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THE ROLE OF SIMULATION SOFTWARE IN AN IDEAL LEARNING ENVIRONMENT

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ABSTRACT

For years, computers have promised to revolutionize education. Educators crave and skeptics demand justification for the large outlay of resources required to introduce information technology into the curriculum. Engineering educators have drawn upon the work of education theorists, computer scientists and communication experts to explore the effectiveness of this promising technology in their curricula.

This paper analyzes three pairs of students using various solution techniques to solve a mechanical engineering design problem. We will focus on the use of a computer-based simulation tool and its effect on the students' process of solving the problem. We will use two learning theories to explore the learning environment and draw conclusions about the effectiveness of the computer simulation for teaching engineering.

SCENARIO

Four pairs of students were videotaped working on an assignment for an upper level (junior and senior), undergraduate, mechanical engineering design course. In previous work we analyzed this scenario with respect to analytical problem solving methodology (Reamon and Sheppard, 1996). This paper will focus on the educational experience of three of the pairs. (The audio portion of the fourth videotape was lost due to technical difficulties.)

The assignment required the students to design a four-bar toggle clamp mechanism with specified force-magnification and dimensional criteria. A range of solutions would meet the criteria and be considered correct solutions. The assignment sheet contained a diagram of a mechanism similar to those which would be considered correct solutions. The students needed to determine the relative lengths and positions of the four links in the mechanism such that the force and length criteria were met.

All of the participants had access to a multi-page handout which had accompanied a lecture on analyzing force-magnification of four-bar mechanisms. The handout outlined a technique for performing such analyses using principles of energy conservation, geometry, and algebra. The technique is called ‘instant-center analysis’ and is based on a concept called ‘virtual work.’ The handout also contained an example analysis for a four-bar mechanism of a similar type to a toggle clamp.

In addition, the participants had taken part in an hour-long tutorial on the use of a mechanical simulation software tool called Working Model™. The tutorial introduced the basic techniques required to build a model and run a simulation, with a special focus on four-bar mechanisms.

All six of the participants were male, and roughly the same age. According to questionnaires completed prior to taping, they were of similar educational backgrounds, and had similar engineering experience and mechanical aptitude. They were all novices with respect to instant-center analysis, and the design of four-bar mechanisms.

All three pairs had access to a work table, paper, pencils, rulers, calculators, the assignment sheet and the handout mentioned above. The 'Paper Pair,' JS and DB, had only these resources available. The 'Computer Pair,' EM and CD, had access to all of the same tools, plus a powerful personal computer with Working Model software running on it. The 'Lego Pair,' MM and BM, had access to all of the previous tools, in addition to a Technics Lego™ building set, provided at MM’s request.

OBSERVATIONS

The participants were taped for one hour while they worked on the problem. This is a brief synopsis of the activity on the tapes for each of the three pairs.

Paper Pair

JS entered the room a few minutes after DB. JS began to read the assignment while DB operated the computer. About five minutes later, DB stated, “They must not want us to use Working Model, 'cause it's not here.” DB moved back to the work table. JS asked DB to describe his ‘approach’ to the problem. JS did not wait for an answer, and began to restate the criteria in the assignment.

After some discussion, the participants began to apply the procedure laid out in the handout to their problem. They ran into several snags in the course of the procedure, regarding issues of force component vectors and nomenclature. They applied various criteria, performed some calculations and determined that the length of one of the links in the mechanism should be -32 centimeters. The negative sign indicated that this was an erroneous result. They spent the remainder of the hour (approximately 20 minutes) attempting to find the source of the error in their calculations, but did not succeed.

After the taping session, the students successfully completed the analytical procedure, and turned in a paper detailing their analysis and the resulting mechanism. They included a cardboard model of the clamp that they constructed.

