms of lower order thinking skills without or with very little relation to application.

Some authors argued that objectives are important in design of constructivist materials as heuristics to guide designers (Wilson, Teslow and Osman–Jouchoux, 1995). An argument in this paper is that generating a learning outcome (rather than learning objectives) is essential in the context of design of learning rather than in the context of implementation of e-learning. A teacher-as-designer must articulate well-written learning outcome that leads to application of knowledge. The learning outcome is important for a teacher-as-designer who uses this statement to guide his or her design of learning – a kind of combination of guide and subsequent quality assurance. A learning outcome is useful as heuristics for design of e-learning rather than as an advanced organizer for learners, that is, a learning outcome should not be communicated to learners - as it is the case with traditional design models - because learning outcome for each of the learners is not completely predictable.

Clear learning outcome also suggests a suitable learning activity. Form a study of teachers-as-designers I understood that in the design of activity-based learning, learning activity must be planned before decisions about a learning object are made. The learning activity contains a task or a problem to be attended by learners. An activity sheet scaffolds knowledge construction through a set of sequential sub-tasks and templates. Depending on learners learning skills, that is, their ability to follow a learning task, level of scaffolding for completion of an activity might increase from more structured templates to broader focus questions. In the later case a teacher-as-designer must be confident that his or her learners have appropriate learning skills, otherwise an activity template might contain scaffolding elements in a form of rubrics, hints, graphs, flow-charts, tables. Learners’ characteristics must be considered only after an activity is defined, in term of their learning scaffold needs rather than in term of their ability to understand content (as it is the case with traditional instructional design approaches). Carefully designed sub-tasks within an activity are to take learners from one level of learning to another, from simple to complex, from lower to higher order thinking, from observation and experimentation to generalizations, application and innovation, from problem understanding to articulation of best solution. The activity involves learners in learning through and from application of knowledge. Sub-tasks within an activity sheet cannot be answered randomly because they are consecutive which leads to completion of a whole task. Completed activity is an artifact of learning which must provide information about learners’ misconceptions. We are looking for learners’ misconceptions because we want to influence learners to construct an approximation of our conceptual model. The activity might also include a task for learners to externalize their own mental models by creating interactive conceptual models. Technology provides a variety of tools that learners can use to create conceptual models. These technology tools are known by literature as “mindtools” (Jonassen, 2002).

Learning objects enable completion of activity, while activity works towards or beyond a learning outcome. A learning object contains data that is implicit rather than explicit, distributed rather than linear, embedded in a context and tools rather than directly accessible, visual rather than raw. The data is required for completion of an activity rather than for a direct achievement of learning outcome. Thus, when we design e-lesson, a learning activity must be designed before learning object is designed or selected from a library of existing objects. A learning object is used within a learning activity rather than used independently from the activity. I feel that self regulated learners might be able to learner through sole interaction with learning objects, that is, without any activity in place. However, this claim should be investigated. However, one of key purposes of an activity is
to engage learners in independent learning and thinking – an activity and post-activity reflection on thinking and learning process should increases learners independence.

Support of learners, which I separated from scaffolding of learning within an activity, must also be planned during Construct stage of e-learning design. Support might be prescribed as a list of frequently asked questions, extra resources and on–line help, and/or be provided in synchronous and asynchronous way using communication tolls such as e–mail, discussion board or chat to learners who need it. Prescribed support should be made available to all learners, but learners would access it when and if needed. The teacher should be approached as the last resource. He or she must be careful to resist temptation to provide ready–made solutions to learners who need support. Learners should make effective use of prescriptive support, support each other and approach a teacher through communication tools if they are not successful in finding an answer to their questions otherwise. Becoming independent and lifelong learner relies on development of learners’ abilities to independently search for information related to their questions, interests, needs and pursuits. If a learner can find answers to his or her questions independently from a teacher, this would increase his or her learning confidence and decrease his or her dependency on a teacher. At the same time, I assume that independency in learning facilitates construction of mental models. However, I call onto researchers to investigate this link.

Examples of learning objects are available for preview at http://www.learnactivity.com/lo/.

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