Computer Pair

As EM read through the handout on virtual work, CD moved to the computer. EM agreed that “Working Model might be a better way to go” and joined CD at the computer. EM began to enumerate the specifications for the toggle clamp, using hand gestures and the diagram in the handout to illustrate. EM wanted to create a model that had the appropriate behavior, but he believed that “there's a bunch of numerical stuff that Working Model can't do.” CD began building a clamp model with the software. The resulting model had two toggle conditions, which the pair found undesirable. They reworked the model twice, attempting to eliminate the second toggle. They discovered a consistent relationship between the lengths of the links. They believed that this concept would allow them to eliminate the unwanted behavior.

They started over with a blank screen, attempting to apply the new concept to a new model. Their first attempt was abandoned, but their second restart resulted in a mechanism that had only one toggle condition and appeared to meet the problem specifications. They measured the link lengths and proposed scaling the lengths to meet the size specifications.

After the taping session, the students scaled down the software model. They used the instant-center analysis technique on the model to show that it provided the specified force magnification. They turned in a cardboard model of the clamp mechanism.

Lego Pair

Prior to the beginning of taping, a Lego set was provided to the pair at MM’s request. Both students began to build models of a toggle clamp with the Legos, based on the diagram in the assignment sheet. MM stated that he wanted to “get a model that works pretty well.” Both students constructed models of the appropriate class. They referred to the criteria in the assignment several times, and revised their models. After about fifteen minutes, they compared the two Lego models and chose BM's, because MM's required a starting position that he deemed undesirable.

BM measured the links in his model and MM constructed a scaled model with the Working Model software. MM worked with the model for about 30 minutes with intermittent input from BM. MM altered the model as he considered the angular and dimensional criteria in the problem statement. Meanwhile, BM read through the handout and decided that the “instant-center stuff is ugly.” MM proposed that the force analysis could be done with the simulation software.

After the taping session, the students successfully analyzed the force ratios with the simulation software. They turned in computer print-outs from the simulation software which depicted the forces at various states of the linkage. They also turned in BM's Lego model of the clamp.

ANALYSIS

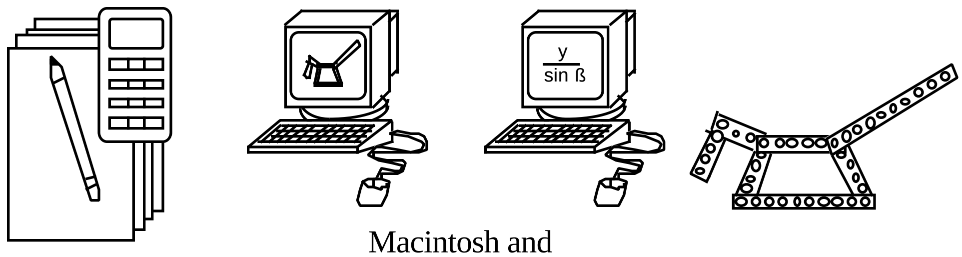
We will now analyze the activities of each of the three pairs using two learning theories: the Situated Learning Theory and the Kolb Learning Cycle. The theories will serve as a basis for a comparison of three different learning situations. We will attempt to discern what aspects of each situation would best promote learning about these mechanisms and identify which pair has the greatest potential for transferring the learning to new situations.

Situated Learning Theory

The Situated Learning Theory is an innovative educational theory developed by Greeno, et al. (1993). This theory is by no means the only one which describes the manner in which people learn, but it is a complete, functional and widely-accepted theory. We begin with a working definition of learning: “*knowing* is ability to interact with things and other people in a situation, and *learning* is improvement in that ability” (Greeno, et al., 1993). Learning depends on, and is influenced by, the situation in which the learning takes place. The situation is created by the properties of the learning environment and the characteristics of the learners, or *agents*. An *affordance* is “a resource in the environment that supports an interactive activity by an agent” (Greeno, 1995). The “characteristics of the agents that enable them to engage in activities”(Greeno, et al., 1993) are called *abilities*.

In the work of the three student groups that we observed, the situations differed primarily in the realm of affordances. Each student certainly had different abilities, but, because of the similar backgrounds and levels of training and expertise, the differences were relatively small. There were four different affordances available in the experiment which influenced the solution methods and strategies, or *schema*, that were utilized (see Figure 1).

Figure 1. Each pair of students had different resources available to them.



	Handout and Paper	Macintosh and Working Model™ Simulation	Macintosh and Working Model™ Analysis	Lego™ Technics
Paper Pair	✓			
Computer Pair	✓	✓	✓	
Lego Pair	✓	✓	✓	✓

The first affordance included the work table, paper, pencils and the handout describing instant-center analysis. This set of items afforded the participants the ability to follow the example analysis and apply the technique to the toggle clamp problem

The second affordance was the Working Model mechanical simulation software. The software afforded the students the ability to create two-dimensional models of mechanisms that functioned like real mechanisms in terms of their motion. It also included the ability to make changes to the dimensional aspects of the model and observe the effects immediately.

The third affordance was the analytical capability of the Working Model software. This capability was briefly introduced to the participants during the tutorial. The tutorial focused on the second affordance, however, and the analytical capability was essentially an aside.

The fourth affordance was the Lego Technics building set. The Legos afforded the students the ability to create approximate physical models of mechanisms. This is a fundamentally different activity than creating software models. The tactile aspect of this activity, the ability to touch the mechanism and feel relative forces, distinguishes it from the software environment. The software environment, however, provided the ability to make minute and/or rapid changes in the model.

The solution schemas that the three pairs chose depended greatly on the affordances available to them. The Paper Pair was limited to an example-following schema, since they only had the first affordance available to them. It was, however, a familiar schema; the use of example problems to teach new analytical techniques is quite common in engineering education.

The Computer Pair used the software to develop a model that behaved correctly according to the qualitative specifications, then followed the analytical example to determine the quantitative behavior. Their solution utilized the successive-approximation affordance of the software, and the analytical affordance of the example in the handout.

The Lego Pair had access to all four affordances, but only used three of them in their solution. They developed an initial physical model with the Legos, then performed finer successive approximations with the software. Finally, they used the analytical capabilities of the software to determine the quantitative results. They did not employ the first affordance at all.

In the process of solving the problem, each pair of participants completed the assignment satisfactorily and created mechanisms that met the stated criteria. By our working definition, each pair learned about designing mechanisms because they interacted ‘successfully’ in their situations. But we can only say that they learned about mechanisms in the particular situation in which they were involved. Each situation was different because of the different affordances available to each pair. The goal of education, however, is to gain a higher level, or more general, understanding. Situated Learning Theory calls this *transfer*. A successful educational experience allows the learning from one situation to be transferred easily to another, somewhat similar situation.

According the Situated Learning Theory, the first step in the transfer process involves forming *representations*. Representations are expressions of the actual or potential states of a situation. There are two primary means of constructing representations as described below:

- *Physical representations* “include physical constructions such as diagrams, graphs, pictures, and models with properties that are interpreted as corresponding to properties of situations” (Greeno, et al., 1993).

• *Mental representations* include mental constructions such as symbolic and mental models (Greeno, et al., 1993). *Symbolic models* are abstract expressions of a situation and typically consist of equations. *Mental models* feature mental constructions which correspond to physical objects, situations, or relationships and that can be used to mentally simulate actions or events in other situations (Greeno, et al., 1993). A student who has formed a complete mental model is commonly attributed with *intuition* about that situation.

An instance of effective learning requires the formation of a complete mental representation of the situation, ideally composed of both symbolic and mental models. The mental representation is commonly derived from experience with physical representations. We will now examine the representations each pair of students developed, based on the affordances available and their choice of solution schema.

The Paper Pair has only some static diagrams available to serve as physical representations. Four-bar mechanisms are simple to construct, but as they can involve rather complex motions, their motions are difficult to convey in a simple, static diagram. The paper-based diagrams available to the Paper Pair were probably not sufficient to allow the participants to form a complete mental model of the situation. The Paper Pair was focused primarily on a symbolic model of the problem, i.e., the equations involved in the instant-center analysis. Such a symbolic model, even if complete and functional, rarely leads to a complete mental model, or intuition about the mechanisms.

There is evidence of the incompleteness of this pair's mental model when they completed a series of computations and concluded that the length of one of the links should be -32 cm. The negative sign was an immediate indicator that the result was invalid, but the participants did not know where the error might have occurred. This is a classic example of the dissociation of a symbolic expression from the situation it describes (Nathan, et al., 1992). The symbolic representation does not have a reliable link to the real-world mechanism in the mental model. If the participants had such a link in the mental model, they would be able to determine which procedure in the symbolic manipulation process was incompatible with the situation and therefore caused the error. This type of error is not at all uncommon in institutional engineering education.

Under the Situated Learning Theory, the Lego Pair should have developed an excellent mental model of the situation. The Lego model and the software model are both dynamic physical representations and should aid in the construction of an accurate mental model of the situation. The interactivity of both the Lego and software models give it obvious advantages over a static diagram. The ability to experiment in the software environment, quickly and easily, allowed the participants to discover patterns in the behavior of the mechanisms. This would eventually enable the participants to make accurate qualitative predictions about the behavior in new, or altered models. This pair did not, however, deal with the symbolic aspect of mental representations. They used the quantitative ability of the software to determine force ratios and neglected the instant-center solution technique and the inherent symbolic representations.

The manner in which they determined the force ratio produced by the mechanism provides evidence of the incompleteness of their mental representation. The software will not display forces directly, so the participants addedsprings to the model, and were able to determine the forces by measuring the displacements of the springs and multiplying by a known spring constant. The software will display velocity directly, however. The virtual work concept that is central to instant-center analysis states that the product of force and velocity at the input is equal to the product at the output. If the Lego Pair had grasped this symbolic concept, they would have been able to obtain a ratio of velocities directly from the software, and invert it to determine the force ratio.

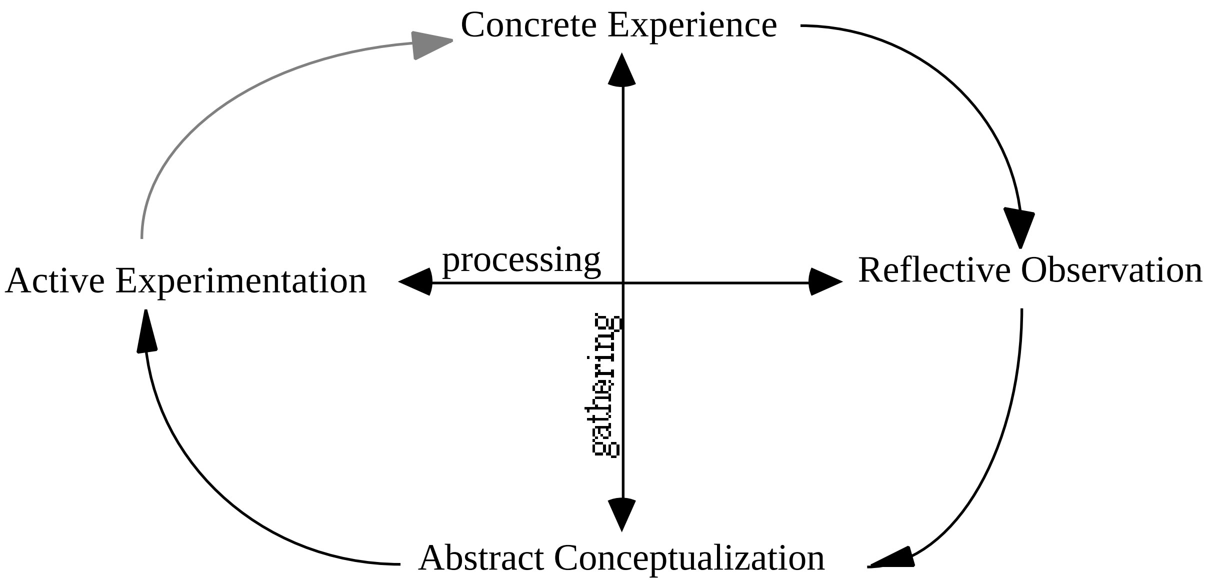
The Computer Pair should have formed the most complete mental representation of the mechanisms. This is because they developed a complete mental model and applied symbolic expressions. Like the Lego Pair, they used the highly-effective, graphic, interactive software environment early in their work session to develop an intuition about the mechanism. They then moved to the symbolic formalisms presented in the instant-center analysis. The abstract nature of the symbolic expressions increases the likelihood of transfer of the knowledge from one situation to another. The Situated Learning Theory states that, "if a learned activity is to transfer, then, it has to be learned in a form that is invariant across changes in the situation or that can be transformed as needed" (Greeno, et al., 1993). Symbolic expressions provide a convenient form to meet this requirement.

Since the Computer Pair did not perform the analysis on tape, we cannot cite evidence of high level abstractions which are likely to lead to transfer. We can, however, cite an example of an abstractable insight that the pair gains in the course of their observations. When the pair was trying to remove the second toggle condition, they discovered a relationship between the link lengths which insured that one of the links would be able to perform a full rotation. This is called Grashof's criterion, and can be expressed in the form of an algebraic equation. Although the pair does not explicitly inscribe this expression during the session, the linking of the mental model to this abstractable insight indicates the completeness of their mental representation and a high probability of transfer.

The Kolb Learning Cycle

As further support for our assertion that the Computer Pair's solution schema is superior, we will apply the Kolb learning cycle to the scenario. The Kolb Learning Cycle is a modified version of the scientific learning cycle which grew out of Piaget's ideas and the educational philosophy known as constructivism (Piaget, 1980). The Kolb Learning Cycle models the way people learn. It is based on a pair of dichotomies. The first dichotomy pertains to how people take in information. Information can either be obtained through abstract conceptualization or concrete experience. Abstract conceptualization focuses on "logical analysis, abstract thinking and systematic planning" (Wankat and Oreovicz, 1993). Concrete experience deals with specific encounters, particularly with people, and is fundamentally less systematic.

Figure 2. The Kolb Learning Cycle includes four different modes of learning. An ideal learning experience begins with a concrete experience and proceeds to the three other modes in a clockwise fashion. The cycle can be completed more than once. (Wankat and Oreovicz, 1993)



The second dichotomy deals with methods of information processing. Information is transformed to knowledge by active experimentation or reflective observation. In active experimentation, learning is accomplished by performing actions and examining results, while reflective observation involves looking at the information from several angles and drawing conclusions (Kolb, 1984).

If the dichotomies of information gathering and processing are placed on orthogonal axes, we have four quadrants that represent the four steps in a learning 'cycle', all of which are important (see Figure 2). "A proficient learner is able to complete all steps in the cycle although he or she prefers certain modes of operation" (Wankat and Oreovicz, 1993). Frequently in education, however, the cycle moves from reflective observation to abstract conceptualization and then stops, neglecting two modes. Research has shown that 20% of knowledge is retained if only abstract conceptualization is used. Knowledge retention climbs to 50% when reflective observation and abstract conceptualization are used, 70% with concrete experience, reflective observation and abstract conceptualization, and 90% with all four modes (Wankat and Oreovicz, 1993).

The Paper Pair in our experiment focuses almost solely on the abstract conceptualization mode of learning. They solve the problem with a very systematic approach, involving abstraction, logic and arithmetic. It could be argued that they use the reflective observation mode to a lesser degree as well. They must look at the new problem and determine how it differs from the example. This activity is similar to reflective observation. In the process of searching for the error that caused the negative result they further employed reflective observation. Thus, the Paper Pair employs two of the four learning modes.

The Lego Pair uses all of the modes except abstract conceptualization. They begin with a very concrete experience by building a Lego model. They use some reflective observation in transferring the model to the software environment, where they perform a great deal of active experimentation in manipulating the model. They employ reflective observation again when they devise a means of obtaining force data by adding springs to the model. They do not, however, apply logic or abstraction to the problem and they never express the situation in a symbolic formalism.

The Computer Pair utilizes all four learning modes. They perform the same cycle of concrete experience, active experimentation and reflective observation that the Lego Pair did, although the concrete experience is somewhat less concrete than the Lego Pair's. They add the additional step of performing abstract, symbolic manipulation to determine the force magnification, thus employing the abstract conceptualization mode that the Lego Pair neglected.

The Kolb Learning Cycle thus supports our conclusion that the Computer Pair employs the most effective solution technique, followed by the Lego Pair, and then the Paper Pair. It is not surprising that the Situated Learning Theory and the Kolb Learning Cycle agree. They originate from the same roots in cognitive psychology. The Kolb Cycle seems to be more directly translatable to practice than the Situated Learning Theory, and it has already been proven to be effective in increasing learning in engineering activities (e.g., Brereton, et al., 1995; Harb, et al., 1993; Lawson et al., 1989).

CONCLUSIONS

Through the application of two learning theories, we have explored the impact of various resources in the solution of a design-sizing problem and the effect the solution methodology has on the learning experience. Generally, more resources create a superior learning environment. The type of resource, however, is also important.

A traditional lecture and problem set curriculum may result in an incomplete learning environment according to both of the learning theories. From the Situated Learning Theory we concluded that the pair of students who solved the problem using the paper and pencil approach was deficient in building a complete mental model. From the second theory we concluded that the Paper Pair employed only two of the four learning modes in the Kolb Learning Cycle.

The simulation software seems to be a valuable addition to the learning environment. The introduction of this tool into the learning environment may have helped the students develop a better intuition, or feel, for the mechanisms. In the terminology of the Situated Learning Theory, we say that they have a well developed mental model of the situation, which is one of the two components of a complete mental representation. The tool also promotes the use of an additional mode of the Kolb Learning Cycle.

Both learning theories indicate that more effective learning environments are created when the software simulation is complemented by the paper analysis. This allows a higher level abstraction to be drawn from the experience, in the form of well-understood equations. According to the Situated Learning Theory this will increase the probability of successful transfer of the learning to other situations. The addition of this activity also engages the final learning mode of the Kolb Cycle, which typically leads to a drastic increase in retained knowledge.

This exploration indicates that the software simulation does not provide an optimal learning experience by itself. When combined with hands-on experience, theory and abstraction, however, the simulation software can be a part of a learning environment that will likely produce excellent results. In other words, software cannot replace traditional instructional techniques, but it can add an important component to the educational experience. A similar conclusion was drawn by Regan and Sheppard (1996).

The *process* of solving this type of open-ended analytical engineering problem has been largely ignored. Traditionally, if the students developed a mechanism that met the stated criteria, the instructor was satisfied that they had learned the material. We have revealed that the nature of the solution process can actually impact the level of learning achieved by the students, just as a design process can determine the quality of a design. The value of observing and exploring the analytic process is discussed further in our previous work (Reamon and Sheppard, 1996).

These explorations represent a preliminary step in our continuing efforts to understand and improve engineering education, with a particular focus on the use of computer technology in curricula. While the sample sizes and metrics used in our study do not produce firm statistical evidence of learning improvements, the qualitative evidence is quite convincing. Certainly the subject is important enough to warrant further exploration in larger scale studies.

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